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Econometric Analyses of Carbon Resource Markets

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Für meine Familie.

Abstract

Carbon resources, mainly the fossil fuels coal, crude oil and natural gas, have been key drivers of global economic development since the industrial revolution, constituting important inputs in the production processes of several sectors, such as power generation, transportation and industry. However, the use of carbon resources has also been a cause of man-made global warming, which is projected to have detrimental consequences for human welfare and global economic performance in the long run should it continue unabated. To contain long-run welfare losses large-scale decarbonization of the global economy must take place, implying a reduction in the use of fossil fuels. A sound understanding of the markets for these resources is of great importance for our ability to anticipate the outcomes of climate policy choices and to minimize the occurrence of unintended consequences and inefficiency. However, our understanding of carbon resource markets is incomplete. This dissertation addresses a number of open questions regarding the markets for hard coal, crude oil, natural gas and the European market for carbon dioxide emission permits. Applying a range of econometric methods we analyze key patterns in these markets based on ex-post economic data, using estimation frameworks from both micro-econometrics and time series analysis. Starting with a regional perspective, we analyze the firm-level drivers of the trade in carbon dioxide emission permits in the European context by means of a selection model. Furthermore, we test whether long-run U.S. prices of bituminous coal, crude oil and natural gas are stationary throughout their recorded history, or if they exhibit breaks in persistence. We then adopt a more international approach: Using cointegration analysis we examine whether the international steam coal trade constitutes a globally integrated market and if it is tied to the crude oil market through the role of oil in steam coal logistics. Finally, taking a fully global perspective we provide a dynamic country-level analysis of the determinants of global crude oil production.

Keywords: climate change, energy, fossil fuels, hard coal, crude oil, natural gas, carbon dioxide, EU ETS, emission permit trade, persistence break testing, unit roots, cointegration, error correction models.

Zusammenfassung

Kohlenstoffressourcen, insbesondere die fossilen Brennstoffe Kohle, Erdöl und Erdgas, sind seit der industriellen Revolution Schlüsselfaktoren der globalen wirtschaftlichen Entwicklung. Sie stellen wichtige Inputs in die Produktionsprozesse verschiedener Sektoren dar, vor allem in der Elektrizitätserzeugung, im Verkehrsbereich sowie im verarbeitenden Gewerbe. Jedoch ist ihre Nutzung auch ein Treiber der von Menschen verursachten globalen Erwärmung, so dass bei einer ungebremsten Fortsetzung ihrer Nutzung negative langfristige Folgen sowohl für das menschliche Wohlergehen als auch für die weltwirtschaftliche Entwicklung zu erwarten sind. Um langfristige Wohlfahrtsverluste zu vermeiden, muss daher eine umfangreiche Dekarbonisierung der Weltwirtschaft stattfinden, was notwendigerweise eine Verringerung des Einsatzes fossiler Brennstoffe nach sich zieht. Ein fundiertes Verständnis der betreffenden Märkte ist von großer Bedeutung, um die Konsequenzen möglicher Klimapolitikoptionen vorherzusehen sowie das Auftreten unbeabsichtigter Politikfolgen und von Ineffizienz zu minimieren. Jedoch lässt unser Wissen über diese Märkte zu wünschen übrig. Diese Dissertation befasst sich mit einer Reihe offener Fragen in Bezug auf die Märkte für Steinkohle, Erdöl, Erdgas sowie den europäischen Handel mit Kohlendioxid-Emissionsrechten. Wir wenden ökonometrische Methoden an, einschließlich Mikroökonometrie und Zeitreihenanalyse, um Fragestellungen basierend auf ex-post Daten zu analysieren. Beginnend mit einer regionalen Perspektive untersuchen wir die Determinanten des europäischen Handels mit Kohlendioxid-Emissionsrechten auf Firmenebene mittels eines Selektionsmodells. Nachfolgend testen wir, ob die langfristigen U.S.-amerikanischen Preise von Kohle, Erdöl und Erdgas als stationär betrachtet werden können oder ob sie Persistenzbrüche aufweisen. Anschließend richten wir unsere Analyse internationaler aus: Zunächst untersuchen wir mittels Kointegrationsanalyse, ob der internationale Handel mit Kraftwerkskohle einen weltweit integrierten Markt darstellt und ob der Kohlehandel durch die Rolle von Öl als Kostenfaktor in seiner Logistik mit dem Rohölmarkt verbunden ist. Abschließend nehmen wir eine globale Perspektive ein und führen eine dynamische Analyse von Determinanten der weltweiten Rohölproduktion auf Länderebene durch.

Schlüsselwörter: Klimawandel, Energie, fossile Brennstoffe, Steinkohle, Erdöl, Erdgas, Kohlendioxid, EU ETS, Emissionsrechtehandel, Persistenztests, Einheitswurzeln, Kointegration, Fehlerkorrekturmodelle.

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I look not back, I look in front.

Lothar Matthäus (2000)

Contents

List of Figures

List of Tables

Chapter 1

Introduction

When I was in primary school, during one lesson my teacher talked about the composition of the earth's atmosphere, which up to that point I had thought was simply made of air. He talked about nitrogen and oxygen as the main elements. Then he looked at the textbook and told us that the number for carbon dioxide printed there was outdated, because it had been based on information several decades old and that in the meantime the CO_2 content in the atmosphere had increased. When somebody asked how that came about he answered that it was probably people who did it, but that he was not sure. I remember being amazed that people could change the way air was made up in the whole world... Many years later, during my first year as a PhD student, I wanted to write my thesis on international economics, with a focus on macro issues, and was looking for a topic. Then I came across some material on energy and environmental economics. As I started reading, it began to dawn on me that the climate externality, with its connection to energy economics, is most certainly a topic in international economics, with very definite macro implications. By writing my dissertation on this area I could also look more deeply into how it was that people could change the way air was made up, and maybe help do something about it.

1.1 The Issue

Carbon dioxide (CO_2) and other greenhouse gases emitted from the earth's surface on account of human economic activity have been flowing into the atmosphere at a rate far exceeding the earth's natural absorption capacity. This excess flow has led to a build-up of greenhouse gases in the atmosphere, raising their concentration from 280 parts per million (ppm) CO_2 equivalent (CO_2e) prior to the industrial revolution to 396 ppm in April 2012 (NOAA, 2012). In turn, this build-up has already led to a rise in the earth's mean temperature, with further increases highly likely if the accumulation continues unabated. Increases in the mean temperature are projected to cause significant disruptions to the world's ecosystems, thus also affecting human welfare (IPCC, 2007). However, the consequences of temperature changes on the earth's ecosystems are both highly non-linear and affect different regions in heterogenous ways, with disruptions being increasingly more severe for each degree by which the mean temperature increases, also due to feed-back mechanisms in the earth's climate systems (IPCC, 2007). The costs of climate change would eventually become very large, threatening global economic development if allowed to continue unconstrained. Increases in the mean temperature of more than 2 degrees centigrade compared to pre-industrial levels are projected to make the consequences of climate change especially costly to human life in general, and global economic performance in particular (Stern, 2007).

Therefore, a policy challenge is to restrict the current and future flow of carbon dioxide and other greenhouse gases from the earth's surface to the atmosphere. A benchmark goal is to manage current and future emissions such that the stock of carbon in the atmosphere is stabilized at or below 550 ppm CO_2e, thus containing the probability of increases in the mean global temperature beyond 2 degrees centigrade (Stern, 2007). Stabilizing the atmospheric concentration of greenhouse gases at these levels will require a decrease in emissions by about 80% by 2050 compared to today (Stern, 2007).

However, carbon resources constitute key inputs into the production processes in a range of sectors, especially in power and heat generation, as well as in transportation. This includes the carbon fuels coal, crude oil and natural gas, as well as the right to emit CO_2 and other greenhouse gases released into the atmosphere during the production processes for goods and services. While carbon fuels are typically priced above zero, the right to emit CO_2 has traditionally been a free good, although a large market for the latter carbon resource has recently been established in Europe through the EU's Emission Trading Scheme. Thus, the right to emit carbon is now also priced above zero, at least in a regional context and for a number of sectors.

The goal of stabilizing the global stock of greenhouse gases implies that the weight of carbon resource inputs in the production of global economic output must be dramatically reduced to achieve the substantial reduction in emission flows required for achieving carbon stock stabilization, unless the carbon contained in these resources can successfully be captured and sequestered permanently. In case the latter option is not available, the global economy must be largely decoupled from carbon resources eventually. A range of policy instruments may be used to achieve the required decarbonization of the global economy, which include both demand and supply side measures. Examples are the promotion of energy efficiency, the development and global transfer of low-carbon technologies, and the substitution of the current high-carbon sources of energy for low-carbon alternatives, e.g. spurred through regulation or market-based measures, such as taxation or carbon trading (IPCC, 2007; Stern, 2007). Thus, while a range of policy options exists, actual policy choices will likely depend on local and regional conditions (IPCC, 2007).

The burning of fossil fuels necessarily leads to greenhouse gas emissions, once we discount the possibility of carbon capture and sequestration. Thus, no matter which policy mix is favored, fundamental changes will be required in the configurations of sectors using carbon resource inputs heavily, as the use of fossil fuels is responsible for more than 50% of global greenhouse gas emissions (IPCC, 2007). Coal use is the largest contributor to global CO_2 emissions, with a share of 44% in global CO_2 emissions from global energy consumption in 2009, whereas the shares of crude oil and natural gas are 36% and 20%, respectively (EIA, 2012). Furthermore, any forced decrease in the use of fossil fuels will affect the electricity supply sector, which alone is responsible for more than 25% of global greenhouse gas emissions and still heavily relies on fossil fuels, as well as the transport sector, which generates 13% of global greenhouse gas emissions (IPCC, 2007).

Therefore, the providers and consumers of fossil fuels will be strongly affected by any policies that are intended to change the status quo in these areas of the economy.

As a result, they may carry a significant proportion of the cost of transitioning to a de-carbonized global economy, giving rise to problems of collective action (Olson, 1965), both nationally and internationally, which must be addressed in a global context eventually to achieve a sustainable stabilization of atmospheric carbon stocks over the long term (Sinn, 2008). Therefore, to increase the likelihood that a policy intervention will have the intended effects an understanding of the set-up of carbon resource markets on both the demand and supply sides, as well as of the behavior of the agents participating in them are of key importance (e.g. Sinn, 2008).

As the required reduction in CO_2 emissions leads to a reduction in the use of fossil fuels, a sound understanding of these markets is of particular importance to foresee the consequences of climate policy measures. However, currently our understanding of these markets is incomplete, thus unnecessarily increasing the probability of the occurrence of unintended consequences and inefficiency when formulating and implementing climate policy. For instance, there is a range of open questions regarding carbon resource markets:

- What drives the trading behavior of emitters in the world's largest emission trading system, the EU's Emission Trading Scheme (EU ETS)?
- Are fossil resource prices stationary over the long term or do they exhibit breaks in persistence, with periods of non-stationarity? Do the prices of all major carbon fuel resources behave similarly in this respect?
- Does an integrated global market for hard coal exist, the resource with the greatest pound-for-pound climate impact when used for combustion?
- How does the supply of crude oil react to changes in current and past oil prices and their volatility?

The general nature of these questions demonstrates that there are significant gaps in our understanding of key drivers of carbon resource markets. However, we believe that some of the questions can be fruitfully addressed, thus increasing our knowledge of the markets relevant to climate policy decisions, in turn decreasing the overall uncertainty when formulating and implementing policy. Some of these questions are aimed at particular aspects of these markets, while others address interdependencies, since some of these resources may be considered substitutes in certain applications, e.g. in power generation or transportation. Therefore, policy decisions aimed at one market may have consequences, intended or unintended, for related markets, too.

We adopt an empirical approach and exploit information about the markets' history, both recent and more distant. Our current knowledge about them is incomplete, also due to the fact that appropriate data have not been widely available. However, this data constraint is gradually being alleviated, while some available long-run data are still under-explored. Concurrently, methodological developments have expanded the possibilities for data analysis, while technological advances have made computational capacity an afterthought, which has been a constraining factor in formal data analysis in the past. This combination of open questions and beneficial developments in the means of analyzing them makes both descriptive as well as formal analyses using econometric methods feasible on a wide range of topics. This thesis seeks to address some of these open questions by applying a range of econometric methods, both micro-econometric and time series techniques, depending on data availability and the question posed, with the goal of contributing to our understanding of the forces driving carbon resource markets.

The remainder of this chapter briefly presents the estimation frameworks used in Chapters 2 to 5, before outlining the contribution of each chapter and providing a brief overall conclusion. The remaining chapters are organized by the regional specificity of the carbon resource markets considered. Accordingly, Chapter 2 analyzes the EU ETS, a regional initiative pricing the right to emit carbon as an input factor and covering part of the EU's aggregate carbon emissions. It considers firm-level determinants of the CO_2-emitting firms' trade with carbon emission permits. Chapter 3 examines the long-run stationarity properties of U.S. prices of the three major fossil fuels hard coal, crude oil and natural gas and tests whether these prices exhibit breaks in persistence. Chapter 4 considers the globalization of steam coal markets and the role of logistics based on international harbor-level prices of steam coal and regional prices of residual fuel oil, the type of oil used to power ships.

Finally, Chapter 5 provides a country-level analysis of the dynamics of global crude oil production in response to changes in global oil spot prices and price volatility, while controlling for a large set of covariates.

1.2 Methodology

We address the questions mentioned in the previous section by analyzing ex-post data on key indicators of market behavior. In each Chapter we first provide a descriptive analysis to give readers an impression of the data. In the more globally oriented Chapters 4 and 5 we formalize the descriptive analysis somewhat by applying principal component analysis in order to discern descriptive patterns more clearly and derive hypotheses for the remainder of the analyses.

However, rigorous analysis of information gained from observed past behavior requires applying econometric methods. Given the wide range of relevant questions, displaying methodological versatility is required. Chapter 2 considers questions of firm behavior in the EU ETS, in particular regarding participation and self-selection, so that micro-econometric methods are the appropriate tools of analysis. The questions in the remaining chapters address the behavior of variables over time, so that time series econometric methods are called for. In Chapter 3 we apply recent advances from persistence break testing to long-run fossil resource prices, whereas Chapter 4 conducts a multivariate cointegration analysis. In Chapter 5 we apply ordinary least squares in a dynamic setting. In the remainder of this section we give a brief overview of all the formal approaches to data analysis used in this dissertation. The various models are introduced in greater detail in the methodology sections of each chapter.

1.2.1 Heckman Two-Step Selection Model

In Chapter 2 the CO_2-emitting firms covered by the EU ETS face a twin decision. They first must decide whether to participate in the permit trade at all and, in case they do participate, how many permits to trade, leading to the following population model:

$$y_{i1} = x_{i1}\beta_1 + \epsilon_{i1} \tag{1.1}$$

$$y_{i2} = x_{i2}\beta_2 + \epsilon_{i2}, \tag{1.2}$$

where y_{i1} denotes the logarithm of the amount of emission permits traded, while y_{i2} is a dummy variable equaling 1 if the firm trades a positive amount and 0 if it does not. Therefore, a positive y_{i1} is only observed for firms participating in trading, while y_{i2} is available for all firms in the sample. Correspondingly, x_{i1} is the set of independent variables containing information about firms that trade, whereas x_{i2} consists of covariates for all firms. Given the selection decision, the regression function for the subset of available data on amounts traded depends not only on x_{i1} but also on the sample selection rule (Heckman, 1979). This issue must be kept in mind to avoid an omitted variable problem (Heckman, 1979), so that we obtain a version of (1.1) corrected for selection bias:

$$E(y_{i1}|x_{i1}, y_{2i} = 1) = x_{i1}\beta_1 + \gamma_1\lambda(x_{i2}\delta_2), \tag{1.3}$$

where $\lambda(x_{i2}, \delta_2) = \frac{\phi(x_{i2}\delta_2)}{\Phi(x_{i2},\delta_2)}$ is the inverse Mills ratio. We estimate (1.3) using Heckman's (1979) two-step procedure. In a first step we obtain $\hat{\delta}_2$, an estimate of the unknown parameter vector δ_2, by performing a probit estimation of the probability that firms will participate in trading:

$$P(y_{i2} = 1|x_{i2}) = \Phi(x_{i2}\delta_2) \tag{1.4}$$

In a second step we regress y_{i1} on x_{i1} and $\hat{\lambda}(\cdot)$, our estimate of the inverse Mills ratio. We test for the existence of a sample selection bias by performing a t-test of $H_0 : \gamma_1 = 0$.

1.2.2 Persistence Break Testing while Accounting for a Structural Break

In Chapter 3 we test whether the long-run prices of the fossil resources bituminous coal, crude oil and natural gas are long-term trend stationary, or whether they exhibit a break in persistence. We consider a Gaussian unobserved components model (Busetti and Taylor, 2004):

$$y_t = d_t + \mu_t + \epsilon_t, \qquad t = 1, ..., T \tag{1.5}$$

$$\mu_t = \mu_{t-1} + I_{(t>\lfloor\tau T\rfloor)}\eta_t \tag{1.6}$$

where $\epsilon_t \sim N(0, \sigma^2)$ and $\eta_t \sim N(0, \sigma_\eta^2\sigma^2)$ are mutually independent i.i.d. processes and $\tau \in]0, 1[$. $I_{(\cdot)}$ is an indicator function taking on the value of 1 for $t > \lfloor\tau T\rfloor$. Thus, starting at point $\lfloor\tau T\rfloor$, η_t from (1.6) affects (1.5), so that y_t becomes non-stationary if η_t has non-zero variance. In order to determine whether y_t is stationary over the entire sample period we test whether the variance of the η_t process is different from zero, leading to the following null and alternative hypotheses:

$$\begin{aligned} H_0: &\quad \sigma_\eta^2 = 0 \qquad \forall t \\ H_1^a: &\quad \sigma_\eta^2 = 0 \qquad \text{for } t \leq \lfloor\tau T\rfloor \\ &\quad \sigma_\eta^2 > 0 \qquad \text{for } t > \lfloor\tau T\rfloor \end{aligned}$$

Thus, H_1^a posits that the series is $I(0)$ until $t = \lfloor\tau T\rfloor$ and $I(1)$ thereafter. We may also want to consider the case in which $I_{(\cdot)}$ takes on the value of one for $t < \lfloor\tau T|\rfloor$ instead of equaling one for $t > \lfloor\tau T\rfloor$. In this case the null hypothesis remains unchanged, while the alternative hypothesis is as follows:

$$\begin{aligned} H_1^b: &\quad \sigma_\eta^2 > 0 \qquad \text{for } t \leq \lfloor\tau T\rfloor \\ &\quad \sigma_\eta^2 = 0 \qquad \text{for } t > \lfloor\tau T\rfloor \end{aligned}$$

We can test H_0 against H_1^a using the ratio-based statistic developed by Kim (2000) and Kim et al. (2002):

$$K(\tau) = \frac{[(1-\tau)T]^{-2}\sum_{i=\lfloor\tau_0 T\rfloor+1}^{T} S_{1,\,i}(\tau)^2}{[\tau T]^{-2}\sum_{i=1}^{\lfloor\tau_0 T\rfloor} S_{0,\,i}(\tau)^2} \tag{1.7}$$

For large values of the test statistic we reject H_0 in favor of H_1^a. Busetti and Taylor (2004) show that we can use the inverse of $K(\tau)$, $K(\tau)^{-1}$, to test H_0 against H_1^b. Again, we reject H_0 for large values of $K(\tau)^{-1}$. Using a set of iteration procedures facilitates consideration of all possible periods when testing for a persistence break, instead of having to test each candidate period separately. We allow for heteroskedasticity of a very general form by performing a wild bootstrap (Cavaliere and Taylor, 2008).

If we find evidence in favor of the series containing a break in persistence, we can estimate the period in which the break occurs by determining τ^* as follows:

$$\Lambda(\tau) \quad = \quad \frac{[(1-\tau)T]^{-2}\sum_{i=\tau T+1}^{T}\widehat{\epsilon}_{1,\,i}(\tau)^2}{[\tau T]^{-2}\sum_{i=1}^{\tau T}\widehat{\epsilon}_{0,\,i}(\tau)^2} \tag{1.8}$$

where τ^* is determined such that $\tau^* = \underset{\tau\in[\tau_l,\tau_u]}{\arg\max}\ \Lambda(\tau)$.

One final concern is that the presence of a structural break can seriously distort the test statistic (Busetti and Taylor, 2004), as with other unit root tests (Perron, 1989). Since the persistence break testing literature has yet to develop a way of endogenously determining structural breaks while performing the persistence break test, we run the persistence break for a range of structural break points suggested by the existing literature, treating the structural break as exogenous. In this manner we aim to disentangle the effects of a structural break from those of a persistence break, thus correctly identifying possible breaks in persistence.

1.2.3 Cointegration Analysis Using a Vector Error Correction Specification

In Chapter 4 we apply cointegration analysis to harbor-level steam importing and exporting coal prices and shipping rates, as well as residual fuel oil prices, applying Johansen's (1988) approach. We consider the vector error correction (VEC) representation of a vector process X_t:

$$\Delta X_t = \alpha\gamma + \Pi X_{t-i} + \sum_{i=1}^{k-1}\Gamma_i \Delta X_{t-i} + \mu + \epsilon_t \tag{1.9}$$

where X_t stands for the data matrix in period t, Π denotes the long-run impact matrix, Γ_i the short-run impact matrices for lag i, μ a vector of intercept terms, $\alpha\gamma$ is the constant term in the cointegration relationship, and ϵ_t a vector of error terms.

Our descriptive analysis shows that the mean of the differenced data is greater than zero, which is consistent with $E[\Delta X_t] \neq 0$, implying a linear trend in the undifferenced data. We thus specify the process allowing for a constant in the differenced data. We also allow for a constant in the cointegration relationship (Johansen, 1994).

Having confirmed that all variables are integrated of order 1, we then test whether variables are cointegrated, by determining the rank of the long-run impact matrix Π using the trace test. The trace statistic is computed as follows:

$$\lambda_{trace} = -T \sum_{i=r+1}^{k} \ln(1 - \lambda_i) \tag{1.10}$$

where λ_i are the estimated eigenvalues of Π and T is the number of observations. Furthermore, Π can be decomposed as follows:

$$\Pi = \alpha\beta' \tag{1.11}$$

where β is the matrix of cointegrating vectors describing the long-run equilibrium of the system, and α is the corresponding matrix of adjustment parameters describing the short-run responses of each variable to deviations from equilibrium. We estimate both cointegration vectors and adjustment coefficients for systems of steam coal prices and freight rates representing the supply and demand side prices for each trade route.

1.2.4 Ordinary Least Squares Including Lagged Variables

In Chapter 5 we extend the seminal analysis by Griffin (1985) of oil markets by estimating a model expressed in the following general form:

$$\Delta Y_{t,i} = \alpha_i + \sum_{k=0}^{K} \beta_{k,i} \Delta X_{t-k} + \sum_{l=0}^{L} \gamma_{l,i} Z_{t-l} + \lambda_i W_{t,i} + \sum_{j=1}^{11} \rho_j D_{t,j} + \epsilon_{t,i} \tag{1.12}$$

where $Y_{t,i}$ is our dependent variable, the quantity of oil produced in country i at time t, and X_t is the matrix of covariates of key interest, the global oil spot price and its volatility, for which we include K lags. Z_t is a matrix of control variables with L lags included, and W_t a matrix of covariates for which we do not include lags due to data availability. Finally, D_t is a full set of monthly dummy variables to control for seasonality.

With our specification we address concerns regarding stationarity arising from the existing literature based on Griffin (1985), which uses logarithms of prices and quantities in levels. However, our results show that both the price and quantity variables are non-stationary over the sample period under consideration, thus providing spurious results in unadjusted ordinary least squares regressions. We thus estimate the model by ordinary least squares, taking first differences of variables found to be non-stationary. Endogeneity of oil prices to the production decision is not a concern, as no single producer is large enough to change the world's crude oil price through his output decision, with the possible exception of Saudi Arabia. We account for heteroskedasticity and autocorrelation by using Newey-West corrected standard errors.

We reject a possible alternative specification as an error correction model, as the existing literature (Kaufmann et al., 2008) already finds more than one cointegration relationship for a more restricted specification than we consider warranted, already leading to multiple sets of estimation results. A further expansion of the model may even exacerbate this multiplicity of results. In addition, estimating a vector system of the model as we envision it would be computationally infeasible.

1.3 Contribution of Chapters

Table 1.1 summarizes Chapters 2 to 5, mentioning publications the chapters are based on and indicates co-authors. It also describes my own contribution to each chapter.

Table 1.1: Summary of Chapters

	Chapter 2: Why do Firms Trade Carbon Emission Permits? Evidence from the European Emission Trading Scheme	**Chapter 3:** Stationarity Changes in Long-Run Fossil Resource Prices: Evidence from Persistence Break Testing	**Chapter 4:** The globalization of steam coal markets and the role of logistics: An empirical analysis	**Chapter 5:** The Dynamics of Global Crude Oil Production
Joint work with		Jan Abrell Anne Neumann	Astrid Cullmann Anne Neumann Christian von Hirschhausen	Georg Zachmann Anne Neumann
Contribution	Author's independent research.	Main author. Main responsibility for data collection and management, literature review, estimation and writing. Computational implementation was collaborative.	Main author. Main responsibility for data management, literature review, estimation and most of writing. Choice of estimation framework and part of writing was collaborative.	Main author. Main responsibility for data collection and management, literature review, estimation and writing. Model set-up and interpretation of results was collaborative.
Publications	DIW Discussion Paper; European University Institute Working Paper Series; submission to *Journal of International Economics.*	DIW Discussion Paper 1152, September 2011; submission to *Oxford Bulletin of Economics and Statistics.*	DIW Discussion Paper 956, December 2009; *Energy Economics 34 (2012)*, pp. 105-116.	DIW Discussion Paper 1075, November 2010; under review, *Energy Economics.*
Notes on versions of this thesis		Minor adjustments compared to DIW Discussion paper version.	Minor adjustments compared to journal article.	Minor adjustments compared to DIW Discussion Paper version.

1.3.1 Chapter 2: Why do Firms Trade Carbon Emission Permits? Evidence from the European Emission Trading Scheme

In Chapter 2 we analyze a carbon resource market which was established as a result of a climate policy intervention, the EU's Emission Trading Scheme (EU ETS). This newly established market has been in operation since 2005 and covers roughly one half all the EU's CO_2 emissions (Ellerman, 2010).

For the CO_2-emitting firms affected by the EU ETS the establishment of this market has turned the right to emit carbon into a positively priced input factor to their production function, as they now need to surrender permits equivalent to the amount of carbon they emit during each ETS compliance year. Thus, firms now not only pay for the carbon resources they use as regular inputs into the production of their final good but also for the right to release carbon dioxide into the atmosphere.

Thus, firms emitting CO_2 are engaged in an asset market, which, due to the input character of the right to emit, is tightly linked with the firm's decisions regarding the production and trade of their final goods output, at least in principle. However, the flexible features of the EU ETS provide CO_2-emitting firms with leeway to decide whether to participate in permit trading in any given year, before deciding on the amount traded, potentially inducing self-selection into trading.

Given that this market is a hybrid between an asset market and an input market and that this chapter is among the first to address determinants of its permit trade flows, it is difficult to formulate hypotheses about drivers of the permit trade at the firm level. However, we do expect that trading behavior should be driven by a mix of firm-specific and market-specific determinants. The existing literature on international goods trade suggests that firms self-select into participating in trade, with certain firm-specific characteristics playing significant roles both in the participation decision and in trading behavior, such as variables capturing firm size and performance (Bernard et al., 2011). Therefore, in this chapter we address two main questions: First, what makes firms trade carbon emission permits? Second, given the flexibility to borrow from one's own allocation for the following compliance year or to bank surplus allowances from the current year afforded by the EU ETS, what is the role of firm-specific relative to market-specific factors?

We seek to understand the drivers of firms' trading behavior in the EU ETS by jointly modeling their participation and amount decisions (Heckman, 1979), while allowing for possible self-selection into participating. Our analysis is based on a newly constructed dataset of inter-firm and intra-firm permit trade flows during the early phase of the EU ETS, both on the supply and the demand sides, augmented by firm-level balance sheet characteristics covering a large proportion of the overall market in European Union Allowances (EUAs). Specifically, we combine transaction level data on EUA flows during the first two compliance years of EU ETS Phase I, 2005 and 2006, with annual balance sheet data on firm characteristics, such as size, profitability and ownership structure. We thus obtain two cross sections based on annually aggregated data, providing wide coverage of the overall EU ETS at the firm level. Our detailed dataset allows us to distinguish inter-firm and intra-firm trade flows, on both the demand and supply sides of the market, thus providing insight into external vis-à-vis internal permit portfolio optimization, whose drivers may differ depending on whether the firm is a buyer or a seller in the permit market.

We evaluate the relative importance of firm-specific and market-specific determinants of the EUA trade by CO_2-emitters and compare firm behavior in the EU ETS with results from the empirical literature on firm-level determinants of trade. We find that participation in the carbon permit trade is driven by firm-specific factors such as size, profitability and ownership structure, which corresponds to results from the existing empirical literature on firm-level determinants of the trade in goods. However, market-specific factors are influential as well, especially in the inter-firm trade. In the intra-firm trade firm-specific factors are found to be relatively more important. In contrast to the literature on the firm-level goods trade we do not find a selection bias into trading.

From a policy perspective, firms in the market behave as would be expected in the market for any good, once we account for the constraint imposed by the requirement to remain in compliance with EU ETS regulations.

1.3.2 Chapter 3: Stationarity Changes in Long-Run Fossil Resource Prices: Evidence from Persistence Break Testing

This chapter takes a long-run perspective, using under-explored annual data on U.S. prices of the three key carbon resource markets, bituminous coal, crude oil and natural gas, ranging back into the 19^{th} century. While an analysis of international long-run prices would also be highly desirable, we are forced to focus on U.S. prices, as these are the only price series reaching sufficiently far into the past to facilitate such an analysis. Recent developments in persistence break testing allow us to test the following hypothesis:

> *Hypothesis*: Long-run U.S. prices of the three major fossil resources are trend stationary over their entire sample period.

The alternative hypothesis is that a change in persistence has taken place, either from trend stationarity to non-stationarity or vice versa. We also estimate the persistence breakpoints. We advance the literature by allowing for a structural break when testing for a change in persistence, thus aiming to avoid a biased test statistic on account of ignoring a potential structural break. To our knowledge this chapter constitutes the first study in the field of non-renewable resource economics attempting to disentangle a deterministic break from a stochastic break in a price series.

Our findings clearly show the importance of specifying a structural break when evaluating the persistence of a resource price series. When ignoring a structural break the prices of all three resources appear to switch from stationarity to non-stationarity. However, this result is reversed for the cases of bituminous coal and natural gas when allowing for a structural break. Furthermore, while for crude oil prices we still find that they have switched from trend stationarity to non-stationarity in the 1970s, the result is considerably weaker when compared to the case in which we ignore a possible structural break.

Thus, our results indicate a divergence between the markets for crude oil and of those for bituminous coal and natural gas with respect to persistence, at least in a U.S. context, suggesting that oil market analysts may want to take the switch in stationarity into account when estimating relationships in this market and when forecasting oil prices.

1.3.3 Chapter 4: The Globalization of Steam Coal Markets and the Role of Logistics: An Empirical Analysis

In Chapter 4 we consider two related questions: First, does a global steam coal market exist? Second, are the steam coal and crude oil market tied together through oil's significant role in the transport cost of steam coal?

We conduct a thorough analysis of three parts of the steam coal value chain: export, transport and import prices. We obtain export prices from the main exporting harbors around the world, as well as import prices from some major destinations of the international seaborne steam coal trade: Europe, Japan and Korea. Furthermore, we gather information on freight rates between these harbors. We thus depict the major parts of both supply and demand side prices, with export prices and freight rates together representing the supply side, and import prices representing the demand side. Our dataset covers the period December 2001 until August 2009 at weekly frequency.

We first conduct a descriptive analysis of the global steam coal trade, establishing that the majority of the trade volumes are traded within the Atlantic and Pacific basins, respectively. However, trade flows occur between the basins as well, suggesting that sufficient global exchange of steam coal may exist to lead to a synchronization of price movements. In a next step, we perform a principal component analysis of each of the major parts of the steam coal value chain, while also including the price of residual fuel oil, the type of oil used to fuel vessels transporting steam coal between export and import locations. We find that export prices, import prices and freight rates appear to share a significant part of their overall variation, while residual fuel oil prices do not appear to co-vary as closely. Based on these results we formulate three main hypotheses:

> *Hypothesis* 1: Prices for steam coal exports, transport and imports, respectively, are integrated to a significant degree.
>
> *Hypothesis* 2: Coal prices and freight rates are not directly related to oil prices.
>
> *Hypothesis* 3: International steam coal market integration is not (yet) complete.

In order to address these hypotheses we conduct a stepwise multivariate cointegration analysis. We first test whether the various demand and supply side components are consistently integrated with one another. Pairwise cointegration tests using Johansen's (1988) approach yield that steam coal export and import prices, as well as freight rates are generally cointegrated. We then investigate whether oil prices are related to either of these components and find that they do not belong to the cointegration space spanned by the components of the steam coal value chain. We then apply the cointegration test to basin-wide and global systems of prices and freight rates and find significant cointegration on the regional and global levels also. Finally, we estimate cointegrating vectors and adjustment coefficients for individual trade routes. Our results indicate significant yet intuitively appealing differences both in the long-run equilibria for each route and in the values of the adjustment parameters. First, the weight of freight rates in the equilibrium relationship rises with increasing distance. Second, the various routes exhibit significantly different adjustment dynamics, with routes featuring strong trading volumes generally adjusting more quickly to shocks.

Overall, based on our results we fail to reject all three main hypotheses. We thus conclude that while globalization of steam coal market still has a significant way to go, substantial international market integration has been achieved already.

From a policy perspective our results suggest that shocks originating due to events in a particular geographic region, either through natural disasters, market events or policy intervention, e.g. through carbon policies, will be transmitted to the entire global trade in steam coal eventually instead of remaining contained in one particular region.

1.3.4 Chapter 5: The Dynamics of Global Crude Oil Production

Chapter 5 analyzes the international oil market on the country level. We study the response of oil production to key global and local determinants of oil producers' output decisions, such as prices, price volatility, investment, real economic activity, the strength of the U.S. dollar and indicators of institutional quality. The analysis is based on a substantially broader dataset than in Chapter 4, as data on the oil market are more readily available. The dataset is at monthly frequency, with the exception of the institutional quality indicators. It covers the period of 1994-2009 for oil production, whereas the available sample period is longer for other variables of interest. For instance, oil prices are available at monthly frequency for the period 1986-2009, Janauary 1986 being the start of the available West Texas Intermediate crude oil spot price series (EIA, 2012). We focus our analysis on the response of local oil production decisions to changes in global oil prices and price volatility, while controlling for a set of important covariates. We conduct the analysis for the three country groups, OPEC, OECD and non- OECD/non-OPEC, and for selected countries representing the majority of each group's oil production.

Based on a descriptive analysis we motivate the division of the countries in our sample into the three groups. We further note that crude oil production is subject to significant lead times of up to 10 years after investments in exploration and development of oil production capacity has taken place (Wurzel et al., 2009). Thus, we derive two hypotheses:

> *Hypothesis* 1: Crude oil production responds to prices and price volatility. A significant response is expected to come from both the current and previous periods along a lag-structure from the very short to the longer term.
>
> *Hypothesis* 2: The reaction of crude oil production to changes in prices and price volatility is heterogeneous among country groups as well as among members within the groups.

We estimate using ordinary least squares, while specifying a generous lag structure ranging from the current period to a lag of nine years. We find that OPEC production is consistent with price stabilization in the short term and with revenue smoothing in the medium to longer term. We also find strong evidence for aversion to price risk in the oil output decisions of OPEC countries. The group of OECD countries exhibits a significantly higher degree of heterogeneity among its major oil producers, although revenue smoothing with respect to the oil price in the short to medium term corresponds to our results on OPEC. We also find a significant amount of aversion to price risk on the country level in the OECD group, with the exception of Norway. We find a largely positive reaction of output to price changes across the major producers in the non-OECD/non-OPEC group. Furthermore, the third group exhibits the least amount of aversion to price risk of our three groups.

In conclusion, OPEC output decisions appear to be better coordinated than those of either OECD or non-OECD/non-OPEC, although we note the coordination is imperfect. Furthermore, substantial differences in the response of oil output, particularly its reaction to price volatility, validate separating the non-OPEC countries into two groups.

1.4 Concluding Remarks

The challenges to contain climate change through a transition to a low-carbon global economy are vast, particularly as carbon resources have been key drivers of global economic development since at least the industrial revolution, and remain so today. Carbon resource markets have been instrumental in providing the fuel for historically unprecedented economic welfare. Therefore, managing these markets appropriately to achieve a carbon-sustainable long-run economic outcome will be of critical importance in order to avoid unnecessary costs in terms of economic well-being. However, any successful management necessitates understanding them well.

This dissertation addresses a number of open questions to improve our understanding of important aspects of these markets by means of a range of econometric methods. We apply micro-econometric methods to the European market for carbon emission permits, the EU ETS. We also apply a number of time series econometric methods to questions regarding markets for the traditional carbon resources hard coal, crude oil and natural gas. In particular, we test for the existence of persistence breaks in U.S. prices of bituminous coal, crude oil and natural gas. Furthermore, we analyze the extent to which the global steam coal trade constitutes an integrated market, and whether the crude oil market is linked to it via the role of oil in the logistics of the steam coal trade. Finally, we examine the dynamics of global crude oil production.

We show that an application of econometric methods can fruitfully explain patterns observed in carbon resource markets in the past and help improve our understanding of their drivers.

We envision extensions to the research performed in this thesis in several directions. First, structural vector models can be applied to further study the time series dimension of fossil fuel markets, e.g. via impulse response analyses. Second, as more data on the EU ETS become available it will become feasible to take into account the panel dimension when analyzing its microstructure. In particular, we will then be able to consider possible structural shifts in this market, e.g. between EU ETS Phase I and Phase II. A third extension would be to explicitly model interdependencies between the main carbon resource price series and jointly estimate demand and supply side behavior.

Chapter 2

Why do Firms Trade Carbon Emission Permits? Evidence from the European Emission Trading Scheme

2.1 Introduction

The EU's Emission Trading Scheme (EU ETS) is the first market for carbon emission rights ever brought into operation on a continental scale, affecting all EU countries and a number of industrial sectors. It covers about one half of EU-wide CO_2 emissions (Ellerman et al., 2010). The genesis of the EU ETS has given rise to the creation of an asset, the European Union Allowances (EUAs), each EUA providing its holder with the right to emit one ton of CO_2. For the firms affected the establishment of the EU ETS has turned the right to emit carbon into a positively priced input factor to their production function, as they now need to surrender permits equivalent to the amount of CO_2 they emit during each ETS compliance year. EU ETS regulations ensure EUA equivalence for compliance purposes, no matter where each particular EUA was issued, making them fully tradable across the entire system. Therefore, as with other inputs, from a firm's perspective emission permits can either be sourced from within the firm's boundaries or acquired externally via the permit market. Thus, firms emitting CO_2 are engaged in an asset market, which, due to the input character of the right to emit is tightly linked with the firm's decisions regarding the production and trade of their final goods output, at least in principle.

In the case of a strict system forcing firms to cover their permit needs on the market in every compliance year the link from production decisions to the market for tradable permits would be very direct. However, certain features of the EU ETS lead to a weakening of this link. First, during EU ETS Phase I, the period for which the appropriate data are currently available, firms received free endowments of EUAs, which in many cases sufficed to fully cover their permit needs (cf. Ellerman et al. (2010) for a thorough analysis of some key features especially of EU ETS Phase I). Second, in the EU ETS firms are not forced into a static optimization decision between abating and going to the market on the demand side for permits, as well as between increasing emissions, selling surplus permits or leaving them unused on the supply side. Instead, a dynamic component is built into the system. Firms can borrow from their own permit allocation for the following year, instead of having to cover a possible deficit via the market immediately, and also allows them to bank unused allowances for future use instead of forcing them to sell immediately. These flexible features allow each firm to decide whether it wants to participate in permit trading in any given year, before deciding on the amount it should trade.

This decision may be based on a cost-benefit analysis of engaging in the market, where some firms, especially on the supply side, may not enter the market if the cost of doing so is too high (Stavins, 1995), where in the EU ETS especially the fixed cost may be significant (Jaraite et al, 2010). However, participation decisions may also be influenced by decision rules other than rational profit maximization, with arguments of bounded rationality potentially applying (Simon, 1979; Radner, 1996). For instance, firms with an allowance deficit may be forced to consider entering the EUA trade in any particular period more strongly since borrowing may only be a temporary reprieve. They would need to cover their deficit via the market eventually, unless they abate the requisite amount of emissions. On the other hand, firms with an allowance surplus may choose to neglect the possibility of making additional profit from entering the EUA trade in the interest of avoiding additional organizational and decision complexity (Simon, 1979).

Therefore, CO_2 emitting firms may face decision problems similar to whether to enter international markets for other goods and services, including intermediate goods, leading to our two main questions: First, what drives firm trading behavior in the EU ETS? Second, to what extent is the behavior of firms in the EU ETS similar to firm behavior observed in the more general empirical literature on firm-level determinants of trade?

There is a large and growing literature on the firm-level determinants of the international trade in goods, both empirical and theoretical (cf. Bernard et al. (2011) for an extensive literature review). Numerous empirical micro studies have analyzed determinants of firm behavior in international trade, both inter-firm and intra-firm. The literature has established a strong positive link between indicators of firm size and firm performance and the probability to enter export markets (e.g. Bernard and Jensen, 1999). One explanation is that firms may self-select into participating in international trade based on above-average productivity (Melitz, 2003), thus being better able to deal with the sunk cost of entry into a new market (Roberts and Tybout, 1997). A substantial empirical literature provides evidence of self-selection on the export side (see Greenaway and Kneller (2007) for a review), while a selection bias is also found on the import side. For instance, Bernard et al. (2011) find evidence of significant selection bias in the decision whether to source intermediate goods within the firm or outside it, where firm productivity also plays a significant role.

The existing empirical literature investigating the EU ETS microstructure is sparse. Jaraite and Kazukauskas (2012) assess the extent of firm-level transaction costs, primarily using EU ETS transactions data. Trotignon and Ellerman (2008) analyze trading patterns across registries and sectors in the EU ETS based on annual EU ETS compliance data, while Abrell et al. (2011) evaluate the effect of the EU ETS on firm outcome variables. The remainder of the existing empirical literature on the EU ETS mostly focuses on analyzing properties of EUA spot and futures prices in a time series context. One stream of literature evaluates the fit of particular time series models to the EUA price series (e.g. Benz and Trück, 2009). Another strand of the literature estimates the relationship between EUA prices and the prices of energy commodities, such as crude oil, natural gas, hard coal and electricity (Fell, 2010; Hintermann, 2010; Bredin and Muckley, 2011).

Our contribution is twofold: First, we seek to understand the drivers of firms' trading behavior by jointly modeling the firms' participation and amount decision, while allowing for possible self-selection into participating. We are able test some predictions from the trade literature regarding the firm-level determinants of the EUA trade, such as the greater propensity for participation in trade based on size and performance indicators, as well as the presence of a possible selection bias. Second, we contribute to the empirical literature on international trade by testing whether the results from this literature carry over to a specific market ultimately driven by the need to remain in compliance with EU climate regulations.

Our analysis is based on a newly constructed dataset of inter-firm and intra-firm EUA trade flows during the early phase of the EU ETS, both on the supply and demand sides, augmented by firm-level balance sheet information. Specifically, we combine transactions data at the installation level covering the first two compliance years[1] of EU ETS Phase I, i.e. 2005 and 2006, with data on key firm characteristics, such as size, profitability and ownership structure. We also add data on ex-post EU ETS compliance.[2] We match these datasets with a minimal loss of information. To our knowledge this study is the first one based on a dataset essentially depicting the entire EU ETS, while including both trading behavior and characteristics of the emitting firms involved.

We estimate a sample selection model for each available cross section, i.e. for both the 2005 and 2006 compliance years, using annually aggregated trading data.

[1]EU ETS compliance years conclude at the end of April of each calendar year. The 2005 compliance year began in February 2005 and ended at the end of April, 2006. The 2006 compliance year started in May 2006 and ended at the end of April, 2007.

[2]Shortly after the end of each compliance year the European Commission publishes the amount of verified emissions, as well as the amount of EUAs surrendered for compliance purposes at the installation level for the previous compliance year. Together with the planned allocations, which are also published by the Comission, this information allows us to compute each installation's compliance position, i.e. whether it had a deficit or a surplus of allowances during that particular compliance year.

We find that the decision to participate in the EUA trade is not driven by the return on assets, our measure of firm performance. However, the probability to purchase EUAs is positively and significantly affected by firm size. Ownership structure and the firm's sector are also significant predictors of participation. The estimated effects are also significant economically. In addition, the value of the initial EUA endowment, as well as a firm's ex-post EUA position significantly predict participation on both sides of the inter-firm EUA trade, whereas the effect of the firm's relative EUA position is found to be weaker in the intra-firm trade. We thus show that participation in the carbon permit market is driven by both firm-specific and market-specific factors, whereas in the intra-firm trade firm-specific factors appear to be relatively more important. The firms' amount decision is mostly driven by its initial EUA allowance and its ex-post net EUA position at the end of the compliance year. However, the return on assets is also positively and significantly related to the amount of EUAs traded on the demand side of the inter-firm market. Again, intra-firm transfers are found to be less strongly determined by market-specific factors. Finally, in contrast to the literature on the firm-level goods trade we do not find a selection bias into EUA trading.

The remainder of the chapter is structured as follows. Section 2.2 introduces the dataset and provides a descriptive overview of the EUA trade. Section 2.3 describes the methodology used, while results are presented and discussed in Section 2.4. Section 2.5 concludes.

2.2 Data and Descriptive Analysis

2.2.1 Data

We first compile a dataset containing transactions in the entire EU ETS for the calendar period 2005-2007, from the EU Commission's Community Independent Transactions Log (CITL).[3] We thus obtain full coverage of EU ETS permit flows for the compliance years 2005 and 2006. This dataset contains transactions on

[3] CITL transactions data are released based on calendar years, with a delay of five years. For this reason data going beyond December 2007 are currently unavailable.

the account level, covering government accounts, pure trading accounts, as well as accounts by installations emitting CO_2 that are required by law to participate in the EU ETS. Each emitting installation has its own account, into which it receives its allocations of EUAs at the beginning of each compliance year, and from which it must surrender the appropriate number of EUAs at the end of each compliance year. For the analysis in this chapter we are interested in the activities of the installation accounts, where an installation is typically a factory or one of several blocks of a large power plant. The data contain information about the amount of EUAs transacted, the time at which the transaction has taken place, as well as some basic information on both parties to the transaction.[4]

However, the transactions data contain no mapping from installations to firms, the relevant unit of analysis, each of which may consist of one or more installations. Therefore, we match the installations from the CITL transactions data to firms, based on the work by Trotignon and Delbosc (2008). To conduct the matching we use information on EU ETS operator holding accounts, also provided by the CITL. The matching covers 83% of the available aggregate allocations for the 2005 compliance year and 91% for the 2006 compliance year, which compares favorably to the existing empirical literature on the firm-level determinants of international trade (e.g. Bernard et al., 2009).[5] We also add annual EU ETS compliance data to this dataset, again using the information on operator holding accounts as a connector.

The firm-level transactions dataset contains transactions by firms with CO_2-emitting installations, regardless of whether the counterparty is another firm with affected installations or a financial intermediary. We exclude transactions involving

[4]It is important to note that the timing of the trade between any two parties may well be different from the timing of the actual transfer of a permit between two parties. For instance, a trade may have been agreed to months before a transaction is settled, sometimes via the EUA futures market. For the purposes of our analysis we will assume that both the trade and the transaction between any two firms have taken place within the same compliance year, so that the distinction between the two becomes immaterial, since we consider data aggregated annually, based on compliance years.

[5]Transactions from the Danish could not be matched very well, as the available information on operator holding accounts did not make this feasible. For the same reason, the matching for the Belgian and German registries is incomplete also, although the problem was far less severe in these cases. Furthermore, we had to exclude transactions from the Austrian and Greek registries, as information on domestic transactions in these registries is not available in the CITL transactions database.

government accounts, as these activities mainly involve the receipt of allowance allocations and the compliance-related surrender of allowances at the end of the compliance year. As the focus is on the behavior of CO_2 emitters, we exclude transactions purely between trading accounts. Thus, for the purposes of this analysis we treat the financial sector as a black box, from which CO_2-emitting firms buy and into which they sell allowances. However, we do not consider what happens within the box as long as firms required to participate in the EU ETS are not involved. The extension of the analysis to determinants of trading between firms using pure trading accounts is left for future work.[6]

However, the CITL data and installation-to-firm matching do not contain information on many relevant firm characteristics. For this reason compile a dataset containing balance sheet information on these firms, from AMADEUS. In a final step we combine the transactions data with the firm data using our installation-to-firm matching.[7] In our final dataset we are able to map 70% and 76% of EU ETS allocations for the 2005 and 2006 compliance years, respectively, to firms including a full set of firm-level control variables.

2.2.2 Descriptive Analysis

Our raw transactions data show an aggregate allocation of about 5,900 million tons of CO_2 for the entire ETS Phase I.[8] Firms in our sample acquired EUAs for a total of 567 million tons of CO_2 through the end of calendar year 2007 over the entire available period, whereas they transfered EUAs for 796 million tons of CO_2 out

[6]Anecdotal evidence suggests that some firms use trading accounts which they own to hold and trade allowances. However, we are currently unable to ascertain whether trading accounts belong to firms that also have CO_2-emitting installations. This may lead to some measurement error of firm-level trade. For instance, a transfer of allowances between an installation account and a trading account belonging to the same firm would be classified as an inter-firm transfer instead of as an intra-firm transfer, increasing our measure of inter-firm trading at the expense of intra-firm trading. A transfer between trading accounts of two firms that both have installations affected by the EU ETS would be treated as a transaction between financial intermediaries and would thus be left out of consideration in the current analysis.

[7]While EU ETS compliance years run from February of each year to April of the following calendar year, firm data in AMADEUS are reported on a calendar year basis. For our merge we assume that the information contained in the firm control variables is stable between December and April of the following year.

[8]The discrepancy to the figure reported in Ellerman et al. (2010) is mostly due to the exclusion of transactions from the Austrian and Greek registries.

of their installations' accounts. The corresponding figures for the period February 2005 through April 2007, the end of the 2006 compliance year, are 502 and 667 million tons, respectively. However, once we account for intra-firm transfers, we find that 390 million tons are purchased between firms, whereas 555 million tons are sold during the first two compliance years. We can establish a benchmark for the relevant size of the market by summing up the absolute values of the firm-level excess allocations, i.e. of the differences between allocations and verified emissions for each company. Doing so yields an overall market size of 450 million tons of CO_2 for the first two compliance years. Thus, the amount of trade roughly compares to the benchmark market size during those years.

We next consider the distribution of EUA trading by the firms in our sample over time. We observe that EUA acquisitions are strongly concentrated in the last month before EUAs must be surrendered (Figure 2.1, top panel). This pattern is very similar for both inter-firm and intra-firm acquisitions (Figure 2.1, middle and bottom panels), suggesting an internal optimization of allowance portfolios toward the end of each compliance year for a significant number of firms to determine a firm's residual demand for allowances. The pattern on the transfer side is somewhat more balanced (Figure 2.2, top panel). While April 2006 and April 2007 are still the months with the greatest volume, significant transfers also took place during the fall months, especially in November and December. The bulk of these transfers took place externally (Figure 2.2, middle panel) although significant internal EUA movements can be observed during the month of April, mirroring the pattern of internal exports (Figure 2.2, bottom panel).

As Table 2.1 shows, the majority of this trade is conducted by a minority of firms. For instance, out of 609 firms in our dataset that received a positive EUA allocation in the 2005 compliance year and for which we have a full set of firm-control variables available, 300 did not participate in inter-firm allowance trading at all (Table 2.1, left column).[9]

Only 108 companies traded EUAs with other firms on both the supply and

[9]The remainder of the descriptive analysis only considers firms for which we have a full set of firm-specific characteristics available for consistency between the samples used for the descriptive analysis and the formal analysis undertaken in Section 2.4.

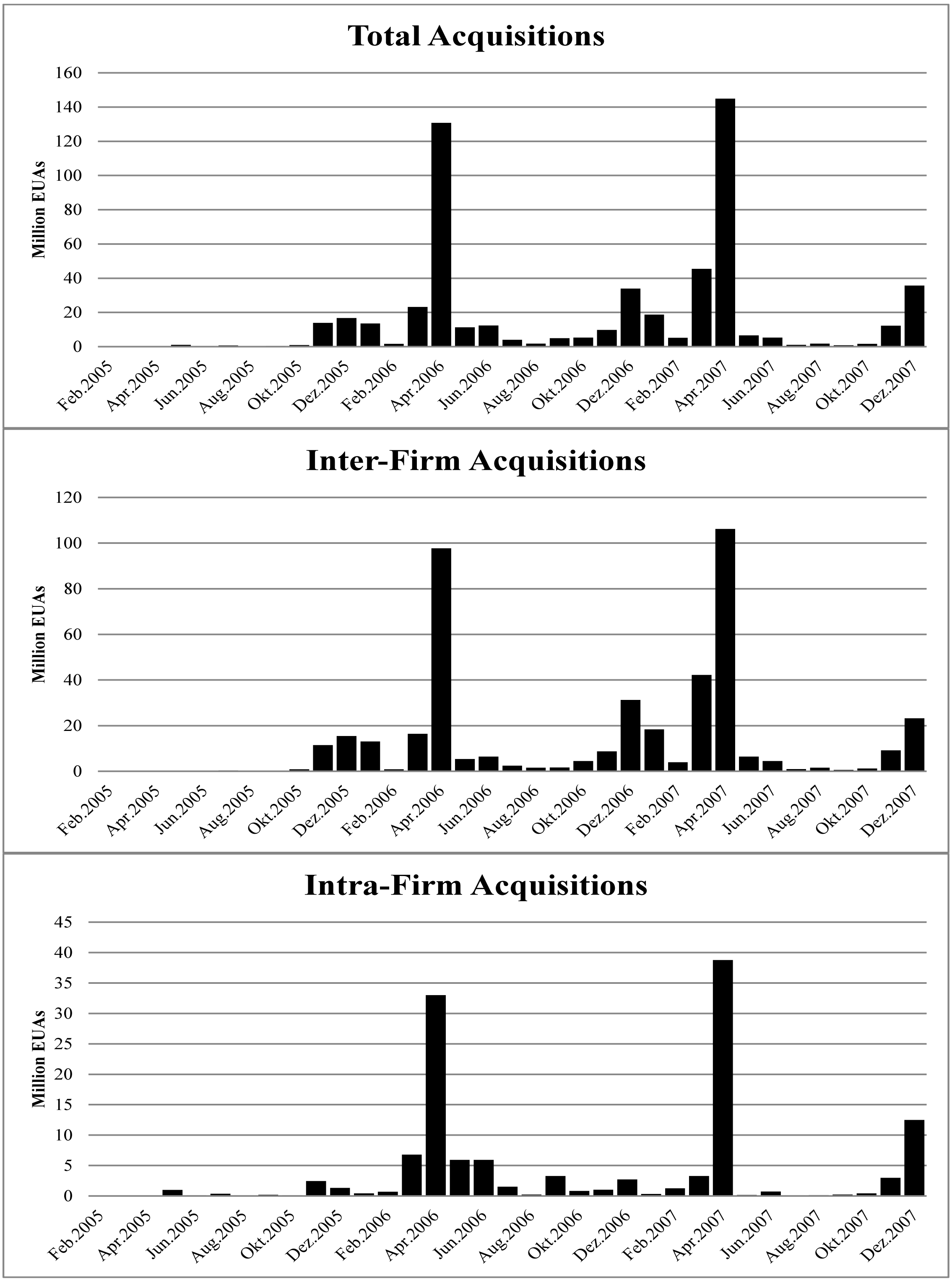

Figure 2.1: Evolution of Total, Inter-Firm and Intra-Firm Acquisitions, in Million EUAs

demand sides. 143 companies only transferred while not acquiring EUAs, whereas for 58 companies the reverse was true. As expected, the majority of the non-participants belong to the group of companies which were long on allowances, whereas only 87

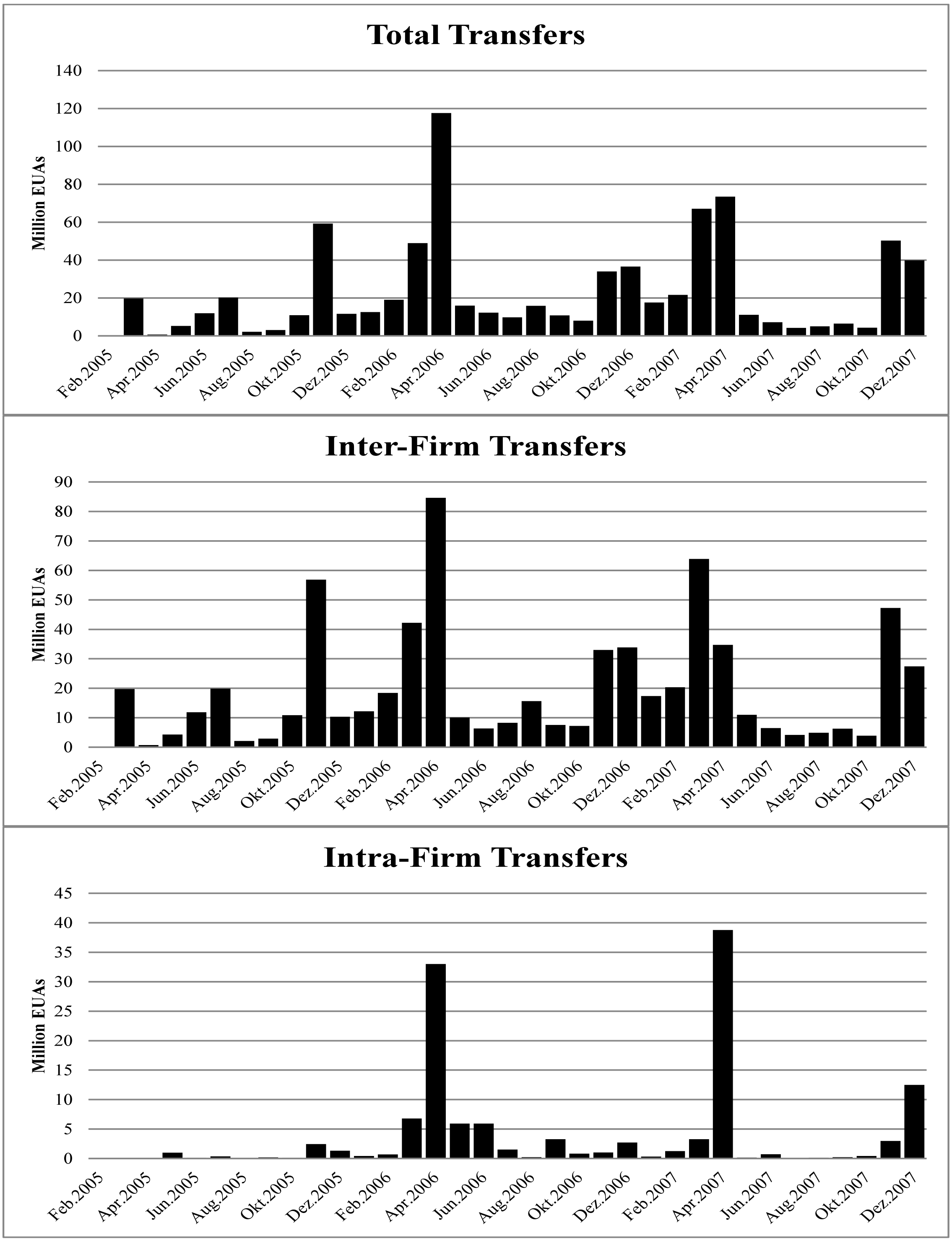

Figure 2.2: Evolution of Total, Inter-Firm and Intra-Firm Transfers, in Million EUAs

companies which were short on allowances did not participate in trading during the 2005 compliance year. We observe a uniform increase in participation during the 2006 compliance year. The number of companies which received a positive allocation of EUAs while also having a full set of firm-level control variables available increased

Table 2.1: Participation in Inter-Firm Trading, by EUA Position

Participation: inter-firm sales vs inter-firm purchases, all companies

2005	Inter-firm purchases 0	1	Total	2006	Inter-firm purchases 0	1	Total
Inter-firm sales 0	300	58	358	Inter-firm sales 0	246	105	351
1	143	108	251	1	160	156	316
Total	443	166	609	Total	406	261	667

Participation: inter-firm sales vs inter-firm purchases, long companies

2005	Inter-firm purchases 0	1	Total	2006	Inter-firm purchases 0	1	Total
Inter-firm sales 0	213	14	227	Inter-firm sales 0	187	22	209
1	140	74	214	1	151	112	263
Total	353	88	441	Total	338	134	472

Participation: inter-firm sales vs inter-firm purchases, short companies

2005	Inter-firm purchases 0	1	Total	2006	Inter-firm purchases 0	1	Total
Inter-firm sales 0	87	44	131	Inter-firm sales 0	59	83	142
1	3	34	37	1	9	44	53
Total	90	78	168	Total	68	127	195

to 667 (Table 2.1, right column), as some laggard registries, mainly the Italian and Polish ones, became fully operational. The number of non-participants fell to 246, whereas now 156 companies both transferred and acquired allowances during the same year. Participation in trading increased for both long and short companies.

Participation is restricted to a small number of transactions per compliance year for most companies. For instance, on the supply side the vast majority of firms either did not trade at all or conducted at most five transactions in either compliance year (Figure 2.3). However, most firms were not autarkic with regard to allowance management (Figure 2.4). Only 35 firms exclusively managed their EUA portfolio internally during the 2005 compliance year, as measured by the ratio of total inter-firm trade to total trade, whereas 38 firms did so during the 2006 compliance year.

The large majority exclusively relied on the external market and did not shift allowances internally at all, as evidenced by 204 and 289 firms with inter-firm to total trade ratios of 1 during the 2005 and 2006 compliance years, respectively. The remaining few firms are spread fairly evenly between the extremes, with a stronger concentration in the top decile of the ratio.

Having examined the firm's trading behavior in the EU ETS, we turn our attention to the characteristics of the firms in our sample. Table 2.2 presents the

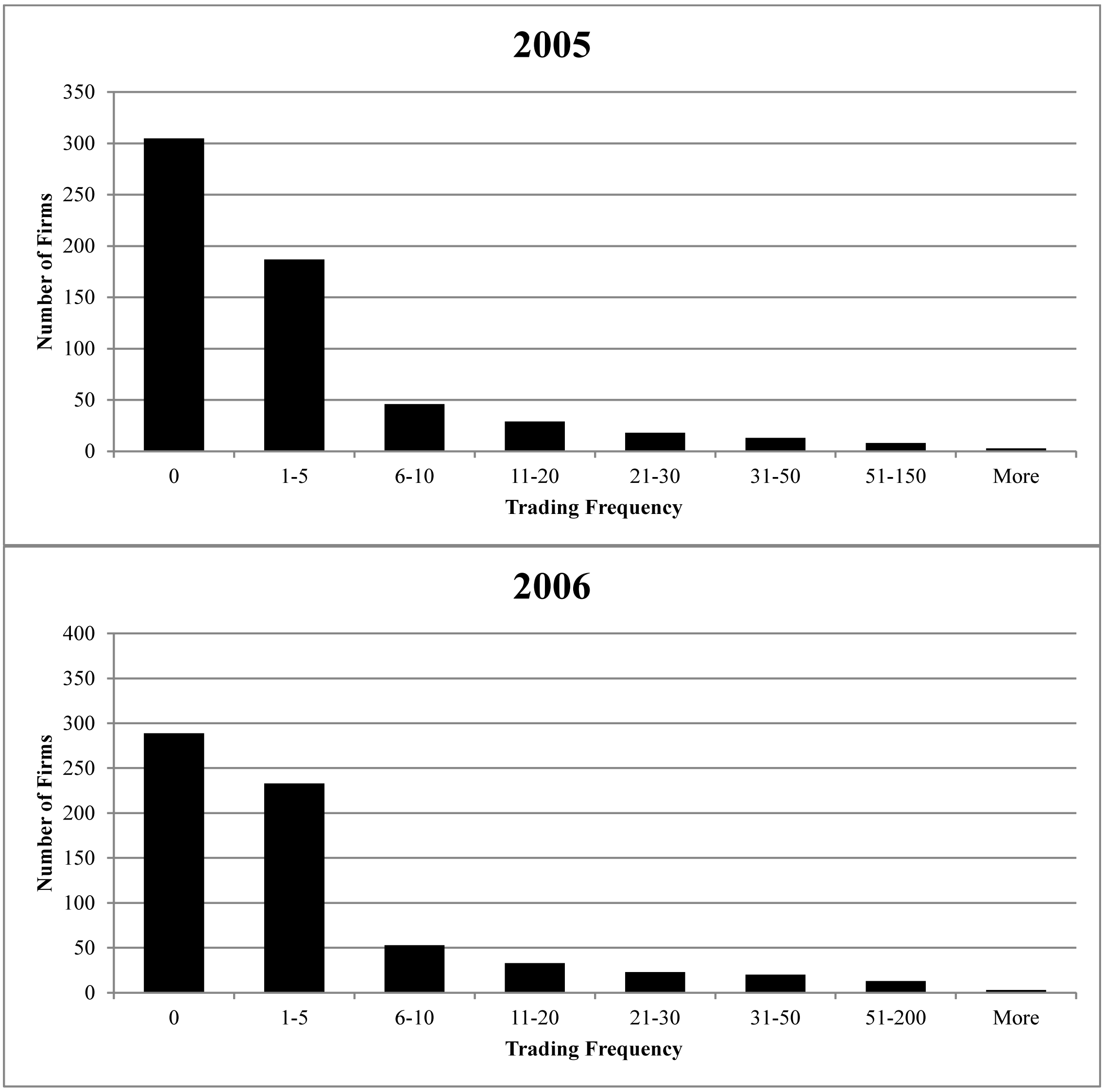

Figure 2.3: Trading Frequency, Total Sales

firms which received a positive allocation during the 2006 compliance year and for which we have a full set of control variables available. We observe that the sample is skewed towards large and more profitable firms receiving large EUAs allocations. The mean firm had a turnover of 5.6 billion Euro, received an allocation for about 2.3 million tons of CO_2 and employed more than 13,000 people. Furthermore, the mean firm was short on EUAs. However, the median firm was much smaller, with a turnover of less than 400 million Euro, an allocation of 200 thousand EUAs and about 927 employees. It was also less profitable, with a return on assets of 4.1%. Furthermore, the median firm was long on EUAs. In addition, 28% of the firms in our sample are government-owned, while 8% are person-owned. 62% of the firms are

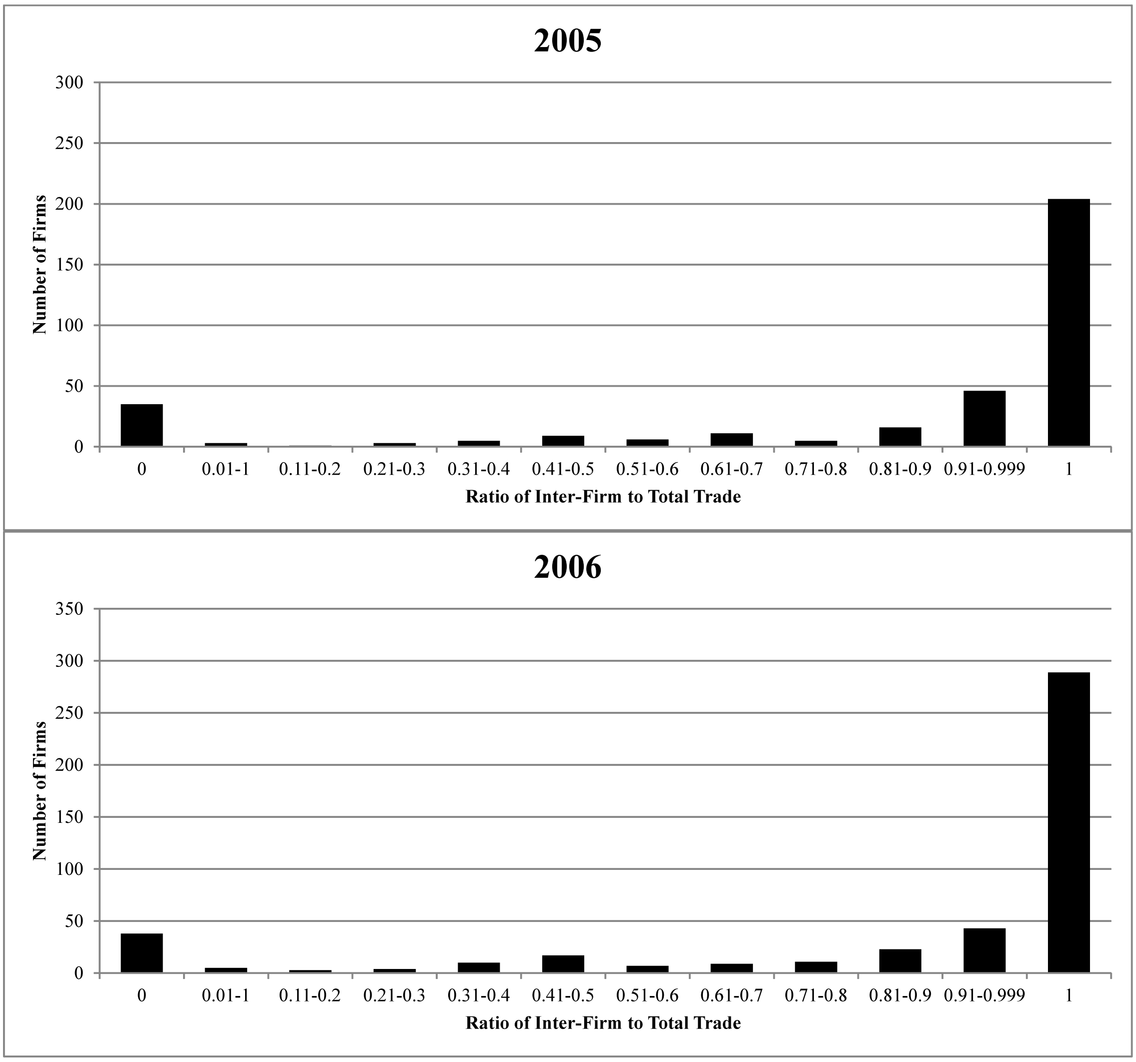

Figure 2.4: Ratio of Inter-Firm to Total Trade

classified as belonging to the combustion category by the CITL, with the remainder having its main ETS-related activity in the industrial sector.[10] The overall range

[10]The CITL assigns main activity codes to each emitting installations' account, with each account receiving only one classification. Codes are divided into the following categories: combustion, mineral oil refining, coke ovens, metal ore roasting, pig iron/steel production, cement production, glass production, ceramics production, paper and pulp production, as well as a residual opt-in category. To avoid problems with the estimation of so many separate dummy variables we create the industry dummy variable equaling zero if the main activity type is combustion and one if the activity falls into any of the other categories, excluding the opt-in activity. The reason for singling out combustion is that the largest share of aggregate EU ETS allocations belongs to this category. In many cases this means electricity generation. However, several firms which would be considered industrial concerns have all of their EU-ETS-related installations classified as having combustion as its main activity. For instance, this typically applies for car manufacturers. Since we do not have any other information available to classify the companies by sector and since we do not want to introduce arbitrariness by re-classifying firms by hand, we have kept the CITL classification. Additionally, after matching installations to firms we sometimes find that installations with several activity types belong to the same firm. In this case we categorize the firm as belonging to the industrial sector if the majority of its emissions is caused in installations classified as industrial.

is fairly large according to all these metrics, giving us confidence that while larger firms are over-represented our sample provides a fair picture of the players in the EU ETS. However, to avoid biases in our estimations we use logarithms of our main quantitative variables.

Table 2.2: Descriptive Statistics, 2006 Cross Section

Variable	Obs.	Median	Mean	Std. Dev.	Min	Max
Allocation (EUAs)	667	199,272	2,269,057	9,221,445	4	150,000,000
Verified emissions (metric tons)	667	160,738	2,301,767	9,773,813	5	157,000,000
Turnover (Thousand Euro)	667	393,113	5,615,122	19,500,000	1,462	248,000,000
Number of employees	667	927	13,662	38,800	4	368,500
Return on Assets (in percent)	667	4.1	5.3	6.4	-17.5	51.0

As a final descriptive step we consider the trading patterns in relation to the firms' EUA position and their degree of market activity. Table 2.3 distinguishes the firms in our two cross sections for which we have a full set of control variables available according to two criteria, the EUA position (long vs. short) and whether the firm has actively managed its EUA portfolio, i.e. whether it has both sold and purchased EUAs outside its boundaries during the compliance year in question. We already outlined the basic participation patterns in Table 2.1.

Table 2.3: EUA Trading Patterns, by Firm Trading Activity and Allowance Position, in Million Tons of CO_2

			Number of firms	Allocation	Surplus allocation	Volume inter-firm sales	Volume inter-firm purchases	Net inter-firm trade
	Long	Active	74	286.3	41.5	67.8	16.5	51.2
		Not active	367	283.7	38.1	19.3	0.2	19.1
2005	Short	Active	34	684.8	-59.0	167.4	126.0	41.4
		Not active	134	175.3	-30.2	0.0	12.0	-12.0
		Sum	609	1,430.1	-9.7	254.5	154.8	99.8
	Long	Active	112	447.5	47.7	85.8	23.7	62.1
		Not active	360	283.4	39.1	32.4	0.3	32.1
2006	Short	Active	44	652.1	-82.0	112.5	187.2	74.7
		Not active	151	130.6	-26.6	0.4	16.5	-16.1
		Sum	667	1,514	-21.8	231.2	227.7	3.5

Note: Long indicates that the firm's allocation exceeds its verified emissions in the respective compliance year; Active is defined as having at least one import and one export transaction during that compliance year; net inter-firm trade is defined as the difference between inter-firm exports and inter-firm imports.

For the 2005 cross section we find that the aggregate ex-post EUA position of all long firms, both active and less active, was similar, only that this overall allowance surplus is divided among far fewer firms for the group of active companies.

Thus, a larger individual allocation appears to be related to stronger involvement in allowance trading. Furthermore, the more active long firms appear to have realized their profit opportunities from selling EUAs more fully during the 2005 compliance year, while the less active long firms only sold about half of their surplus allowances during the 2005 compliance year. Active short firms represent an allocation of about 685 million EUAs, with most of the largest players by allocation size belonging to this group. During the 2005 compliance year this group exhibits net sales on aggregate, despite being short, meaning that the actively trading firms that were short on EUAs resorted to significant borrowing for the 2005 compliance year. Such a large deficit position by the active short group suggests an expectation of at least non-increasing prices during the remainder of ETS Phase I. The group of less active firms almost exclusively bought EUAs to cover some of their deficit, but also borrowed significantly, about 18 million tons. These trends in aggregate trading behavior led to net sales of almost 100 million EUAs in our sample.

When considering the 2006 compliance year, we notice that the aggregate amount of EUAs covered by our sample increases from 1.43 billion to 1.51 billion tons of CO_2, mainly as a result of the Italian and Polish registries becoming operational. The majority of these new entrants appears to have been long on EUAs and actively involved in trading, since the aggregate allocation for this group increases from 286 million to 448 million EUAs. Active short firms became major buyers during the 2006 compliance year, although they did not quite cover their allocation deficit for even that year. Less active short firms also covered a larger share of their shortfall for 2006 from the market but also appear to have resorted to some borrowing in 2006. On balance we observe net sales of 3.5 million tons of CO_2 during the 2006 compliance year.

2.3 Methodology

The firms in our sample face a twin decision. They first must decide whether to participate in trading at all and, in case they do participate, what amount to trade. This decision problem gives rise to the following population model:

$$y_{i1} = x_{i1}\beta_1 + \epsilon_{i1} \quad (2.1)$$

$$y_{i2} = x_{i2}\beta_2 + \epsilon_{i2}, \quad (2.2)$$

where y_{i1} denotes the logarithm of the amount of emission permits traded, while y_{i2} is a dummy variable equaling 1 if the firm trades a positive amount of EUAs and 0 if it does not. Therefore, a positive y_{i1} is only observed for firms participating in trading, while y_{i2} is available for all firms in the sample. Correspondingly, x_{i1} is the set of control variables containing information about firms that trade, whereas x_{i2} consists of covariates for all firms. Given the selection decision, the regression function for the subset of available data on amounts traded depends not only on x_{i1} but also on the rule according to which the sample has been selected. Thus, (2.2) enters the conditional expectation of (2.1) as follows:

$$E(y_{i1}|x_{i1}, \epsilon_{2i}) = x_{i1}\beta_1 + E(\epsilon_{1i}|x_{i2}, \epsilon_{2i}) = x_{i1}\beta_1 + \gamma_1\epsilon_{2i} \quad (2.3)$$

Accordingly, the existence of a sample selection bias depends on the correlation between the error terms in (2.1) and (2.2). Neglecting this issue by estimating (2.1) only based on the information from the selected sample can give rise to an omitted variable problem (Heckman, 1979). However, as Heckman (1979) has shown, this bias can be corrected for by including an additional regressor in (2.1). Using iterated expectations on (2.3) we obtain

$$E(y_{i1}|x_{i1}, y_{2i} = 1) = x_{i1}\beta_1 + \gamma_1\lambda(x_{i2}\delta_2), \quad (2.4)$$

where $\lambda(x_{i2}, \delta_2) = \frac{\phi(x_{i2}\delta_2)}{\Phi(x_{i2},\delta_2)}$ is the inverse Mills ratio. Estimating (2.4) yields consistent estimates of β_1. $\lambda(x_{i2}\delta_2)$ cannot be directly computed from the data, as it involves the unknown parameter vector δ_2. However, it can be consistently estimated using Heckman's (1979) two-step procedure. In a first step we obtain $\hat{\delta}_2$ by performing a probit estimation of the probability that firms will participate in trading:

$$P(y_{i2} = 1|x_{i2}) = \Phi(x_{i2}\delta_2) \quad (2.5)$$

In a second step we regress y_{i1} on x_{i1} and $\hat{\lambda}(\cdot)$, our estimate of the inverse Mills ratio. A simple t-test of $H_0 : \lambda_1 = 0$ allows us to test for the existence of a selection bias in the firms' amount decision induced by its participation decision. Furthermore, in addition to yielding consistent estimates for the coefficient vector in the amount decision we obtain determinants of the probability to participate in trading, which is also of primary interest in this study.

In principle x_{i1} and x_{i2} can contain identical regressors. However, in the case of identical regressors we rely on the non-linearity of $\hat{\lambda}(\cdot)$ for identification. To avoid a possible collinearity problem, it is desirable to use exclusion restrictions, if applicable, so that x_{i1} and x_{i2} differ, i.e. to include variables in the estimation of the firm's participation decision which do not affect its amount decision (e.g. Bernard et al., 2010). We assume that a firm's total size, as measured by turnover, determines participation, while it is not related to the amount decision. The reason is that firms are covered by the EU ETS unevenly, depending on their activities, so that smaller firms may end up with a larger EUA allocation than large corporations with activities that mostly lie outside the EU ETS. Furthermore, the relationship between turnover and firms' excess allocation amounts, i.e. the difference between allocation and verified emissions, is even weaker. The excess allocation determines whether the firm will tend to be on the supply or on the demand side in the allowance trade, so that a systematic relationship between firm size and excess allocation could be expected to influence the amounts traded.[11] Instead, we use turnover as a proxy for a firm's ability to overcome the fixed cost of participating in EUA trading, based on the premise that larger firms are more likely to have the resources necessary to overcome the costs of engaging in trading. Our second exclusion restriction is that the ratio of the EUA stock to turnover also only affects participation. This variable serves as a proxy for the firm's incentive to overcome the cost of participating, measuring the relative value of the firm's EUA stock in proportion to its overall size. A larger value of this ratio should provide a greater incentive to engage in trading, especially in inter-firm trading, while the actual amount traded should be

[11] The pairwise correlation coefficients between turnover and the company-level allocation is 0.27 and 0.29 for the full 2005 and 2006 estimation samples, respectively, while the correlations between turnover and excess allocation are -0.1 and -0.08 for the respective full samples.

driven by the absolute value of the EUA stock only.

The remainder of x_{i2} and all of x_{i1} are made up as follows: We include turnover as a measure of firm size,[12] the return on assets as a proxy for firm performance, and dummy variables indicating whether a company was government-owned or person-owned. We also include dummy variables indicating if a company was based in an EU accession country and whether it belonged to the industrial sector or had its ETS relevant activities in combustion. Finally, we also include variables capturing EU ETS specific aspects of the firm. A dummy indicates whether a firm was long on EUAs at the end of the compliance year, based on the difference between its allocation and its verified emissions. Finally, we include the value of the stock of each firm's actual allocation. Details on the precise definition of all variables in our dataset, including data sources, can be found in the Appendix A.1.

We conduct separate estimations for cross sections for the 2005 and 2006 compliance years of EU ETS Phase I, since each year displays a distinct evolution of the EUA spot price, and also to capture possible learning effects from one compliance year to the next.[13] For each cross section we perform estimations for two samples of companies. The full sample contains information on all companies for which the full set of data is available, while the less-active sample excludes firms that have both imported and exported at least once during the same compliance year. With this, admittedly rough, criterion we aim to distinguish between firms that managed their allowance portfolio actively from those that may have bought and sold mostly based on residual concerns.

[12]The results are similar when using employment or total assets to capture firm size.

[13]We do not report results for 2007, for two reasons. First, data availability does not allow for a complete picture of the trading behavior during that year. Transaction data are currently only available through the end of the 2007 calendar year, whereas most of the trade for both the 2005 and 2006 compliance years took place during the months immediately prior to the end of the compliance year. Second, 2007 was the last year of the self-contained first ETS trading period, with EUA prices close to zero, suggesting that a significant proportion of trading may have been driven by residual concerns at the end of the period. However, estimation results based on currently available data are available upon request.

2.4 Results and Discussion

2.4.1 Inter-Firm Acquisitions

We first consider the demand side of the inter-company trade in EUAs (Table 2.4). The first stage of our estimation reveals that several company characteristics significantly predict participation in inter-company EUA trading on the buyer side. Company size, as measured by the natural logarithm of turnover is positively and significantly related with the probability to engage in EUA purchases. Our estimates for the full samples indicate that a one percent increase in turnover leads to a 3.7% increase in the probability to participate when considering the full samples for both years. This finding corresponds to results from the empirical literature on international trade, which finds that larger firms are more likely to engage in trade. The log of the total value of a firm's EUA allocation available for trade[14] is also found to increase the participation probability in both years, with a one-percent increase leading to a 4.6% and 4% increase in the participation probability, respectively. This effect is robust to excluding less actively trading companies in the 2006 cross section, while being insignificant in 2005. Thus, the size of the effect of a firm-specific characteristic is on par with an EU-ETS-specific variable in its impact on the likelihood to participate in trading.

Furthermore, we find a positive but insignificant effect of the relative value of the EUA allocation to the firm, as measured by the value of the annual EUA allocation as a share of firm size, on participation. Ownership structure also has a positive and significant impact on participation in 2005, while being insignificant in 2006, at least for the full sample. We find that government-owned firms were 14% more likely to purchase EUAs externally in 2005. On the other hand, person-owned companies were less likely to participate in 2005, by 14.8% in the full sample. Again, in 2006 this effect is no longer significant. The firm's sector also has a negative and significant impact on participation in both years. Having its main activity in the industrial

[14]This variable measures the actual stock of EUAs transferred into the firms' accounts by the national registries during a particular compliance year, which is why the full sample is smaller for the 2005 compliance year, as some firms did not receive their allocation before the start of the 2006 compliance year.

sector rather in combustion reduces the participation probability by around 14.1% and 13.2%, respectively.

Table 2.4: Determinants of Inter-Firm EUA Acquisitions

	2005		2006	
	Full sample	Not active	Full sample	Not active
	ln(Value of inter-firm acquisitions)			
ln(Value of EUA stock)	0.809***	0.533***	0.824***	0.660***
	(0.000)	(0.000)	(0.000)	(0.000)
EUA position: long	-3.135***	-2.111	-2.417***	-2.237
	(0.000)	(0.499)	(0.001)	(0.187)
Return on assets	0.070**	0.045	0.041*	0.051**
	(0.042)	(0.402)	(0.053)	(0.032)
Government-owned	0.616	0.576	0.147	-0.100
	(0.318)	(0.395)	(0.718)	(0.845)
Person-owned	-2.959	-1.627	-0.684	-0.006
	(0.219)	(0.214)	(0.343)	(0.991)
Industry	0.204	-0.265	-0.502	-0.255
	(0.744)	(0.849)	(0.249)	(0.509)
New EU members	-1.172	n/a	-0.898	-0.566
	(0.572)	n/a	(0.151)	(0.338)
Inverse Mills Ratio	1.149	0.715	0.857	0.969
	(0.367)	(0.794)	(0.454)	(0.444)
Constant	-0.539	3.643	-0.225	1.540*
	(0.883)	(0.404)	(0.905)	(0.089)
	Participation: inter-firm acquisitions			
Value of EUA stock / turnover	0.00002	0.000008	0.0001	0.0001
	(0.759)	(0.803)	(0.638)	(0.439)
ln(Turnover)	0.037***	0.005	0.037***	0.017*
	(0.001)	(0.232)	(0.001)	(0.077)
ln(Value of EUA stock)	0.046***	-0.000	0.040***	-0.016*
	(0.000)	(0.992)	(0.000)	(0.051)
EUA position: long	-0.304***	-0.169***	-0.421***	-0.487***
	(0.000)	(0.000)	(0.000)	(0.000)
Return on assets	0.0004	0.001	0.0002	0.0003
	(0.907)	(0.490)	(0.941)	(0.903)
Government-owned	0.140**	0.008	-0.026	-0.066*
	(0.020)	(0.655)	(0.634)	(0.098)
Person-owned	-0.148**	-0.017	-0.077	0.001
	(0.013)	(0.184)	(0.298)	(0.993)
Industry	-0.141***	-0.032**	-0.137***	-0.058
	(0.001)	(0.049)	(0.003)	(0.127)
New EU members	-0.072	-0.069***	-0.030	-0.024
	(0.308)	(0.009)	(0.637)	(0.608)
Constant	-3.943***	-1.374*	-2.138***	0.329
	(0.000)	(0.065)	(0.000)	(0.580)
Observations	609	501	667	511
Censored Observations	443	443	406	406
Wald chi2	48.292	24.956	146.350	174.051
Wald chi2 p-value	0.000	0.000	0.000	0.000

Bootstrap p-values are in parentheses based on 1000 replications, with *, **, *** indicating significance at the 10%, 5% and 1% levels, respectively. Marginal effects are reported for the participation equation. Marginal effects for dummy variables are computed for a discrete change from 0 to 1.

However, this effect is much diminished or even insignificant when excluding the active firms from the sample. Thus, we find evidence of a more active allowance management in the combustion sector relative to the industrial sector. Other firm characteristics, such as being based in an EU accession country and firm profitability are not found to have a significant impact on participation. Finally, we find strong evidence that firms which were long on EUAs were significantly less likely to engage in inter-firm EUA purchases, across all samples and in both 2005 and 2006. Quantitatively the result is also very significant. Long firms were 30.4% less likely to participate in EUA purchases for the full 2005 sample, while this probability falls to 16.9% for the less-active sample. This effect even strengthens in 2006, the probability of non-participation increasing above 40% in both samples. Thus, while market-specific factors such as the available stock of EUAs and the relative compliance position of the firm significantly predict the probability to engage in carbon permit trading, a number of company-specific characteristics are also significant, indicating that in the EU ETS both sets of determinants come together in influencing the firms' decision whether to trade.

We next turn to the relationship between the participation and amount equations. Our estimate of the inverse Mills ratio is positive but insignificant in all cases for the 2005 and 2006 cross sections. Therefore, we find no evidence of a selection bias, suggesting that the decisions whether to engage in EUA purchasing at all and how much to purchase were not significantly related. This finding is in contrast to the results in the trade literature, suggesting that firm specific self-selection does not rule the participation decision to the same extent as is the case for regular traded goods.

Considering the amount decision, we find that a larger initial EUA allocation leads to larger purchases in all three years, suggesting that an increase in the value of the EUA stock by 1% increases purchases by between 0.53% and 0.82%, depending on year and sample. We also find that more profitable firms purchased more EUAs both in 2005 and 2006. We estimate that a one percentage point increase in the return on assets led to an increase in EUA purchases by 7% and 4.1% for the full 2005 and 2006 samples, respectively. Finally, we find that firms that were long on EUAs ex post bought significantly fewer EUAs both in 2005 and 2006, ceteris paribus. However, this effect is no longer significant in the less-active sample. Thus, the amount decision appears to be dominated by EU ETS specific concerns, although better performing firms tend to trade more intensively.

2.4.2 Inter-Firm Transfers

We next consider the supply side of the EU ETS (Table 2.5). We find that the value of the EUA stock available for trading positively and significantly predicts the likelihood of engaging in the sale of EUAs both in 2005 and 2006. Coefficient estimates are larger than on the demand side, with a one percent increase in the value of a firm's initial EUA stock increasing its probability to participate in selling EUAs by around 10% in the full samples.

Table 2.5: Determinants of Inter-Firm EUA Transfers

	2005		2006	
	Full sample	Not active	Full sample	Not active
	ln(Value of inter-firm transfers)			
ln(Value of EUA stock)	1.170***	0.765**	0.560***	0.785***
	(0.000)	(0.028)	(0.009)	(0.000)
EUA position: long	2.001*	1.272	-0.321	1.722
	(0.084)	(0.781)	(0.694)	(0.348)
Return on assets	0.017	0.016	-0.007	0.018
	(0.479)	(0.651)	(0.683)	(0.426)
Government-owned	0.678	0.380	-0.330	-0.196
	(0.252)	(0.685)	(0.260)	(0.582)
Person-owned	-0.514	0.203	-0.208	-0.412
	(0.553)	(0.869)	(0.651)	(0.464)
Industry	-0.321	-0.036	0.322	-0.479
	(0.516)	(0.966)	(0.507)	(0.438)
New EU members	0.251	0.431	0.704**	0.481
	(0.600)	(0.548)	(0.016)	(0.156)
Inverse Mills Ratio	1.614	-0.013	-1.928	0.786
	(0.305)	(0.996)	(0.177)	(0.647)
Constant	-8.550	-0.168	5.789	-1.510
	(0.162)	(0.989)	(0.225)	(0.803)
	Participation: inter-firm transfers			
Value of EUA stock / turnover	-0.0001	-0.0001	-0.0002	-0.0002
	(0.270)	(0.397)	(0.429)	(0.407)
ln(Turnover)	0.001	-0.013	0.002	-0.013
	(0.930)	(0.221)	(0.842)	(0.247)
ln(Value of EUA stock)	0.099***	0.054***	0.103***	0.060***
	(0.000)	(0.000)	(0.000)	(0.000)
EUA position: long	0.282***	0.309***	0.302***	0.332***
	(0.000)	(0.000)	(0.000)	(0.000)
Return on assets	-0.003	-0.002	0.003	0.003
	(0.437)	(0.585)	(0.487)	(0.344)
Government-owned	0.195***	0.089	0.075	-0.00007
	(0.004)	(0.149)	(0.208)	(0.999)
Person-owned	-0.167**	-0.061	-0.112	-0.051
	(0.036)	(0.376)	(0.147)	(0.479)
Industry	-0.164***	-0.113***	-0.204***	-0.159***
	(0.001)	(0.005)	(0.000)	(0.001)
New EU members	-0.064	-0.039	-0.051	0.011
	(0.435)	(0.529)	(0.506)	(0.871)
Constant	-4.967***	-4.524***	-4.314***	-3.506***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	609	501	667	511
Censored Observations	358	358	351	351
Wald chi2	139.430	58.998	156.631	96.158
Wald chi2 p-value	0.000	0.000	0.000	0.000

Bootstrap p-values are in parentheses based on 1000 replications, with *, **, *** indicating significance at the 10%, 5% and 1% levels, respectively. Marginal effects are reported for the participation equation. Marginal effects for dummy variables are computed for a discrete change from 0 to 1.

The value of the EUA stock relative to the value of the firm is again insignificant, as is the log of a firm's turnover. The results regarding the ownership, industry and new-EU dummies are similar to our findings on the demand side regarding sign and significance for the 2005 cross section, while the absolute values of the coefficient estimates are generally larger. For the 2006 cross section neither government or private ownership nor being based in an EU accession country has a significant impact on the probability to participate in importing EUAs. However, the industry dummy is still negative and significant in both years and for both samples, with the coefficient estimate suggesting a decrease in the participation probability by up to 20.4% if the firm's main activity lay outside the combustion category.
Furthermore, again we find a strongly significant effect on participation for firms that were long on allowances. Being long on allowances increased the probability to sell EUAs by some 30%, in both years and both samples. Thus, it appears that the participation decision on the supply side was also driven by a combination of firm-specific and market-specific factors during the first EU ETS compliance year, again partially analogous to findings from the wider trade literature. However, in the second year market-specific concerns appear to have dominated, apart from the sectoral distinction in trading probability between combustion and industry.

Again, we find that the participation and amount decisions appear to be distinct, as the inverse Mills ratio is never significant. Our results suggest that there is no significant selection bias on the supply side of the EU-ETS, supporting our finding for the import side in this respect. Again, this is in contrast to the results in the trade literature.

We then consider the amount decision on the supply side. As in the case of purchases, we find that a larger EUA allocation is positively and significantly related to the amount sold for both years and all samples, while the coefficient estimates are somewhat larger than their equivalents on the demand side. We also find fairly weak evidence that firms which turned out to be long on allowances at the end of the compliance year sold a larger amount during the 2005 compliance year, ceteris paribus. This variable is no longer significant in 2006 or in the restricted sample in 2005. Thus, our results indicate that firms' sale decisions regarding EUAs were less strongly related to their eventual EUA position than the inter-firm purchasing decisions of companies that turned out to be short on EUAs, indicating potential sluggishness on the supply side during the first compliance year. Finally, firms based in new EU member countries sold significantly more allowances when considering the full sample of the 2006 cross section, while neither the ownership nor the industry dummies are found to have a significant impact on the amount supplied.

2.4.3 Intra-Firm Acquisitions

Finally, we estimate the determinants of intra-company acquisitions of EUAs, i.e. one installation of a company receiving EUAs from another installation within the same company. Thus, we consider the extent to which firms optimize their permit portfolio internally.[15]

The determinants of the participation decision are similar to those of the participation decision in inter-company purchases in terms of the sign and significance of the value of the firm's EUA stock, as well as of the ownership and industry dummies for the 2005 cross section. However, the ownership dummies are also significant in the 2006 cross section, unlike in the case of inter-company purchases. The industry dummy is no longer significant in the 2006 cross section, except for the case of one restricted sample, in contrast to the result for inter-company EUA buying. The results are somewhat weaker statistically, while the coefficient estimates are also less significant economically.

The key differences are that, first, the EUA-stock-to-turnover ratio is significant and negative in both 2005 and 2006, although this is only true for the restricted sample in the 2005 cross section. This result suggests that the greater the value of the stock of EUAs relative to the value of the company, the less likely it is to transfer them internally. Second, the size of the company, as measured by turnover, does not significantly predict intra-company transfers. Also, while being long on EUAs only significantly lowers the participation probability in 2005 it is insignificant in the 2006 cross section. Being long on EUAs predicts a decrease in the participation

[15]The results in this section are essentially identical to the results on intra-firm "sales", which is why we only report one set of estimation results.

probability by 7.3% in the full 2005 sample. Thus, the firms' EUA position appeared to have a weaker impact on internal than on external permit portfolio optimization.

Table 2.6: Determinants of Intra-Firm EUA Acquisitions

	2005		2006	
	Full sample	Not active	Full sample	Not active
	ln(Value of inter-firm acquisitions)			
ln(Value of EUA stock)	0.513*	0.341	0.694***	0.634***
	(0.061)	(0.496)	(0.000)	(0.000)
EUA position: long	-0.748	-0.496	-0.383	-0.090
	(0.260)	(0.714)	(0.268)	(0.835)
Return on assets	-0.021	0.007	0.023	0.030
	(0.730)	(0.934)	(0.420)	(0.425)
Government-owned	-1.073	-1.582	-1.498**	-1.251**
	(0.244)	(0.405)	(0.015)	(0.044)
Person-owned	-0.828	1.482	-1.463**	-0.759
	(0.565)	(0.622)	(0.032)	(0.341)
Industry	-0.349	0.790	-0.487	0.012
	(0.697)	(0.635)	(0.163)	(0.984)
New EU members	-1.185	-0.270	0.267	0.333
	(0.731)	(0.941)	(0.767)	(0.730)
Inverse Mills Ratio	-1.646	-2.380	0.110	-0.120
	(0.396)	(0.582)	(0.900)	(0.922)
Constant	5.844	8.999	1.072	1.687
	(0.374)	(0.488)	(0.719)	(0.621)
	Participation: inter-firm acquisitions			
Value of EUA stock / turnover	-0.0001	-0.0002**	-0.001**	-0.001**
	(0.194)	(0.017)	(0.044)	(0.038)
ln(Turnover)	0.008	-0.002	0.013	0.002
	(0.511)	(0.809)	(0.225)	(0.846)
ln(Value of EUA stock)	0.044***	0.024	0.044***	0.027***
	(0.000)	(0.158)	(0.000)	(0.001)
EUA position: long	-0.073*	-0.041	-0.006	-0.009
	(0.061)	(0.332)	(0.850)	(0.769)
Return on assets	-0.001	0.001	-0.001	-0.0001
	(0.634)	(0.676)	(0.621)	(0.969)
Government-owned	0.144**	0.073	0.180***	0.103*
	(0.029)	(0.355)	(0.003)	(0.073)
Person-owned	-0.103**	-0.073	-0.093**	-0.071*
	(0.034)	(0.354)	(0.042)	(0.070)
Industry	-0.092**	-0.061	-0.024	-0.047
	(0.021)	(0.285)	(0.507)	(0.164)
New EU members	-0.102	-0.058	-0.164***	-0.101*
	(0.101)	(0.404)	(0.000)	(0.055)
Constant	-4.002***	-3.113***	-3.684***	-2.692***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	609	501	667	511
Censored Observations	468	413	498	411
Wald chi2	25.447	12.405	163.821	106.641
Wald chi2 p-value	0.001	0.088	0.000	0.000

Bootstrap p-values are in parentheses based on 1000 replications, with *, **, *** indicating significance at the 10%, 5% and 1% levels, respectively. Marginal effects are reported for the participation equation. Marginal effects for dummy variables are computed for a discrete change from 0 to 1.

As in the case of inter-firm trade both on the supply and demand sides, the intra-firm EUA trade also does not exhibit a significant selection bias.

When considering the amount decision we find that the amount of EUAs transferred internally increases with the value of the EUA stock available to the firm in the respective compliance year. However, intra-company EUA flows were less elastic to the value of the firm's available permit stock than in the case of both inter-company exports and imports. A one-percent-increase in the EUA stock approximately resulted in 0.51% and 0.63% increases in intra-firm transfers, respectively. The government dummy is negative and strongly significant in the 2006 sample, while being insignificant in 2005. Thus, for the 2006 sample we find that while government-owned companies were more likely to participate in intra-company permit transfers, they transferred smaller amounts, ceteris paribus. Person-owned companies also transferred smaller amounts, given participation, although the result is only significant in the full sample of the 2006 cross section.

Hence, while our results suggest that both the intra-firm and inter-firm EUA trade share a subset of determinants, firm-specific factors seem to be relatively more important in the intra-firm trade. In particular, unlike in the inter-firm permit trade the influence of the firms' relative EUA position is either weakened or insignificant, both in the participation and amount decision.

2.5 Conclusion

Based on a newly constructed dataset combining transactions data on the first two compliance years of the European Emission Trading Scheme with balance sheet information on firm-specific characteristics, this chapter addresses two main questions. First, what makes firms trade carbon emission permits? Second, given the flexibility afforded by the EU ETS, what is the role of firm-specific relative to market-specific factors? We thus conduct a thorough analysis of the microstructure of the EU ETS, both descriptively and analytically, while comparing our own results with those of the existing literature on the firm-level determinants of international trade.

Estimating a selection model (Heckman, 1979) for the supply and demand sides of both the inter-firm and intra-firm trade with EUAs, we find that firm-level factors such as size, profitability, and ownership structure play a significant role, particularly in the firms' decision whether to participate in the permit trade. However, market specific factors such as the firm's initial EUA allocation and its relative compliance position are also very significant. The amount decision for the selected samples is mostly dominated by market-specific factors.

When comparing results for the inter-firm trade with those concerning the intra-firm trade, we find that firm-specific factors play a larger role in the intra-firm trade. Our results suggest that the flexible mechanisms of the EU ETS afford firms sufficient leeway to exhibit behavior similar to the patterns revealed by the existing literature on firm-level determinants of the trade in goods. However, the requirement to remain in compliance with EU ETS regulations leads to a strong influence of market-specific determinants, particularly in the amount decision. Thus, the from the emitting firms' perspective the EU ETS remains a hybrid market.

Chapter 3

Stationarity Changes in Long-Run Fossil Resource Prices: Evidence from Persistence Break Testing

3.1 Introduction

The long-run behavior of non-renewable resource prices has long been a topic of considerable interest; both in the theoretical and in the applied literature (cf. Krautkraemer, 1998, for a literature review). One key property of each price series is its persistence. A series may exhibit persistence of the same type over the entire sample period, e.g. (trend) stationarity, or it may experience a change in persistence, from stationarity to non-stationarity or vice versa. Understanding the character of resource price paths with respect to persistence as well as determining whether a series has experienced changes in persistence is relevant, both from an analytical and a policy perspective.

Determining the persistence properties of a resource price series is one approach to testing the validity of theoretical approaches to modeling resource markets. As Aherns and Sharma (1997) note, (trend) stationarity indicates that resource markets may be mostly driven by market fundamentals (Hotelling, 1931), whereas non-stationarity is consistent with the view that exogenous shocks may dominate (Slade, 1988). Evaluating whether a time series is piecewise stationary may allow us to distinguish periods during which market fundamentals dominated from those in which exogenous shocks may have played a more prominent role.

Furthermore, knowing whether a change in persistence has occurred in energy resource prices will be beneficial for the purposes of inference and forecasting. As Lee et al. (2006) point out a variable's persistence characteristics determine the admissibility of certain estimation frameworks. This consideration extends to changes in persistence as well. When estimating a relationship using a price series that exhibits a break in persistence at some point of its evolution, one may need to consider the pre and post break periods separately. Also, correctly handling the persistence properties of price series can substantially improve the performance of forecasting, as shown by Berck and Roberts (1996) and Lee at al. (2006).

We are particularly interested in analyzing the long-run persistence properties of primary energy commodity prices since bituminous coal, crude oil and natural gas may be considered partial substitutes in electricity generation. Thus, understanding whether the persistence properties of all three fuel prices are similar may shed some light on the degree of their connectedness, i.e. whether these three commodity markets could react differently to shocks caused by the implementation of certain direct or indirect policy options.

There is a substantial empirical literature devoted to the analysis of the persistence properties of resource price time paths. Implicitly assuming trend stationarity, Slade (1982) analyzes the evolution of a number of resource prices and concludes that prices follow a U-shaped time path. Pindyck (1999) analyzes the price paths of bituminous coal, crude oil and natural gas, respectively, and finds a quadratic trend in the data, which is unstable over time. Slade (1988) finds empirical support for prices being non-stationary and concludes that uncertainty appears to be a strong determinant of price formation, as opposed to Hotelling (1931) type deterministic models. Berck and Roberts (1996) also find that resource prices are non-stationary. Ahrens and Sharma (1997) conclude that the evidence is more mixed after analyzing the long-term development of eleven non-renewable resource prices, finding non-stationarity for five price series and trend stationarity for six. Their analysis is partly based on Perron (1989), allowing for a single exogenous structural break per series in 1929, 1939 and 1945, respectively. Using the same data and applying the unit root test by Lee and Strazicich (2003), which allows for up to two endogenously determined structural breaks, Lee et al. (2006) find overwhelming evidence against non-stationarity and in favor of trend stationarity. These studies have in common that they assume that each price series is stable with respect to persistence over its entire sample period.

However, recent developments in persistence testing theory allow us to test the null hypothesis of (trend) stationarity over the entire sample period against the alternative hypothesis that a change in persistence has occurred either from stationarity to non-stationarity or vice versa (Kim, 2000; Kim et al., 2002; Busetti and Taylor, 2004). In addition, the period in which the break has occurred can be estimated. Dvir and Rogoff (2010) apply this methodology to an analysis of long-term crude oil prices. They find that oil prices switch from non-stationarity to stationarity in 1877 and back to non-stationarity in 1973 without allowing for structural breaks. Moreover, we are not aware of a study in the field of resource economics applying the persistence break testing methodology while allowing for a structural break. However, as Perron (1989) shows and as Busetti and Taylor (2004) acknowledge in the context of persistence break testing, an unaccounted-for structural break of a significant magnitude typically biases unit root tests in favor of finding a unit root. In other words, a break in the deterministic trend causes the unit root test to erroneously conclude that a series contains a stochastic trend.

Our contribution to the literature is to allow for a structural break when testing for a break in persistence, thus aiming to disentangle the effect of a deterministic break from that of a stochastic break and adjusting for potential biases from disregarding a possible structural break. A range of potential structural break years is chosen from the existing literature (Perron, 1989; Ahrens and Sharma, 1997; Lee et al., 2006).

Using annual U.S. price data from the 19th century to the early 21st century we first analyze the three price series without allowing for a structural break. In this case we find that all three series exhibit changes from trend stationarity to non-stationarity. However, once we allow for structural breaks, our results diverge for the three series. We find that bituminous coal and natural gas prices are trend stationary throughout their sample periods. However, crude oil prices still exhibit a break from trend stationarity to non-stationarity, although the result is considerably weaker than in Dvir and Rogoff (2010). In our analysis, the persistence breaks for the case of crude oil are all estimated to have occurred during the 1970s, either during the first or the second oil price crisis, depending on the structural break year chosen. Overall, our results are fairly robust to the choice of the structural break period. Thus, we demonstrate that specifying a structural break at all appears to be more important than doing so at a specific point in time.

The remainder of this article is structured as follows: Section 3.2 provides a descriptive analysis of the data, while section 3.3 introduces the persistence break testing methodology. We present our results in Section 3.4 and discuss them in Section 3.5. The final section summarizes and concludes.

3.2 Data

Descriptive statistics on the three annual price series from the U.S. are presented in Table 3.1. While the coverage for bituminous coal and crude oil prices is comparable[1], the sample period of natural gas prices is considerably shorter. Furthermore, we notice that oil prices exhibit the greatest variation around their mean, natural gas prices being an intermediate case and coal prices being the most stable. We deflated all three price series using the U.S. CPI, as in Hamilton (2011).

Table 3.1: Real Oil, Coal and Natural Gas Prices: Descriptive Statistics

Variable	Obs.	From	To	Mean	SD	Min	Max
Real bituminous coal price per ton	140	1870	2009	5.76	2.10	3.40	11.60
Real crude oil price per barrel	128	1882	2009	25.73	18.35	9.15	96.91
Real natural gas price per barrel	88	1922	2009	12.75	11.04	3.19	47.57

Sources: Bituminous coal prices are from Manthy (1978) and from the U.S. Energy Information Administration (EIA), crude oil prices from BP, and natural gas prices from the EIA.
Note: All prices are annual and were deflated using the U.S. CPI index with the basis year 2009.

The evolution of the three prices series over time is depicted in Figure 3.1. The coal price series remained stable until after World War I and did not stray far

[1] Oil prices are available from 1861. However, in our analysis we use oil price data starting in 1882, as prior to this the oil market was in its infancy and thus in considerable turmoil (Dvir and Rogoff, 2010; Yergin, 1991).

from that level over the following half-century. However, two deviations are notable in the period from the early 1920s until the late 1960s. First, there was a sharp although relatively short-lived spike after World War I. Second, there was a more gradual increase starting in the mid-1930s, reaching a peak in 1948, and from there gradually decreasing again, until by the early 1960s it returned to the level of the late 1930s. A great increase in real terms followed, before the price gradually settled down toward the end of the 20th century, until rising again during the past decade.

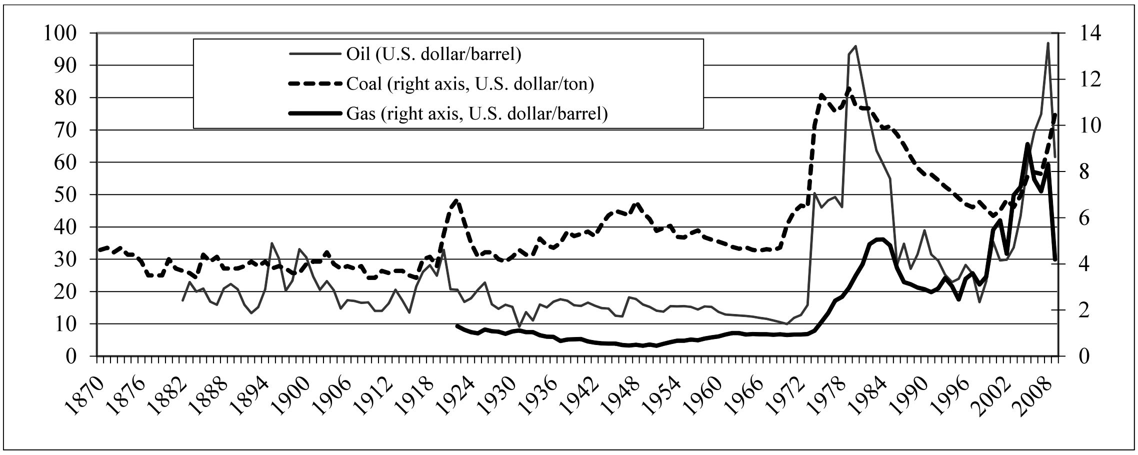

Figure 3.1: Evolution of Real Crude Oil, Bituminous Coal and Natural Gas Prices

The oil price is also relatively stable from the 1880s until the early 1970s, with peaks at the end of the 19th century, as well as during and after World War I. Strikingly, World War II only had a small impact on the oil price, most likely due to regulation by U.S. state regulatory bodies, mainly the Texas Railroad Commission (Hamilton, 2011) and price controls during World War II (Yergin, 1991). The oil price remained stable in real terms until the two oil crises in the 1970s, when it rose sharply. During the 1980s and 1990s it returned to a level slightly higher than before the crises. As in the case of the coal price, another significant price increase is observed during the past decade. Furthermore, the oil price is characterized by intermediate and low volatility from the late 19th century until the 1970s, respectively, and then by a marked increase in volatility since then (Dvir and Rogoff, 2010). Overall, the variation in oil prices is significantly greater than that of coal prices.

The natural gas price was stable from the 1920s until the early 1970s. After that it mainly followed the price of oil, although it exhibited smaller price swings. We observe similar increases in the natural gas price as in the case of oil both during the 1970s and in the first decade of the end of the 21st century. In terms of variation around its mean, the natural gas price is an intermediate case between the prices of oil and coal.

3.3 Methodology

We consider the Gaussian unobserved components model, as presented in Busetti and Taylor (2004):

$$y_t = d_t + \mu_t + \epsilon_t, \qquad t = 1, ..., T \tag{3.1}$$

$$\mu_t = \mu_{t-1} + I_{(t>\lfloor \tau T \rfloor)} \eta_t \tag{3.2}$$

where $\epsilon_t \sim N(0, \sigma^2)$ and $\eta_t \sim N(0, \sigma_\eta^2 \sigma^2)$ are mutually independent IID processes and $\tau \in]0, 1[$. $I_{(\cdot)}$ is an indicator function taking on the value of 1 for $t > \lfloor \tau T \rfloor$. Thus, starting at point $\lfloor \tau T \rfloor$, η_t from (3.2) affects (3.1). Suppose that the point $\lfloor \tau T \rfloor$ is known. Following Busetti and Taylor (2004) we set $d_t = d$ and the starting value $\mu_0 = 0$, without loss of generality.[2] Plugging in for μ_t in (3.1) yields

$$y_t = d + \epsilon_t \qquad \forall t \leq \lfloor \tau T \rfloor \tag{3.3}$$

We thus obtain a stationary process. We then substitute for μ_t:

$$\begin{aligned} \mu_t &= \mu_{t-1} + \eta_t \\ &= \mu_{t-2} + \eta_{t-1} + \eta_t \\ &\vdots \\ &= \sum_{i=1}^{t} \eta_i \end{aligned}$$

Using this result in (3.1) yields

$$y_t = d + \sum_{i=\lfloor \tau T \rfloor}^{t} \eta_i + \epsilon_t \qquad \forall t > \lfloor \tau T \rfloor \tag{3.4}$$

[2] In our actual analysis we allow for both an intercept and a trend.

This represents a non-stationary process if η_t has non-zero variance. In this manner the summation of a (trend) stationary process yields a non-stationary one (Cavaliere and Taylor, 2008). Therefore, in order to determine whether y_t is stationary throughout we must test whether the variance of the η_t process is different from zero, leading to the following null and alternative hypotheses (Busetti and Taylor, 2004):

$$\begin{aligned} H_0: &\quad \sigma_\eta^2 = 0 &\quad \forall t \\ H_1^a: &\quad \sigma_\eta^2 = 0 &\quad \text{for } t \leq \lfloor \tau T \rfloor \\ &\quad \sigma_\eta^2 > 0 &\quad \text{for } t > \lfloor \tau T \rfloor \end{aligned}$$

Thus, H_1^a posits that the series is $I(0)$ until $t = \lfloor \tau T \rfloor$ and $I(1)$ thereafter. We next consider an alternative case for μ_t, in contrast to the representation in (3.2)

$$\mu_t = \mu_{t-1} + I_{(t \leq \lfloor \tau T \rfloor)} \eta_t \tag{3.5}$$

Our null hypothesis remains the same, while the alternative hypothesis changes as follows:

$$\begin{aligned} H_1^b: &\quad \sigma_\eta^2 > 0 &\quad \text{for } t \leq \lfloor \tau T \rfloor \\ &\quad \sigma_\eta^2 = 0 &\quad \text{for } t > \lfloor \tau T \rfloor \end{aligned}$$

Thus, we are now testing the null hypothesis of constant stationarity against an alternative hypothesis of $I(1)$ behavior up until the break point and $I(0)$ behavior afterwards. Finally, we can also combine both approaches and test the null hypothesis of constant $I(0)$ behavior against an alternative hypothesis of a change in persistence in either direction, as follows:

$$\begin{aligned} H_1^c: &\quad \sigma_\eta^2 > 0 &\quad \text{for } t \leq \lfloor \tau T \rfloor \\ &\quad \sigma_\eta^2 = 0 &\quad \text{for } t > \lfloor \tau T \rfloor \\ OR & & \\ &\quad \sigma_\eta^2 = 0 &\quad \text{for } t \leq \lfloor \tau T \rfloor \end{aligned}$$

$$\sigma_\eta^2 > 0 \qquad \text{for } t > \lfloor \tau T \rfloor$$

In the following we lay out a procedure for testing H_0 against H_1^a, H_1^b and H_1^c, respectively. Kim (2000) develops a ratio-based statistic to test H_0 against H_1^a. We first define the following partial sum process S_t, as in Kim (2000) and Kim et al. (2002):

$$S_t = \sum_i^t \tilde{\epsilon}_i, \qquad t = 1, ..., T \tag{3.6}$$

where $\tilde{\epsilon_t}$, $t = 1, ..., T$ are ordinary least square (OLS) residuals from a regression of a time series on an intercept and a trend. Suppose that we wish to test whether a change in persistence has occurred at a specific point $t = \lfloor \tau T \rfloor$, $\tau \in]0,1[$.[3] We next consider the process before and after $\lfloor \tau T \rfloor$:

$$S_{0,t}(\tau_0) = \sum_{i=1}^{\lfloor \tau_0 T \rfloor} \widehat{\epsilon}_{0,\,i}, \qquad t = 1, ..., \lfloor \tau T \rfloor \tag{3.7}$$

$$S_{1,t}(\tau_0) = \sum_{i=\lfloor \tau_0 T \rfloor + 1}^{t} \widehat{\epsilon}_{1,\,i}, \qquad t = \lfloor \tau T \rfloor + 1, ..., T, \tag{3.8}$$

where $\widehat{\epsilon}_{0,\,t}$, $t = 1, ..., \lfloor \tau T \rfloor$ and $\widehat{\epsilon}_{1,\,t}$, $t = \lfloor \tau T \rfloor + 1, ..., T$ are OLS residuals from a regression of y_t on intercept and trend for the periods before and after the proposed break, respectively. We thus obtain the components necessary for computing the test statistic:

$$K(\tau) = \frac{[(1-\tau)T]^{-2} \sum_{i=\lfloor \tau_0 T \rfloor + 1}^{T} S_{1,\,i}(\tau)^2}{[\tau T]^{-2} \sum_{i=1}^{\lfloor \tau_0 T \rfloor} S_{0,\,i}(\tau)^2} \tag{3.9}$$

For large values of the test statistic we reject H_0 in favor of H_1^a.

Busetti and Taylor (2004) show that we can use the inverse of Kim's (2000) test statistic $K(\tau)^{-1}$ to test H_0 against H_1^b. Again, we reject H_0 for large values of $K(\tau)^{-1}$. Furthermore, Busetti and Taylor (2004) also show that we can test H_0

[3]For computational reasons τ is chosen such that $\tau \in [\tau_l, \tau_u]$ to obtain finite value test statistics (Kim, 2000), with the requirement that the interval be symmetric around τ to ensure consistency of the test statistic (Busetti and Taylor, 2004). We choose $\tau \in [0.1, 0.9]$.

against H_1^c by means of the following maximum statistic:

$$K(\tau)^{\max} = \max\left\{K(\tau), K(\tau)^{-1}\right\} \tag{3.10}$$

Once again, we reject H_0 in favor of H_1^c for large values of $K(\tau)^{\max}$.

It is not necessary to make any pre-judgement about a potential break point. Rather, we can apply three approaches to computing the test statistics for unknown break points, as suggested by Kim (2000):

$$\begin{aligned} MX(K(\cdot)) &= \max_{\tau \in T} K(\tau) &(3.11)\\ MS(K(\cdot)) &= \int_{\tau \in T} K(\tau)\mathrm{d}\tau &(3.12)\\ ME(K(\cdot)) &= \log\left\{\int_{\tau \in T} \exp\left(\frac{1}{2}K(\tau)\right)\mathrm{d}\tau\right\}, &(3.13)\end{aligned}$$

where $MX(K(\cdot))$ is the maximum over the sequence of statistics for all possible break points (Andrews, 1993), $MS(K(\cdot))$ the mean score statistic (Hansen, 1991) and $ME(K(\cdot))$ the mean-exponential statistic (Andrews and Ploberger, 1994).

Additionally, Kim's (2000) ratio statistic is robust to autocorrelation in the time series under consideration. In order to allow for non-stationarity volatility of a very general form, we employ a wild bootstrap procedure following Cavaliere and Taylor (2008), using 10,000 re-samplings.

In case we reject H_0, i.e. if we find evidence in favor of the series containing a break in persistence, we estimate the period in which the break occurs by determining τ^* in the following criterion, as suggested by Kim (2000):

$$\Lambda(\tau) = \frac{[(1-\tau)T]^{-2}\sum_{i=\tau T+1}^{T} \widehat{\epsilon}_{1,\,i}(\tau)^2}{[\tau T]^{-2}\sum_{i=1}^{\tau T} \widehat{\epsilon}_{0,\,i}(\tau)^2} \tag{3.14}$$

where τ^* is chosen such that $\tau^* = \underset{\tau \in [\tau_l, \tau_u]}{\arg\max}\ \Lambda(\tau)$.

Finally, as shown in Busetti and Taylor (2004) the presence of a structural break can seriously distort the test statistic. Perron (1989) and Lee and Strazicich (2003) also demonstrate the existence of this problem in the context of other unit root tests.

For this reason we also conduct versions of the test allowing for structural breaks in both level and trend to occur.[4] Since the persistence break literature has yet to develop a way of endogenously determining structural breaks while performing the persistence break test, we will treat structural breaks as exogenous and aim to disentangle the effects of structural breaks from those of persistence breaks in this manner. Thus, for the case of a structural break in both the constant and trend our regressor matrix becomes $x_{t\,break} = (1, t, w_t, w_t t)$, where

$$w_t = \begin{cases} 0 & \text{for} \quad t \leq \lfloor \delta T \rfloor \\ 1 & \text{for} \quad t > \lfloor \delta T \rfloor \end{cases} \tag{3.15}$$

and $\delta \in]0, 1[$.[5] We then perform the persistence break using test structural break points suggested by the existing literature (Perron, 1989; Ahrens and Sharma, 1997; Lee et al., 2006).

3.4 Results

For conciseness we only report the results based on $K(\tau)$ and $K(\tau)^{-1}$, since the $K(\tau)^{max}$ statistic unequivocally yields that $K(\tau)$ is always the larger of the two test statistics, for all three commodity price series and for all possible structural break points considered. Thus, our first general finding is that, if anything, all three price series change from $I(0)$ to $I(1)$.

We then first consider the results for bituminous coal prices (Table 3.2). Computing the test statistics without allowing for a structural break leads us to rejecting H_0 in favor of H_1^a, i.e. to finding that the coal price series has become non-stationary. The change in persistence is estimated to have occurred in 1964.[6] However, once we allow for an exogenous structural break in both level and trend our conclusion about the stationarity properties of bituminous coal prices changes. Allowing for

[4] Based on our descriptive analysis of the three commodity price series we hypothesize that at most one structural break has occurred during the sample period for each series.

[5] We have also performed calculations allowing for breaks in trend and constant in different periods. These are available upon request.

[6] We only estimate a persistence break date if at least two versions of the $K(\tau)$ statistic are significant.

a break in 1945 (Ahrens and Sharma, 1997) the result in favor of H_1^a is already significantly weakened.[7] When considering structural breaks in 1902, 1915, 1972 and 1973, respectively (Perron, 1989; Lee et al., 2006), we can no longer reject the hypothesis of trend stationarity of coal prices throughout the sample period.[8]

Table 3.2: Testing for Change in Persistence of Bituminous Coal Prices

Structural Break Type and Year	**Mean Score Statistic**		**Mean-Exponential Statistic**		**Maximum Statistic**	
No Structural Break	MS	18.2224**	ME	42.1462***	MX	93.7435***
		(0.030)		(0.007)		(0.007)
	MS^R	0.8269	ME^R	2.14**	MX^R	12.3016**
		(0.172)		(0.026)		(0.020)
	Estimated change point $I(0)$ to (1)			1964		
Level and trend break in 1902	MS	43.5966*	ME	51.7712	MX	111.902
Lee et al. (2006)		(0.098)		(0.132)		(0.133)
	MS^R	0.2235	ME^R	0.1587	MX^R	2.936*
		(0.209)		(0.124)		(0.069)
Level and trend break in 1915	MS	49.9862	ME	50.9666	MX	109.8864
Lee et al. (2006)		(0.104)		(0.175)		(0.178)
	MS^R	0.1904	ME^R	0.1279	MX^R	2.5984*
		(0.225)		(0.140)		(0.059)
Level and trend break in 1945	MS	18.3296	ME	31.9403*	MX	73.1709*
Ahrens and Sharma (1997)		(0.101)		(0.062)		(0.061)
	MS^R	0.1795	ME^R	0.1081	MX^R	2.4281*
		(0.668)		(0.577)		(0.072)
	Estimated change point $I(0)$ to (1)			1965		
Level and trend break in 1972	MS	3.4708	ME	3.5868	MX	14.9986
Lee et al. (2006)		(0.378)		(0.341)		(0.301)
	MS^R	0.502	ME^R	0.2656	MX^R	1.3896
		(0.615)		(0.624)		(0.722)
Level and trend break in 1973	MS	3.5195	ME	3.6529	MX	15.1371
Perron (1989)		(0.319)		(0.341)		(0.314)
	MS^R	0.4814	ME^R	0.2533	MX^R	1.354
		(0.730)		(0.737)		(0.807)

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Bootstrap p-values are in parentheses. The bootstrap has been performed using 10,000 samplings.

Table 3.3 summarizes the results for crude oil prices. Again, when considering the persistence break test without allowing for a structural break we find strong evidence in favor of a switch from $I(0)$ to $I(1)$. The changepoint is estimated for 1973, as already shown by Dvir and Rogoff (2010). However, contrary to the results for coal prices, allowing for the structural break points identified by the existing literature no longer reverses this result unequivocally. In fact, for most of the suggested structural break points we still find evidence that the series has become non-stationary, although the result is significantly weaker than when ignoring a

[7] The results for the other cases that Ahrens and Sharma (1997) consider are similar and available upon request.

[8] For the structural breaks from Lee et al. (2006) we only consider the break periods based on their analysis using linear trends.

possible structural break. For all cases in which the persistence break test yields a significant result the change in persistence is estimated to have occurred during the 1970s, either around the time of the first or the second oil price shocks.

Table 3.3: Testing for Change in Persistence of Crude Oil Prices

Structural Break Type and Year	**Mean Score Statistic**		**Mean-Exponential Statistic**		**Maximum Statistic**	
No Structural Break	MS	39.3676***	ME	201.0695***	MX	411.447***
		(0.009)		(0.000)		(0.000)
	MS^R	0.9087*	ME^R	4.7968***	MX^R	18.6498***
		(0.053)		(0.006)		(0.006)
	Estimated change point $I(0)$ to (1)			1973		
Level and trend break in 1896	MS	65.0405***	ME	176.1284***	MX	361.5646***
Lee et al. (2006)		(0.007)		(0.007)		(0.007)
	MS^R	0.6898**	ME^R	2.6517***	MX^R	13.9871***
		(0.039)		(0.006)		(0.005)
	Estimated change point $I(0)$ to (1)			1972		
Level and trend break in 1945	MS	30.6408	ME	49.5806	MX	108.4637
Ahrens and Sharma (1997)		(0.188)		(0.179)		(0.177)
	MS^R	0.1745	ME^R	0.1342	MX^R	3.773**
		(0.404)		(0.209)		(0.015)
Level and trend break in 1971	MS	29.7929	ME	74.8542*	MX	159.0152*
Lee et al. (2006)		(0.123)		(0.100)		(0.100)
	MS^R	0.1132	ME^R	0.0593	MX^R	1.0073
		(0.813)		(0.807)		(0.512)
	Estimated change point $I(0)$ to (1)			1977		
Level and trend break in 1973	MS	31.8084	ME	80.6055*	MX	170.5188*
Perron (1989)		(0.108)		(0.096)		(0.095)
	MS^R	0.091	ME^R	0.0464	MX^R	0.4438
		(0.903)		(0.903)		(0.887)
	Estimated change point $I(0)$ to (1)			1978		

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Bootstrap p-values are in parentheses. The bootstrap has been performed using 10,000 samplings.

Table 3.4: Testing for Change in Persistence of Natural Gas Prices

Structural Break Type and Year	**Mean Score Statistic**		**Mean-Exponential Statistic**		**Maximum Statistic**	
No Structural Break	MS	19.2233**	ME	18.9935***	MX	43.8405***
		(0.018)		(0.008)		(0.008)
	MS^R	0.0585	ME^R	0.0293	MX^R	0.0741
		(0.987)		(0.987)		(0.997)
	Estimated change point $I(0)$ to (1)			1973		
Level and trend break in 1973	MS	17.8299	ME	17.338	MX	40.5187
Perron (1989), Lee et al. (2006)		(0.724)		(0.609)		(0.602)
	MS^R	0.0634	ME^R	0.0317	MX^R	0.0842
		(0.273)		(0.274)		(0.362)

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Bootstrap p-values are in parentheses. The bootstrap has been performed using 10,000 samplings.

Finally, the results for natural gas are presented in Table 3.4. Unfortunately, the small sample size does not allow us to perform a full analysis for this case.[9] However,

[9] We cannot compute the test statistics using the truncation limits applied to the cases of coal and oil prices. We are forced to truncate the gas price series more severely to $\tau_{gas} \in [0.4, 0.6]$ in order to obtain finite value test statistics, limiting our evaluation of the structural break points proposed by the existing literature. However, fortunately we are still able to evaluate the period of the early 1970s.

the results again clearly display a discrepancy between allowing for a structural break or not. When not allowing for a structural break we clearly reject trend-stationarity in favor of a change from I(0) to I(1). When allowing for a structural break to occur in 1973 (Perron, 1989; Lee et al., 2006) we again fail to reject trend-stationarity for the entire sample period.

3.5 Discussion

Our results clearly demonstrate the importance of allowing for a structural break when testing for a change in persistence, providing empirical support for results in the existing literature (Perron, 1989; Lee and Strazicich, 2003; Busetti and Taylor, 2004).

Concretely, we find that the behavior of coal prices differs from that of oil prices both in terms of finding a persistence break and in terms of the timing of the break when the null hypothesis of trend stationarity is rejected.[10] Once we allow for a structural break in the coal price series we mostly fail to reject the hypothesis of trend stationarity, confirming results from the existing literature (Ahrens and Sharma, 1997; Lee et al., 2006). For the cases in which we do find a persistence break it is estimated to occur in the middle of the 1960s, a period of consolidation in the U.S. coal industry (EIA, 1993). In contrast, for the oil price the evidence is in favor of a change from trend stationarity to non-stationarity, corroborating the finding by Dvir and Rogoff (2010), although this result is considerably weakened once we allow for a structural break. In all significant cases the break is found to occur during the 1970s, indicating that the coal and oil markets may have diverged with respect to persistence during that time. Our descriptive analysis has shown that the natural gas market appears to be similar to the oil market in terms of the direction of price movement, but closer to the coal market in terms of price variation. Thus, it is plausible that a break in the persistence of natural gas prices may have occurred during the 1970s as well. Our result on natural gas prices is consistent

[10] Since our analysis of natural gas prices is constrained by data limitations, in our further discussion we will mostly focus on the results for the other two fuels under consideration, bituminous coal and crude oil prices.

with this assertion when we ignore a possible structural break. However, as for coal prices, this result no longer holds once we account for a possible structural break, suggesting that the natural gas market may be an intermediate case between the coal and oil markets in terms of persistence.

Overall, our results are consistent with the view that the coal market may be predominantly determined by fundamentals, whereas the oil market appears to be more strongly affected by exogenous shocks, with the natural gas market again an intermediate case. Thus, when performing inference using the oil price and when forecasting it may be advantageous to consider the periods before and after the estimated persistence break points separately.

3.6 Summary and Conclusions

This chapter applies recent developments in persistence testing to the question of whether the long-run U.S. prices of the key non-renewable energy resources bituminous coal, crude oil and natural gas exhibit a change in stationarity. We test the hypothesis of trend stationarity over the entire sample period against an alternative of a change in persistence, from trend stationarity to non-stationarity and vice versa. We also estimate the persistence breakpoints. We advance the literature by allowing for a structural break when testing for a change in persistence, thus aiming to avoid a biased test statistic on account of ignoring a potential structural break. To our knowledge this is the first study in the field of resource economics attempting to disentangle a deterministic break from a stochastic break in a price series.

Our findings clearly show the importance of specifying a structural break when evaluating the persistence of a resource price series. When ignoring a structural break the prices of all three resources appear to switch from stationarity to non-stationarity. However, this result is reversed for the cases of bituminous coal and natural gas when allowing for a structural break. Furthermore, while for crude oil prices we still find that they have switched from trend stationarity to non-stationarity in the 1970s, the result is considerably weaker when compared to the case in which we ignore a possible structural break.

Our results indicate a divergence between the markets for crude oil and of those for bituminous coal and natural gas with respect to persistence, at least in a U.S. context, suggesting that oil market analysts may want to take the switch in stationarity into account when estimating relationships in this market and when forecasting oil prices. Our analysis also indicates that a policy intervention may be more promising in the coal market, since it exhibits greater price stability than the oil market, thus facilitating policy targeting.

A fruitful avenue for further research could be to consider whether an analysis of long-run international energy resource prices confirms our results for the U.S. case.

Chapter 4

The Globalization of Steam Coal Markets and the Role of Logistics: An Empirical Analysis

4.1 Introduction

The price formation for steam coal, the most important type of coal and its dynamics is often unclear even to many insiders, and widely unknown even to the specialized economics community. Although coal is one of the most important commodities traded internationally, the market remains largely non-transparent, and is far less sophisticated than the markets for oil and natural gas. The international markets have remained segmented for a long time, in particular between the Atlantic and Pacific basins, but also with respect to coal qualities, shipping vessel size, and sectoral demand.

To our knowledge there has been no systematic analysis of global coal price dynamics. Most of the common knowledge about how coal markets function appears to be based upon anecdotal evidence promulgated by market participants. Even the most "standardized" prices, such as the API-2 (CIF1[1] price received in the ARA-region Amsterdam-Rotterdam-Antwerp) and the API-4 (FOB South African coal

[1]CIF is the price including cost, insurance and freight; FOB is free on board, i.e. the price paid at the export location.

price out of Richards Bay), derive from individual statements by selected traders willing to reveal the prices of their latest deals. We note in passing that an environment in which information brokers pay for information is ripe for market manipulation. Also, a high market concentration on the supplier side (China, the US, South Africa, Indonesia and Australia together comprise 78% of world steam coal production) adds to the potential to drive prices away from competitive levels.[2]

This potential may have diminished due to increased competition around the turn of the century with the advent of new shipping sizes, fewer constraints on downloading and uploading port facilities, and the emergence of liquid "hubs" in several market segments, such as South Africa and Australia. Furthermore, the price spike during the recent "oil price crisis", where coal prices have peaked similarly drastically as oil prices, may have caused greater awareness by potential new market participants about the available rents in this business. Increasing price pressure on the major buyers of steam coal, i.e. electric utilities, is an additional factor driving towards price integration. The fact that even Australia has entered the Atlantic market is also considered as an indication that the globalization of coal markets has advanced.[3]

On the other hand, a closer look at the technical aspects of the markets and the anecdotal evidence about the lack of reliable marker prices for globally traded steam coal suggest a less sanguine interpretation of coal market activity. The use of steam coal in boilers for electricity generation critically hinges upon the tight specification of coal composition, e.g., heat value, ash, sulphur, moisture content, granularity, etc. Steam coal is not easily standardized, which greatly reduces the applicability of commodity price indices, such as the API-2 and the API-4. Today, there is no world-wide price index for this important commodity that is based on publicly quoted supply and demand. Even the most commercialized route, South Africa to ARA, has been unable to produce a market price that can serve as a basis

[2]Even though there are many smaller producers involved in steam coal mining and international trade, four large companies dominate the international market, i.e. export capacities: BHP Billiton, Rio Tinto, XStrata, and Anglo. The four were responsible for almost one-third of global steam coal export capacity in 2007 (Rademacher, 2008).

[3]"The inability of producers in the Atlantic to completely meet the coal trade demand in that region has allowed Australia to be the price setter in the Atlantic market as well" (EPRI, 2007, 1-6).

for liquid spot and forward trading.

Furthermore, an analysis of the international steam coal trade would be incomplete without taking into account that logistics are of paramount importance for the industry. International steam coal prices depend very strongly on logistics costs, such as railway or domestic shipping (inland), transhipment, sea transport (international trade) and transportation to the final customer (inland). In turn, logistics costs depend on both fuel oil prices and the availability of transport capacities, since steam coal competes for capacity with other dry bulk products, such as coking coal. Thus, a comprehensive market analysis must incorporate both extraction costs and the price and availability of the logistical services needed to bring steam coal to the end-users.

Specific segments of international coal markets have been analyzed in the academic literature, albeit with heterogeneous results. There is no clear consensus whether the "globalization" of steam coal trading has already occurred. Ellerman (1995) documents that the U.S. was the price setter in a unified world coal market from the 1970s until the 1990s. The two chapters by Ekawan and Duchêne (2006) and Ekawan et al. (2006) suggest that the international markets for steam coal were already integrated in the early 2000s[4]; however, the chapters do not provide econometric evidence to support this hypothesis. Warell's (2005) empirical work on quarterly import prices suggests regional markets but without a clear trend towards integration. In an extension, Warell (2006) argues that the integration of markets in Europe and Japan was interrupted during the 1990s. Li et al. (2010) show that monthly export prices from the main steam coal exporting regions are generally highly integrated, with the exception of Indonesia. EPRI's (2007) analysis also tends to indicate global price transmission via freight rates (and exchange rates), showing that "the role of Australian coal price is similarly important now to the Atlantic market" (EPRI, 2007, 1-8). It suggests that due to a change in relative prices the U.S. lost its position as a swing supplier in the Atlantic basin, and was replaced by Colombian (and Venezuelan) producers with lower delivery costs to the

[4] "With regard to regional markets, coal from any of the major exporters will find markets in either Europe or Asia, depending principally on freight costs" (Ekawan and Duchêne, 2006, 1487).

U.S. East Coast, and thus to Europe as well.

In this chapter we provide a comprehensive analysis of the global price dynamics of steam coal. We compile a richer dataset than was used in the literature so far in terms of scope and frequency, and conduct a comprehensive multivariate cointegration analysis of three major pieces of the value chain of steam coal, namely export, transport and import prices, both separately and jointly. We perform our analysis at the level of individual routes, at the regional (i.e. basin) level, and at the global (i.e. inter-basin) level. We propose that although the industry is gradually moving from a segmented, OTC-dominated activity to a higher degree of commoditization and international integration, a truly integrated single-world coal market has yet to be achieved.

Our data are sampled at weekly frequency, whereas existing literature on international coal market integration is based on monthly or even quarterly data. In addition to coal prices our dataset includes freight rates which have not previously been used in an analysis of coal market integration. We test whether the demand side of the steam coal market, proxied by the CIF price, and the supply side, i.e. export prices plus freight rates, are integrated among each other, and whether systems of demand and supply are integrated when exports, imports, and freight rates are combined for individual trading routes, across basins, and globally. We find evidence of significant yet incomplete integration. Using the weekly frequency of our data we also estimate short-term dynamics of individual markets. Furthermore, we examine whether logistics enter the steam coal market via the direct transmission of the oil price, the main driver of seaborne transport costs, in coal prices and freight rates. Finding that the oil price is not linked to export, import, or transport prices in any systematic way, we conclude that logistics enter the system of steam coal prices in a more complex manner.

The remainder of the chapter is structured as follows. In Section 2 we present a descriptive analysis from which we derive testable hypotheses. Section 3 introduces the main method of analysis, Johansen Cointegration methodology, and analyzes route-specific, intra-basin, and global steam coal market integration. Section 4 discusses the evidence on market integration. Section 5 summarizes the main findings, and suggests topics for further research.

4.2 Data and Hypotheses

4.2.1 A Brief Geography of International Steam Coal Markets

International seaborne coal trade developed rapidly in the 1970s and has increased manifold since. In 2009, a total of 1.882 million tonnes (mt) of steam, coking and hard coal were traded of which about 91% account for seaborne trade, i.e. international trade across the basins.

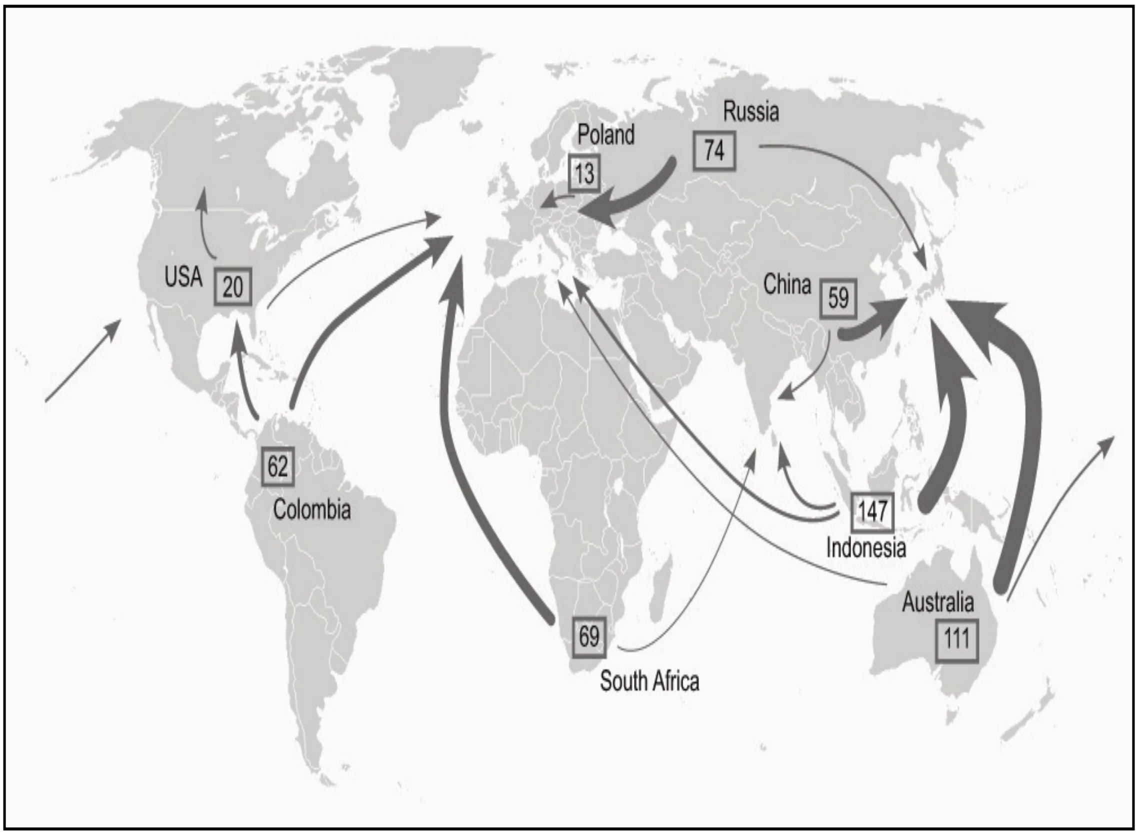

Figure 4.1: International Steam Coal Trade (in mt).
Source: Own illustration based on IEA, 2010 using http://www.indexmundi.com/map/creator/.

International steam coal trade amounted to 706 mt (that is 13.5% of total steam coal production) of which more than 90% was seaborne steam coal trade (IEA, 2010). Indonesia, Australia, Russia, Colombia and South Africa account for more than three quarters of all exports. Steam coal imports in the Asian-Pacific region in 2009 represent more than half of total steam coal trade. Another third of total world trade was received by the European market while the North and Latin American markets only imported 6% of total internationally traded volumes. The main international trade routes are Indonesia to Asia (210 mt), Australia to Asia (144 mt), China to Asia (20 mt), South Africa to Europe (38 mt), Colombia to Europe (30 mt), Colombia to North America (18 mt), and Indonesia to Europe (13 mt). Hence, the main trade is still taking place within the Atlantic and Pacific basins, respectively (Fig. 4.1).

4.2.2 Data

In this section we perform a descriptive analysis of steam coal prices, freight rates, and the prices of residual fuel oil. The results motivate the remainder of our analysis. We present descriptive statistics and a principal component analysis (PCA), from which we derive three main testable hypotheses. We use weekly time series data on CIF and FOB prices as well as on a number of freight rates between major export and import locations for steam coal provided by Platts.[5] For the longest available time series our data ranges from December 2001 until August 2009, about 400 observations per time series in some cases. However, given a number of changes in coverage during the sample period, the length of the individual series varies considerably. In order to investigate the role of logistics of international seaborne steam coal trade we use the corresponding price for residual fuel oil (used to fuel ships) for each region. Given the loose integration of the domestic U.S. market we do not consider U.S. coal prices (Bachmeier and Griffin, 2006). In addition, including several available local U.S. prices would introduce a large amount of heterogeneity.

Tables 4.1 and 4.2 provide an overview of our dataset. Table 4.1 reveals substantial heterogeneity in the characteristics of coal prices, in particular FOB prices, and also shows uneven coverage for the various price variables.

[5]The price data are collected by interviewing "trusted" traders, so that transparency on price formation is far from complete.

Table 4.1: Weekly Import and Export Prices in US Dollars, by Region.

Variable	Energy value (kcal/kg)	Basis	Quality Sulf. % (max)	Quality Ash % (max)	From	To	Obs.	Mean	SD	Min	Max
Atlantic											
CIF ARA	6000	NAR	1	16	01-12-03	09-08-17	393	72.11	37.73	25.90	218.00
FOB Bolivar	6300	GAR	0.8	9	01-12-03	09-08-17	393	58.11	30.47	22.50	179.00
FOB Bolivar	6450	GAR	0.8	9	05-08-29	09-08-17	204	73.74	33.40	39.25	179.75
FOB Maracaibo	7000	GAR	0.8	7	05-08-29	07-04-02	82	60.05	4.26	50.40	65.40
FOB Richards Bay	6000	NAR	1	16	01-12-03	09-08-17	393	56.43	30.66	20.50	177.00
Poland Baltic	6300	GAR	0.8	15	05-08-29	09-08-17	204	81.08	36.88	44.00	192.00
Russian Baltic	6400	GAR	1	16	05-08-29	09-08-17	204	79.93	36.89	40.00	190.00
Pacific											
CIF Japan	6080	NAR			03-01-06	09-08-17	339	79.42	41.42	30.75	230.00
CIF Korea	6080	NAR	1	17	03-07-07	09-08-17	313	77.90	38.11	31.05	210.00
Russian Pacific	6300	GAR	0.4	15	05-08-29	09-08-17	204	82.24	39.88	42.50	195.00
FOB Qinhuangdao	6200	GAR	0.8	10	03-02-03	09-08-17	335	69.42	39.33	25.70	207.00
FOB Kalimantan	5900	GAR	1	15	01-01-07	09-08-17	389	51.54	26.73	21.00	165.00
FOB Kalimantan	5000	GAR	0.8	8	07-01-01	09-08-17	136	56.23	17.57	32.75	100.00
FOB Gladstone	6500	GAR	0.6	12	05-08-29	09-08-17	204	78.69	38.54	38.00	195.00
FOB Newcastle	6300	GAR	0.8	13	01-12-03	09-08-17	393	57.57	33.45	22.10	185.00

Note: GAR means gross as received, NAR means net as received. The FOB Kalimantan 5900 series was extended backwards using the FOB Kalimantan 6300 series, whereas the CIF Japan Basket series was extended backwards using the CIF Japan 6300 series.
Source: Platts.

Table 4.2: Weekly Freight Rates in US Dollars, for Capesize and Panamax Vessels.

Variable	Series begins	Series ends	Obs.	Mean	SD	Min	Max
Capesize vessels							
Colombia/Puerto Bolivar–Rotterdam	01-12-03	09-08-17	390	18.35	11.89	3.85	62.50
South Africa/Richards Bay–Rotterdam	01-12-03	09-08-17	390	18.75	11.29	4.65	61.00
Australia/Queensland–Rotterdam	01-12-03	09-08-17	389	25.19	14.51	6.30	75.25
Australia/Queensland–Japan	01-12-03	09-08-17	389	15.69	10.25	3.60	56.90
Australia/New South Wales–Rotterdam	01-12-03	09-08-17	389	27.60	15.59	7.50	82.10
Australia/New South Wales–Korea	01-12-03	09-08-17	389	20.02	13.32	4.10	73.35
Panamax vessels							
US/Mobile–Rotterdam	01-12-03	09-08-17	390	21.71	13.33	5.70	67.50
Colombia/Puerto Bolivar–Rotterdam	04-10-04	09-08-17	250	24.23	12.21	7.40	61.50
South Africa/Richards Bay–Rotterdam	01-12-03	09-08-17	390	21.25	12.01	6.35	63.00
China–Rotterdam	01-12-03	04-09-27	140	17.82	8.73	8.25	38.95
China–Rotterdam (adjusted)	01-12-03	09-08-17	388	28.38	18.98	4.29	99.36
Australia/Queensland–Rotterdam	01-12-03	09-08-17	389	31.37	17.38	9.75	92.50
Australia/New South Wales–Rotterdam	01-12-03	09-08-17	390	31.66	17.50	10.00	93.50

Note: China–Rotterdam (adjusted) is a counterfactual continuation of the China–Rotterdam series using the Baltic Exchange Dry Index.
Source: Platts.

Fig. 4.2, Panel A shows the evolution of representative steam coal import and export prices over the sample period. Coal prices move within a fairly narrow band from the beginning of the sample until spring 2007. Since then for roughly a year prices almost quadruple before decreasing precipitously. By the end of 2008 they revert to the levels seen before 2007. This mirrors the increase and subsequent fall

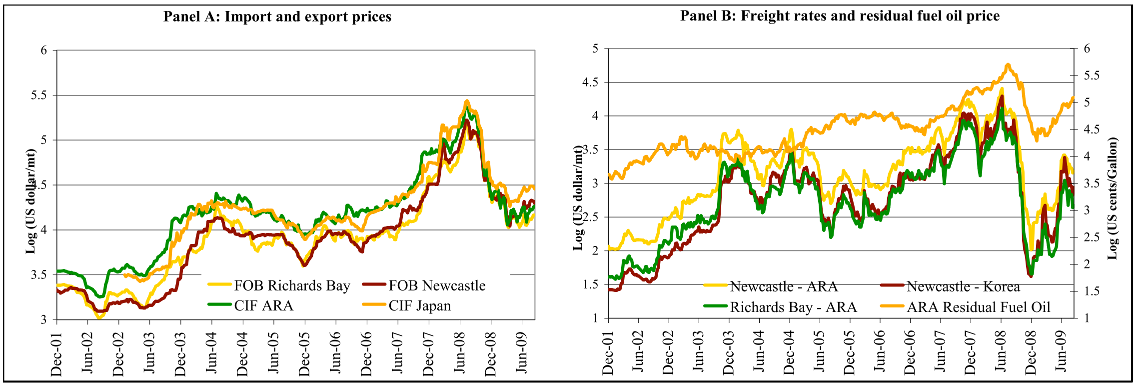

Figure 4.2: Evolution of Import and Export Prices, Freight Rates and Residual Fuel Oil Prices.

Note: All computations are based on weekly data with all variables in natural logarithms. All freight rates are for capesize vessels, except for the rate from China to Rotterdam, which is for panamax vessels. The price data for oil is from the US Energy Information Administration. Prices for steam coal and freight rates are in natural logarithms of US dollars per metric ton and for residual fuel oil in natural logarithms of US cents per gallon. ARA residual fuel oil is plotted on the right axis.

seen in a number of commodity prices, including oil. Fig. 4.2, Panel B depicts several freight rates, in addition to the ARA residual fuel oil price, which was obtained from the Energy Information Administration (EIA) together with other benchmark fuel oil rates, such as the Singapore and New York fuel oil prices. We see that while the freight rate and fuel oil series share certain similarities, they also exhibit marked differences. During several periods oil prices and freight rates move in opposite directions, e.g., between early 2005 and early 2007. Movements in freight rates are stronger, with greater changes over short periods of time than for the fuel oil price.

Whereas data on freight rates cover imports to Europe quite comprehensively, trading routes to Japan and Korea are less covered (Table 4.2). Also, freight rates from China to Rotterdam are not available for the whole sample period. Therefore, we compute a counterfactual continuation of the series using the Baltic Exchange Dry Index (BDI)[6] for capesize vessels. Although freight rates are available for both capesize and panamax vessels[7] for a number of trading routes, we focus on capesize vessels, since the majority of international steam coal shipping uses them (Ritschel and Schiffer, 2007).

Results of testing all variables in natural logarithms for stationarity using the augmented Dickey-Fuller test are presented in Table 4.3.

[6]The BDI is obtained from Thomson Datastream.

[7]Capesize vessels have a capacity of around 150,000 metric tons (mt) of coal, while panamax vessels can transport up to around 70,000 mt. Panamax vessels are constructed to just fit the Panama Canal, while capesize vessels must travel the longer routes around the Cape.

We find that all FOB and CIF coal prices are clearly integrated of order one, I(1), as are the residual fuel oil prices. However, while we find that the freight rates are also I(1), in some cases they appear to be fairly close to stationarity. This observation contradicts the assertion that freight rates are purely driven by oil prices. Instead it appears that other considerations, such as capacity constraints due to competition for shipping capacity from other dry bulk commodities also play an important role.

Table 4.3: Unit Root Tests: Augmented Dickey-Fuller Tests.

Variable	Logs of variables			First Differences of Logs		
	Lags	Test statistic	p-value	Lags	Test statistic	p-value
CIF ARA	2	-1.524	0.522	1	-11.726	0.000
CIF Japan	2	-1.739	0.411	4	-6.271	0.000
CIF Korea	4	-2.074	0.255	3	-6.824	0.000
FOB Bolivar	6	-1.731	0.415	1	-11.899	0.000
FOB Richards Bay	2	-1.308	0.626	1	-11.880	0.000
FOB Qinhuangdao	2	-1.657	0.454	1	-9.889	0.000
FOB Kalimantan	7	-1.430	0.568	6	-6.048	0.000
FOB Gladstone	2	-1.305	0.627	1	-8.198	0.000
FOB Newcastle	2	-1.259	0.648	1	-10.763	0.000
Colombia/Puerto Bolivar–Rotterdam	4	-2.796	0.059	3	-7.568	0.000
South Africa/Richards Bay–Rotterdam	4	-2.811	0.057	3	-7.711	0.000
China–Rotterdam (Adjusted)	4	-2.846	0.052	3	-7.415	0.000
Australia/Queensland–Rotterdam	4	-2.757	0.065	3	-7.647	0.000
Australia/Queensland–Japan	4	-2.666	0.080	3	-7.956	0.000
Australia/New South Wales–Rotterdam	4	-2.670	0.079	3	-7.742	0.000
Australia/New South Wales–Korea	4	-2.667	0.080	3	-8.003	0.000
New York Residual Fuel Oil	4	-1.984	0.293	3	-8.690	0.000
ARA Residual Fuel Oil	4	-1.565	0.501	3	-8.585	0.000
Singapore Residual Fuel Oil	4	-1.959	0.305	3	-7.351	0.000

4.2.3 Principal Components Analysis (PCA) and Hypotheses

In a first step of detecting relations within international steam coal markets we conduct principal component analyses (PCA) for import prices, export prices, and freight rates to detect market integration. If prices at each step of the value chain (i.e. export, transport, and import) move proportionally over time their corresponding correlation structure would be best described by only one common factor. If prices are not fully integrated more than one common factor is needed. Hence, the objective of the PCA is to determine the smallest number of common factors that best account for correlation among the time series (Siliverstovs et al., 2005). In the case that more than one common factor is needed, the PCA allows to group variables with similar dynamics. For each case we first consider coal prices and freight rates separately, before including the benchmark residual fuel oil prices. We use Jolliffe's criterion, according to which components with an eigenvalue below 0.7 should be discarded from further analysis (Dunteman, 1989). Further, we conduct the PCA for natural logs of all variables involved.

The PCA of export prices shows that one component explains around 98% of the variance in the data.[8] While all FOB prices have very similar coefficients in the first eigenvector, the second component reveals a significant difference. Although the second component only explains a small proportion of the common variance, it reveals a regional divide (Fig. 4.3, Panel A).

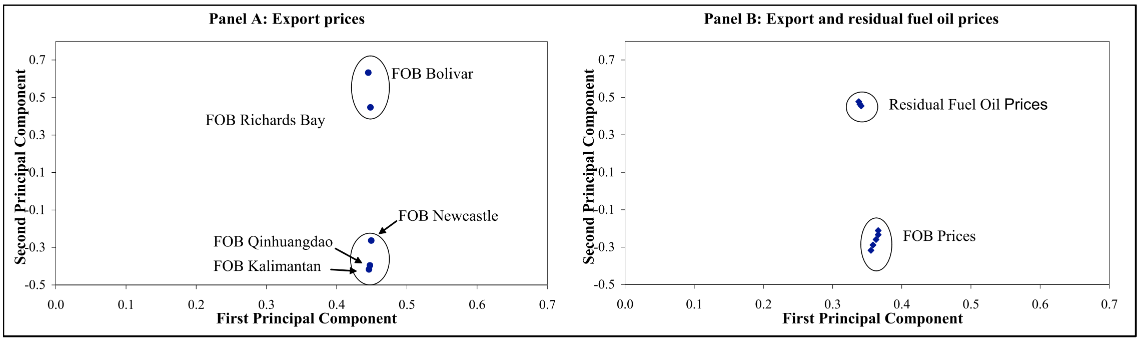

Figure 4.3: First Two Principal Components of Export Prices, Excluding and Including Residual Fuel Oil Prices.

Note: All computations are based on weekly data with all variables in natural logarithms. The price data for oil is from the US Energy Information Administration.

Including residual fuel prices for the Atlantic and Pacific basins makes the second component significant and now explains 10% of the variance, while the first component explains 88%. Furthermore, while great similarity in the coefficients of the first component across fuels remains, there are now two distinct groups in the second component. Panel B in Fig. 4.3 illustrates that the group of coal export prices and fuel prices is located similarly in one dimension, while showing distinct separation according to the second dimension. Based on this evidence we find that coal and residual fuel oil appear to share common aspects in their price formation, although a substantial gap remains which appears to be related to causes other than

[8]Due to space limitations we illustrate our results from the PCA using graphs. Tables with the numerical results are available upon request.

fuel prices. The results for import and export prices are similar.[9]

The PCA of freight rates shows that the first component explains about 78% of the variance, while the second explains about 9%. All freight rates appear to be fairly closely related, with differences in the second component for the freight rates Colombia to ARA and China to ARA (Fig. 4.4, Panel A), suggesting that freight rates, independent from location, may essentially be formed according to the same criteria.

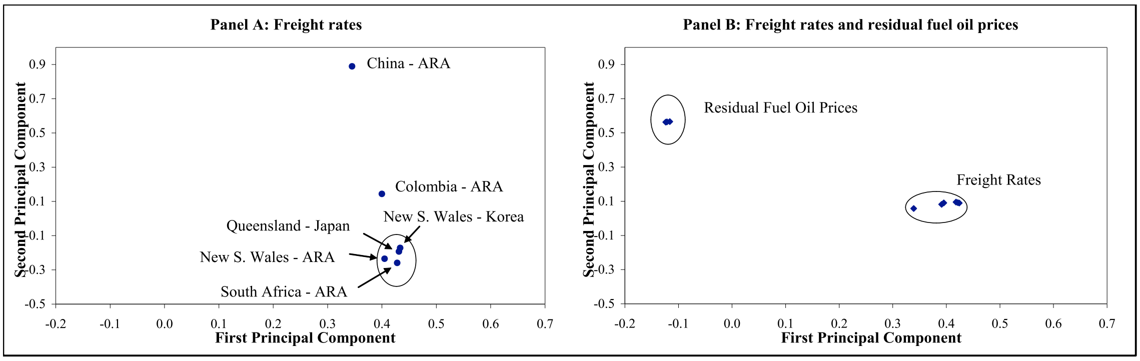

Figure 4.4: First Two Principal Components of Freight Rates, Excluding and Including Residual Fuel Oil Prices.

Note: All computations are based on weekly data with all variables in natural logarithms. All freight rates are for capesize vessels, except for the rate from China to Rotterdam, which is for panamax vessels. The price data for oil is from the US Energy Information Administration.

Again, including residual fuel oil prices leads to a significant second component explaining about 32% of the variance, while the first component explains 53%. Freight rates form a distinctly separate group from the group of fuel prices (Fig. 4.4, Panel B). However, in contrast to our results for import and export prices we find that freight rates and fuel prices differ in both “significant” eigenvectors.

Thus, from our descriptive analysis we derive three testable hypotheses: As nearly the whole variability of different prices along the value added chain is accounted for by one common component, meaning that the variables are similar in their characteristics and trends, we derive our first hypothesis:

Hypothesis 1. Prices for steam coal exports, transport and imports, respectively, are integrated to a significant degree.

Including residual fuel oil prices in the analysis increases the explained variability

[9]Graphs with CIF prices are available upon request.

of the second component, suggesting differences in the characteristics and trends of the variables. From this we draw Hypothesis 2:

Hypothesis 2. Coal prices and freight rates are not directly related to oil prices.

Taking together all parts of the value chain (export, freight, and import) results in a second component explaining some of the variance in the data. From this we obtain Hypothesis 3:

Hypothesis 3. International steam coal market integration is not (yet) complete.

4.3 Methodology and Empirical Evidence

4.3.1 Cointegration Analysis

To test these hypotheses we use cointegration analysis of prices and freight rates applying Johansen's approach based on maximum likelihood estimation which allows us to test for multiple cointegration relationships (Johansen, 1988). This enables us to draw conclusions about market integration, i.e. to evaluate both hypotheses.

We consider the vector error correction (VEC) representation of a vector process X_t:

$$\Delta X_t = \alpha\gamma + \Pi X_{t-i} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + \epsilon_t \tag{4.1}$$

where X_t stands for the data matrix in period t, Π denotes the long-run impact matrix, Γ_i the short-run impact matrices for lag i, μ a vector of intercept terms, $\alpha\gamma$ is the constant term in the cointegration relationship, and ϵ_t a vector of error terms.

We are primarily interested in the long-run impact matrix Π. The rank of Π determines whether the variables in X_t are cointegrated. For I(1) variables a zero rank of Π implies no cointegration relationship between variables in X_t. If Π has rank $r < k$, where k denotes the number of variables in X_t we conclude that the system is cointegrated (Hendry and Juselius, 2000; Johansen, 1988). If Π has rank $r = k$, i.e. is of full rank, the vector process X_t is stationary.

Furthermore, Π can be decomposed as follows:

$$\Pi = \alpha\beta' \tag{4.2}$$

where β is the matrix of cointegrating vectors describing the long-run equilibrium of the system, and α is the corresponding matrix of adjustment parameters describing the short-run responses of each variable to deviations from equilibrium. In our analysis we determine the rank of Π by means of the trace test, and estimate β and α.

Recall that the trace statistic is computed as follows:

$$\lambda_{trace} = -T \sum_{i=r+1}^{k} \ln(1 - \lambda_i) \tag{4.3}$$

where λ_i are the estimated eigenvalues of Π and T is the number of observations. Given that T is relatively large in our case we need to keep in mind the case described in Hendry and Juselius (2000): Even with a small λ_i, indicating the presence of a unit root or near-unit root, the large number of observations could cause us to reject the hypothesis that λ_i is zero for $i = k$. Thus, the trace test might conclude that Π has full rank and therefore the process X_t is stationary (Hendry and Juselius, 2000). For this reason Hendry and Juselius (2000, p. 24) suggest that "it is often good to approximate a near-unit root by a unit root even when it is found to be statistically different from one".

Moreover, correct specification of the VEC system in terms of constants and trends is important Johansen (1994). We find that the mean of the differenced data is greater than zero, which is consistent with $E[\Delta X_t] \neq 0$, implying a linear trend in the undifferenced data. Therefore, we allow for a linear trend in the data and a constant in the cointegration relationships (Hendry and Juselius, 2000).

To test Hypothesis 1 we conduct the cointegration analysis in several stages. We start with a simple X_t matrix consisting of only two variables, and progressively add other variables to it. First we concentrate on pairwise comparisons of components of the supply and demand sides by considering export and import prices and freight rates separately, testing whether in each case Π is of rank $0 < r < k$, i.e. whether they are cointegrated. Such pairwise analysis allows us to compare results with the existing literature (Li et al., 2010; Warell, 2006), although for a different sample period and a different sampling frequency. To test Hypothesis 2 we also include the relevant oil price, i.e. the price of residual fuel oil, which is used for powering vessels between export and import locations. This allows us to determine whether they belong to the same system.[10] For integrated fuel oil prices and components of the steam coal value chain, this implies a significant impact of logistics working through the price of fuel oil, the main driver of transport costs of the international steam coal trade.

We then go beyond the existing literature by testing Hypothesis 3 and analyzing coal market integration in a comprehensive framework of supply and demand. We conduct a cointegration analysis of the demand and supply system, based on the premise that FOB prices together with the appropriate freight rates should be related to CIF prices in the long term. We consider systems of CIF and FOB prices and the freight rate for specific trading routes. Based on these findings we repeat the cointegration analysis using aggregated FOB prices and freight rates to facilitate a clearer interpretation of the results regarding market integration. Then we expand the analysis to the regional, i.e. intra-basin level and also test for global market integration. Finally, we estimate cointegration vectors and adjustment coefficients for the available routes to analyze both the nature of long-run relationships and short-run dynamic adjustments for each route.

4.3.2 Results on Hypothesis 1 (Steam Coal Price Integration)

In the first part of our analysis we test Hypothesis 1 by determining the rank of Π for pairs of FOB and CIF prices, as well as freight rates. This allows us to compare our results with the existing literature on steam coal market integration (Li et al., 2010; Warell, 2006). We then incorporate the price of residual fuel oil in our analysis to test Hypothesis 2.

[10] Given the large number of observations we consider the 5% significance level, except where specifically mentioned. Lag lengths are determined using Akaike's Information Criterion.

Table 4.4: Determination of Cointegration Rank – Pairwise Analysis, Including and Excluding Residual Fuel Oil Price.

			H_0: $r = 0$		$r \leq 1$		$r \leq 2$	
Variable	Obs.	Lags	λ_1	Trace statistic	λ_2	Trace statistic	λ_3	Trace statistic
Export prices								
FOB Bolivar 6300, FOB Richards Bay 6000	386	2	0.030	**13.418**	0.005	1.745	–	–
FOB Bolivar 6300, FOB Richards Bay 6000, ARA Residual Fuel	386	2	0.038	**23.654**	0.016	8.841	0.007	2.517
FOB Bolivar 6300, FOB Qinhuangdao 6200	332	2	0.024	**11.151**	0.009	3.153	–	–
FOB Bolivar 6300, FOB Qinhuangdao 6200, ARA Residual Fuel	332	2	0.047	**22.776**	0.018	6.821	0.003	0.847
FOB Bolivar 6300, FOB Kalimantan 5900	378	6	0.033	**14.872**	0.006	2.309	–	–
FOB Bolivar 6300, FOB Kalimantan 5900, ARA Residual Fuel	378	6	0.067	33.820	0.015	**7.804**	0.006	2.097
FOB Bolivar 6300, FOB Gladstone 6500	202	2	0.046	**11.332**	0.009	1.760	–	–
FOB Bolivar 6300, FOB Gladstone 6500, ARA Residual Fuel	201	3	0.088	31.674	0.052	**13.171**	0.012	2.405
FOB Bolivar 6300, FOB Newcastle 6300	386	2	0.027	**12.146**	0.004	1.686	–	–
FOB Bolivar 6300, FOB Newcastle 6300, ARA Residual Fuel	386	2	0.052	**28.028**	0.015	7.504	0.005	1.810
FOB Richards Bay 6000, FOB Qinhuangdao 6200	332	2	0.047	18.823	0.009	**2.976**	–	–
FOB Richards Bay 6000, FOB Qinhuangdao 6200, ARA Residual Fuel	332	2	0.066	30.599	0.021	**7.907**	0.003	0.977
FOB Richards Bay 6000, FOB Kalimantan 5900	378	6	0.041	18.092	0.006	**2.174**	–	–
FOB Richards Bay 6000, FOB Kalimantan 5900, ARA Residual Fuel	378	6	0.064	34.653	0.019	**9.656**	0.006	2.407
FOB Richards Bay 6000, FOB Gladstone 6500	202	2	0.082	19.115	0.009	**1.802**	–	–
FOB Richards Bay 6000, FOB Gladstone 6500, ARA Residual Fuel	200	4	0.099	35.426	0.058	**14.642**	0.013	2.608
FOB Richards Bay 6000, FOB Newcastle 6300	386	2	0.046	19.906	0.004	**1.599**	–	–
FOB Richards Bay 6000, FOB Newcastle 6300, ARA Residual Fuel	386	2	0.071	36.932	0.016	**8.318**	0.005	1.914
FOB Qinhuangdao 6200, FOB Kalimantan 5900	332	2	0.067	25.392	0.008	**2.514**	–	–
FOB Qinhuangdao 6200, FOB Kalimantan 5900, Singapore Residual Fuel	331	3	0.079	34.926	0.018	**7.729**	0.005	1.602
FOB Qinhuangdao 6200, FOB Gladstone 6500	202	2	0.044	**11.104**	0.010	2.108	–	–
FOB Qinhuangdao 6200, FOB Gladstone 6500, Singapore Residual Fuel	200	4	0.076	**29.525**	0.055	13.780	0.013	2.564
FOB Qinhuangdao 6200, FOB Newcastle 6300	332	2	0.046	19.237	0.010	**3.486**	–	–
FOB Qinhuangdao 6200, FOB Newcastle 6300, Singapore Residual Fuel	332	2	0.053	**25.097**	0.016	7.154	0.005	1.815
FOB Kalimantan 5900, FOB Gladstone 6500	202	2	0.086	19.774	0.008	**1.644**	–	–
FOB Kalimantan 5900, FOB Gladstone 6500, Singapore Residual Fuel	201	3	0.077	30.294	0.058	**14.121**	0.011	2.145
FOB Kalimantan 5900, FOB Newcastle 6300	381	3	0.060	25.363	0.004	**1.629**	–	–
FOB Kalimantan 5900, FOB Newcastle 6300, Singapore Residual Fuel	381	3	0.062	33.063	0.016	**8.489**	0.006	2.301
FOB Newcastle 6300, FOB Gladstone 6500	197	7	0.078	19.906	0.020	3.971	–	–
FOB Newcastle 6300, FOB Gladstone 6500, Singapore Residual Fuel	199	5	0.099	32.104	0.044	**11.417**	0.012	2.412
Import prices								
CIF ARA, CIF Japan	336	2	0.045	18.856	0.010	**3.418**	–	–

Continued on next page

Table 4.4: Determination of Cointegration Rank – Pairwise Analysis, Including and Excluding Residual Fuel Oil Price. – continued from previous page

Variable	Obs.	Lags	H_0: $r = 0$		$r \leq 1$		$r \leq 2$	
			λ_1	Trace statistic	λ_2	Trace statistic	λ_3	Trace statistic
CIF ARA, CIF Japan, ARA Residual Fuel	335	3	0.074	31.919	0.014	**6.214**	0.005	1.540
CIF ARA, CIF Korea	309	3	0.055	21.995	0.014	4.422	–	–
CIF ARA, CIF Korea, ARA Residual Fuel	310	2	0.075	30.959	0.019	**6.928**	0.004	1.118
CIF Japan, CIF Korea	310	2	0.101	37.053	0.013	4.036	–	–
CIF Japan, CIF Korea, Singapore Residual Fuel	309	3	0.084	34.215	0.016	**7.157**	0.007	2.098
Freight rates								
Colombia–Rotterdam, South Africa–Rotterdam	384	4	0.054	28.793	0.020	7.665	–	–
Colombia–Rotterdam, South Africa–Rotterdam, ARA Residual Fuel	385	3	0.091	49.049	0.020	**12.529**	0.013	4.847
Queensland–Rotterdam, New South Wales–Rotterdam	385	3	0.105	48.838	0.015	5.974	–	–
Queensland–Rotterdam, New South Wales–Rotterdam, Singapore Residual Fuel	385	3	0.111	56.160	0.018	**11.048**	0.011	4.098
Queensland–Japan, New South Wales–Korea	384	4	0.047	24.884	0.017	6.502	–	–
Queensland–Japan, New South Wales–Korea, Singapore Residual Fuel	385	3	0.056	35.025	0.020	**12.855**	0.013	4.883

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π. Results are robust to choosing either New York, ARA or Singapore residual fuel oil prices for systems of prices from different basins. All freight rates are for capesize vessels, except for China–Rotterdam, which is for panamax vessels.

In all cases we observe that the estimates of λ_i, i.e. the eigenvalues of Π, are fairly close to zero, particularly λ_i for $i > 1$. We find one cointegration relationship at the 5% level in almost all cases, with the exception of the FOB Bolivar price which is not cointegrated with any of the other FOB prices. This might be due to about half of Colombia's exports going to the U.S. There is also no evidence of a cointegration relationship between FOB Qinhuangdao and FOB Gladstone. This contradicts our finding that FOB Qinhuangdao and FOB Newcastle are cointegrated so that according to the trace test, one Australian export price appears to be cointegrated with FOB Qinhuangdao while the other does not. However, for FOB Gladstone the available sample period is much shorter (ranging from mid-2005 to mid-2009) than for other FOB prices considered in our analysis. Another factor is the Chinese government's significant restrictions on coal exports as a result of a security of supply policy (Minchener, 2007). Thus, the available sample for FOB Gladstone covers the period when the Chinese export price was no longer solely determined by international demand. Hence, a combination of data availability and policy intervention on exports potentially explains this result.

Finally, the results of the trace test suggest that FOB Gladstone and FOB Newcastle are both stationary, contradicting the findings from the ADF test. We observe that for this case $\lambda_2 = 0.02$, with the small size of λ_2 indicating the presence of either a near-unit root or a unit root in X_t (Hendry and Juselius, 2000). Comparing the results for the other export prices we observe that λ_2 is in line with the size of the corresponding eigenvalues for other price pairs, and the test statistic is just large enough for the trace test to reject the hypothesis of cointegration. Given the evidence from both the ADF test and the size of the eigenvalue, we conclude that the pair FOB Gladstone and FOB Newcastle are cointegrated of order one.

The analysis of cointegration ranks of pairs of import prices (Table 4.4) reveals a similar pattern. There is one cointegration relationship between CIF ARA and CIF Japan at the 5% level. For the pairs CIF ARA-CIF Korea and CIF Japan-CIF Korea Π has full rank at the 5% level in each case, again contradicting our finding of non-stationarity from the Dickey-Fuller tests. However, when inspecting λ_2 for each pair of import prices we observe that they are similar in all cases, so that again, in conjunction with evidence from ADF testing we conclude that all import prices appear to be cointegrated of order one.

Our results for freight rates are more ambiguous. We typically find that Π has full rank for the respective pairs of freight rates, although the estimated eigenvalues of Π are in line with those for coal prices.[11] However, ADF tests for freight rates indicate a certain proximity to stationarity, so that evidence from univariate unit root testing is not as strong as in the case of coal prices. Nevertheless, since we still find that the ADF shows non-stationarity and that eigenvalues are similar to those for coal prices, we conclude that the large number of available observations for all freight rates leads to the case described in Hendry and Juselius (2000), where the trace statistic reaches the size necessary for the conclusion of stationarity despite evidence for non-stationarity. Therefore, we again conclude that the pairs of freight rates are cointegrated of order one.

The findings on FOB prices partially confirm the result from Li et al. (2010),

[11] We do not include all possible pairs of freight rates for clarity of presentation. Results for the remaining pairs are comparable to those presented in Table 4.4.

who analyze integration of monthly FOB prices vis-à-vis the South African FOB price. The main differences are that we do not detect integration of South African and Colombian export prices, whereas we do find integration between the South African and Indonesian prices. Comparability of results is, however, restricted by frequency of the data used and the different sample periods covered. In addition, analysis by Li et al. (2010) is centered around the South African price. On the import side we confirm Warell's (2006) result of integration between European and Japanese CIF prices for the sample period starting in 2001.

4.3.3 Results on Hypothesis 2 (The Role of Oil Prices in Transport)

We next evaluate Hypothesis 2 following a similar approach suggested by Siliverstovs et al. (2005). We add the relevant fuel oil price to the pairs of FOB and CIF prices, as well as freight rates to test whether oil prices belong to the same price system as coal prices and freight rates.[12] If we find that the added fuel oil price does not add cointegration relationships, we conclude that the oil price does not belong to the same system. As shown in Table 4.4 we conclude that adding the fuel price does not increase the number of cointegration relationships in most cases. However, we do find that including the fuel price increases the cointegration rank for the pairs FOB Bolivar–FOB Kalimantan and FOB Bolivar–FOB Gladstone. This may indicate that pricing for FOB Bolivar, which we did not find to be integrated with other export prices, is more strongly tied to the price of oil. We conclude that the oil price may be related to the prices of coal and to freight rates to some extent, but is not part of the long-run equilibrium relationships formed by coal prices and freight rates in any consistent fashion.

Summarizing our findings for Hypothesis 2 we have sufficient evidence to accept

[12]We consider three relevant prices: New York, ARA, and Singapore residual fuel oil. We add the regionally relevant price to each collection of coal prices or freight rates, e.g., for the pair of FOB Qinhuangdao and FOB Kalimantan, both of which are Pacific basin prices, we add the Singapore residual fuel oil price. When it is unclear which fuel oil price may be the relevant one, i.e. when our coal prices are from different regions, we check our results for robustness by using all the other fuel oil prices. For the most part our results are robust to the inclusion of any of the three residual fuel oil prices. We also include the WTI crude oil price as a robustness check and confirm the results.

it as true, confirming the result by Bachmeier and Griffin (2006) on a more global level, who find no integration between coal and oil markets in the U.S. Thus, we omit oil prices from further analysis.

4.3.4 Results on Hypothesis 3 (Global Market Integration)

Having found that our results are largely in line with the existing literature on coal market integration when using a comparable approach (although for different sample periods and sampling frequency) we now extend our analysis beyond the existing literature by taking a systemic view of integration in the steam coal market. We thus now focus on analyzing the extent of market integration in depth. The remainder of our analysis is based on the notion that for each trading route CIF prices should directly relate to a combination of FOB prices and freight rates in the long term, with CIF prices representing the demand side of the market and the combined FOB prices and freight rates representing the supply side.

Table 4.5: Determination of Cointegration Rank – Joint Analysis.

				H_0: $r = 0$		$r \leq 1$		$r \leq 2$	
Number variables	Route	Obs.	Lags	λ_1	Trace statistic	λ_2	Trace statistic	λ_3	Trace statistic
Atlantic basin									
1	CIF ARA, FOB Bolivar 6300, Freight Rate (FR) Colombia–Rotterdam	382	6	0.086	54.560	0.036	20.213	0.016	6.218
2	CIF ARA, FOB Richards Bay 6000, FR South Africa–Rotterdam	384	4	0.093	51.936	0.027	**14.621**	0.011	4.132
3	CIF ARA, FOB Qinhuangdao 6200, FR China–Rotterdam	327	5	0.133	60.132	0.027	**13.290**	0.013	4.270
4	CIF ARA, FOB Gladstone 6500, FR Australia/Queensland–Rotterdam	200	4	0.113	34.914	0.035	**10.984**	0.019	3.760
5	CIF ARA, FOB Newcastle 6300, FR Australia/New South Wales–Rotterdam	386	2	0.067	48.178	0.036	21.215	0.018	6.873
Pacific basin									
6	CIF Japan, FOB Gladstone 6500, FR Queensland–Japan	200	4	0.137	46.828	0.061	17.373	0.023	4.720
7	CIF Korea, FOB Newcastle 6300, FR New South Wales–Korea	308	4	0.102	49.310	0.029	16.282	0.023	7.199

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π.

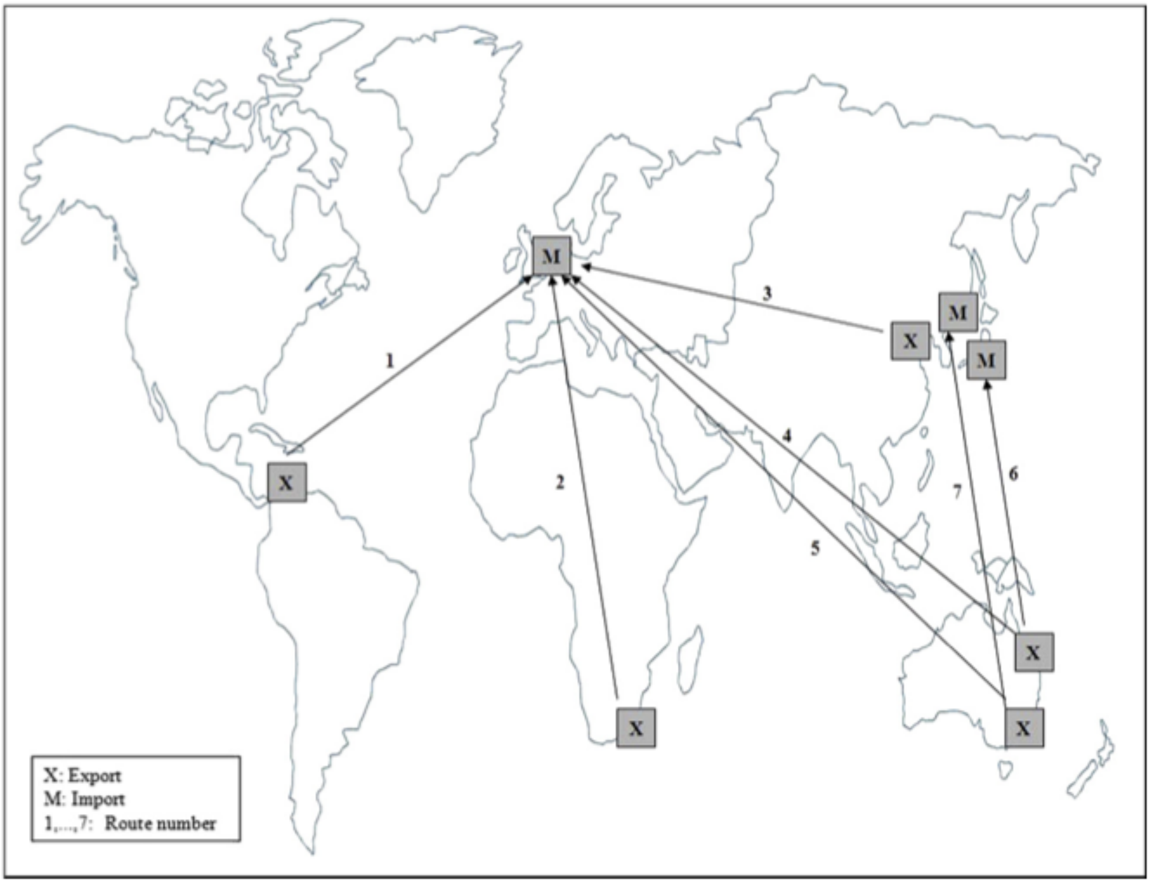

Figure 4.5: Regional Trading Routes.
Source: Own illustration using http://www.indexmundi.com/map/creator/.

This approach allows us to consider route-wise regional (as illustrated in Fig. 4.5) and global integration of steam coal markets, and is novel in the existing literature on coal market integration.

We apply Johansen's cointegration test to a different data matrix X_t in (4.1), which now consists of a CIF price, an FOB price, and a freight rate for each route. If routes are integrated a cointegration relationship between the three variables should exist. We expect individual routes to be cointegrated. Finding that multiple trading routes are cointegrated would add evidence that the global steam coal trade is taking place in an integrated marketplace. However, a caveat is that the limited availability of data on freight rates particularly constrains our analysis of price formation in the Pacific basin.

Our results support integration of a number of routes to ARA at the 5% level, although we find that vector processes X_t for the routes Colombia to ARA and Newcastle to ARA and both routes to Asia appear to be stationary (Table 4.5).

Again, we believe that our previous argument applies for the routes Colombia to ARA and Newcastle to ARA, as well as for the route Newcastle to Korea. λ_2 for Colombia to ARA and Newcastle to ARA is almost identical to λ_2 for the route Gladstone to ARA, which is found to be cointegrated. The only difference is that we have a larger number of observations for the routes Colombia to ARA and Newcastle to ARA, which raises the trace statistic beyond the 5% critical value. λ_2 for the route Newcastle to Korea is slightly larger than λ_2 for South Africa to ARA. Based on this comparison we conclude that the evidence points to integration of routes.

We next aggregate export prices and freight rates for each route and test for cointegration of the respective routes. All aggregated variables are non-stationary, and we are now testing pairwise relationships for each route. We thus have the CIF price representing the demand side of the market, while the combined FOB price and freight rate represent the supply side of the market for each route. The results are clearer than when separating the supply side into export prices and freight rates (Table 4.6).

Table 4.6: Determination of Cointegration Rank – Joint Analysis of Aggregated Routes.

Number variables	Route	Obs.	Lags	$H_0: r = 0$		$r \leq 1$	
				λ_1	Trace statistic	λ_2	Trace statistic
Atlantic basin							
1	CIF ARA, FOB Bolivar 6300 + FR Colombia–Rotterdam	381	7	0.058	26.393	0.009	**3.602**
2	CIF ARA, FOB Richards Bay 6000 + FR South Africa–Rotterdam	386	2	0.087	37.674	0.006	**2.446**
3	CIF ARA, FOB Qinhuangdao 6200 + FR China–Rotterdam	325	7	0.031	**13.829**	0.011	**3.722**
4	CIF ARA, FOB Gladstone 6500 + FR Australia/Queensland–Rotterdam	202	2	0.068	16.603	0.011	**2.280**
5	CIF ARA, FOB Newcastle 6300 + FR Australia/New South Wales–Rotterdam	386	2	0.058	25.737	0.007	**2.572**
Pacific basin							
6	CIF Japan, FOB Gladstone 6500+FR Australia/Queensland–Japan	200	4	0.077	18.984	0.014	**2.867**
7	CIF Korea, FOB Newcastle 6300+FR Australia/New South Wales–Korea	310	2	0.072	28.958	0.019	5.872

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π.

We find that all routes to Europe and Asia are cointegrated at the 5% level with the exception of the route China to ARA. This result is expected given the Chinese export restrictions discussed above, so that traders are constrained in using arbitrage to equilibrate prices (Minchener, 2007). Further, for the Newcastle to Korea route we still find the contradictory result of stationarity at the 5% level. When considering λ_2 for this route we observe that it is somewhat larger than λ_2 for the other routes, resulting in a larger value for the trace statistic which is clearly above the critical value. While we still tend to conclude that the route is cointegrated, we are slightly less confident about doing so in this particular case. However, we still estimate the VEC system based on a cointegration rank of one (Hendry and Juselius, 2000).

Having confirmed route-wise integration for most cases we test for regional and global integration of steam coal markets (Table 4.7).

Table 4.7: Determination of Cointegration Rank – Basin-Wise and Inter-Basin Analysis.

Variables	Number of variables in system	Obs.	Lags	$H_0: r \leq 2$		$r \leq 3$		$r \leq 4$		$r \leq 5$	
				λ_3	Trace statistic	λ_4	Trace statistic	λ_5	Trace statistic	λ_6	Trace statistic
Atlantic system	6	200	2	0.106	49.846	0.065	**27.339**	0.046	13.859	0.022	4.374
Pacific system	4	201	3	0.049	**15.384**	0.026	5.294	–	–	–	–
Global system	10	200	2	0.243	200.337	0.187	144.703	0.164	103.218	0.127	**67.304**

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π. The Atlantic system contains the variables CIF ARA, FOB Bolivar 6300 + FR Colombia–Rotterdam, FOB Richards Bay 6000+FR South Africa–Rotterdam, FOB Qinhuangdao 6200+FR China–Rotterdam, FOB Gladstone 6500+FR Australia/Queensland–Rotterdam, and FOB Newcastle 6300+FR Australia/New South Wales–Rotterdam. The Pacific system contains the variables CIF Japan, CIF Korea, FOB Gladstone 6500+FR Queensland–Japan, and FOB Gladstone 6500+FR Queensland–Japan. The Global System combines all variables from the Atlantic and Pacific systems.

We find that the routes within the Atlantic and the Pacific basins have multiple cointegration relationships. For the system of routes to the Atlantic basin we find three relationships, and for the Pacific basin we find two. From this we conclude that coal markets are integrated regionally. We then consider whether all available routes are cointegrated globally. When combining the variables from the two systems we find five cointegration relationships. From this we conclude that the international steam coal trade takes place in basin-wise and globally integrated markets. Although the exchange of coal between the Atlantic and Pacific basins is limited in terms of quantity (EPRI, 2007), the interaction is sufficient to cause inter-basin integration of steam coal markets.

Based on the results presented in Table 4.6 we estimate cointegration vectors and adjustment coefficients for the various routes using the disaggregated specification from Table 4.5 which allows us to disentangle relative effects of export prices and freight rates. We perform the estimation assuming one cointegration relationship for the routes China to ARA and New South Wales to Korea. We expect weaker or insignificant results for the estimated adjustment parameters for these routes, which would confirm our findings of incomplete integration. Hence, we examine the internal working of coal pricing systems (Table 4.8).

Table 4.8: VEC Estimation.

CIF ARA, FOB Bolivar, FR Colombia/Puerto Bolivar–ARA (CI Rank=1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Bolivar)	-0.450	0.000
ln(FR Puerto Bolivar–Rotterdam)	-0.521	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.045	0.000
D(ln(FOB Bolivar))	-0.035	0.004
D(ln(FR Puerto Bolivar–Rotterdam))	0.128	0.000
Lags	6	
Observations	382	

CIF ARA, FOB Richards Bay, FR South Africa/Richards Bay–ARA (CI Rank=1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Richards Bay)	-0.664	0.000
ln(FR Richards Bay–Rotterdam)	-0.340	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.123	0.000
D(ln(FOB Richards Bay))	-0.113	0.000
D(ln(FR Richards Bay–Rotterdam))	0.200	0.003
Lags	4	
Observations	384	

CIF ARA, FOB Qinhuangdao, FR Qinhuangdao–ARA (CI Rank=1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Qinhuangdao)	0.184	0.394
ln(FR Qinhuangdao–Rotterdam)	-1.525	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.014	0.000
D(ln(FOB Qinhuangdao))	-0.008	0.011
D(ln(FR Qinhuangdao–Rotterdam))	0.042	0.000
Lags	5	
Observations	327	

Continued on next page

Table 4.8: VEC Estimation – continued from previous page

CIF Korea, FOB Newcastle, FR Australia/New South Wales–Korea (CI Rank=1)

Cointegrating vector (coefficient on ln(CIF Korea) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF Korea)	1.000	n/a
ln(FOB Newcastle)	0.472	0.183
ln(FR New South Wales–Korea)	-1.766	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF Korea))	-0.012	0.000
D(ln(FOB Newcastle))	-0.009	0.000
D(ln(FR New South Wales–Korea))	0.023	0.013
Lags	4	
Observations	308	

CIF ARA, FOB Gladstone, FR Australia/Queensland–ARA (CI Rank=1)

Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Gladstone)	-0.374	0.003
ln(FR Queensland–Rotterdam)	-0.694	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.058	0.000
D(ln(FOB Gladstone))	-0.031	0.019
D(ln(FR Queensland–Rotterdam))	0.049	0.093
Lags	4	
Observations	200	

CIF ARA, FOB Newcastle, FR Australia/New South Wales–ARA (CI Rank=1)

Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Newcastle)	-0.384	0.000
ln(FR New South Wales–Rotterdam)	-0.608	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.043	0.000
D(ln(FOB Newcastle))	-0.027	0.005
D(ln(FR New South Wales–Rotterdam))	0.052	0.036
Lags	2	
Observations	386	

CIF Japan, FOB Gladstone, FR Australia/Queensland–Japan (CI Rank=1)

Cointegrating vector (coefficient on ln(CIF Japan) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF Japan)	1.000	n/a
ln(FOB Gladstone)	-0.776	0.000
ln(FR Queensland–Japan)	-0.298	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF Japan))	-0.093	0.000
D(ln(FOB Gladstone))	-0.065	0.012
D(ln(FR Queensland–Japan))	0.198	0.013
Lags	4	
Observations	200	

We first analyze the relative contribution of export prices and freight rates to the equilibrium relationship for the various routes. Then we describe the speed of adjustment to the long-run equilibrium relationship.

In almost all cases our estimates of the coefficients of β in Eq. (4.2) are highly significant. The exceptions are the China to ARA and Newcastle to Korea routes, which we expect given the lack of cointegration we find for China to ARA and the somewhat ambiguous result on integration for Newcastle to Korea. In the cases of identified normalized cointegrating vectors, their respective coefficients have the same sign across routes. Thus, the basic setup of the equilibrium relationship is identical for each route. However, the relative importance of export prices and freight rates differs by route; the weight of the freight rate increases with the growing distance between export and import locations.

The respective adjustment coefficients have the same signs in all and are highly significant in most specifications. The coefficients on CIF and FOB prices are always negative, although the coefficients on CIF prices are always larger in absolute value, whereas the coefficients on freight rates are always positive. This is consistent with our observation that CIF and FOB prices move together, driven by demand from import locations.

Our estimates of the adjustment coefficients indicate that CIF prices adjust back to the equilibrium level in case of a deviation from equilibrium. FOB prices move in the same direction as CIF prices, slowing down the adjustment process. Freight rates have positive adjustment coefficients, which in many cases are larger in absolute value than those of coal prices, indicating that freight rates also move the system back to equilibrium and that they do so quite strongly.

However, while the signs of the corresponding coefficients are identical, their magnitudes differ substantially across routes. The coefficients for the route South Africa to ARA are largest in absolute value while the routes China to ARA and Newcastle to Korea are smallest, but highly significant. This implies that the route South Africa to ARA returns to equilibrium the quickest, which seems reasonable since it is the most commercialized route and active arbitrage is taking place.

The results for China to ARA and Newcastle to Korea imply that these systems only slowly revert to long-run equilibrium. This is in line with our earlier finding of no cointegration, at least for the case of China, where the Chinese government's restrictions on coal exports weaken the influence of market forces and prevent a quick adjustment to equilibrium. Overall the different speeds at which the individual routes return to the long-run relationship indicate that there is still significant international market segmentation.

4.4 Discussion

We conclude that the evidence mostly favors the hypothesis of global integration of the steam coal market, but we find signs that integration is not yet complete. While the FOB price for Colombia is not cointegrated with any of the other export prices, we find that the route Colombia to ARA is integrated with a large adjustment coefficient. This suggests that the freight rate is mostly responsible for equilibrating this particular market and for creating an integrated shipping route, while the Colombian export price itself may still have to complete the integration process in the supply side of the international market for steam coal.

We also find evidence that government policy has caused some disintegration from the global market in the case of China. Starting in 2004, the Chinese government gradually moved from supporting coal exports through tax credits to constraining them through ever-tightening export restrictions (Minchener, 2007). The result of these policy-induced restrictions has been a disconnect from the global market as exemplified by a lack of cointegration of FOB Qinhuangdao with FOB Gladstone, one of the Australian prices which constitute the benchmark price for coal traded in the Pacific basin. We also find that the route China to ARA is not integrated. Even if we suppose that the China to ARA route is weakly integrated, our estimates of the adjustment coefficients show that once disturbed, it is slow in adjusting back to long-run equilibrium. Our interpretation of this finding is that export restrictions have weakened the forces of arbitrage on the China–ARA route so that Chinese suppliers of steam coal are constrained in reacting to information about changed market conditions at the same speed as less-encumbered suppliers of coal (such as South African ones) are able to do.

Further evidence of incomplete integration of the global market is the significant difference between adjustment coefficients for the respective trading routes. Different routes adjust at significantly different speeds, showing that substantial rigidities remain in the international steam coal market, even though prices are generally integrated.

While identifying some evidence of incomplete integration and rigidities in the international steam coal market, we conclude that the main evidence favors global steam coal market integration. In addition, our confirmation of Hypothesis 2 shows that the coal market may be integrated within itself, but it does not appear to be integrated with the larger market for fossil fuels (Bachmeier and Griffin, 2006).

4.5 Summary and Conclusions

In this chapter we analyze the integration of the seaborne international steam coal trade using a richer dataset than the existing literature in terms of scope and frequency. Following a descriptive analysis we derive three testable hypotheses. Our first hypothesis is that international steam coal prices are directly related to each other, and our second hypothesis is that the prices of steam coal and freight rates for transportation are not integrated with the price of oil. This implies that logistics do not enter the pricing system for coal through the main driver of shipping costs, but in a more complex manner. Additionally, our third hypothesis is that global markets for steam coal are not yet completely integrated when taking into account systems of supply and demand.

We use a detailed multivariate cointegration analysis of the system of demand and supply of steam coal consisting of CIF prices on the demand side and FOB prices and freight rates on the supply side. From our analysis of the various components of the demand and supply sides separately we can partially confirm the findings in the existing literature. We find that the majority of export prices are cointegrated, with the two notable exceptions of Colombian prices with any of the other export prices, and Chinese exports with exports from one Australian location, Gladstone. We also confirm results about the integration of import prices from the existing literature

(Warell, 2006).

We conclude that the price of (residual fuel) oil does not belong to the same system of either coal prices or freight rates, confirming our hypothesis that logistics affect the steam coal trade in more complex ways than simply through the price of oil.

With FOB prices and freight rates aggregated, we test the integration of the demand and supply sides of the coal market for each route by basin and globally. This analysis is novel compared to the existing literature. We find significant integration of the international trade in steam coal, with the notable exception of the China to ARA route, and contradictive evidence for the New South Wales to Korea route. Once we expand our analysis to the regional and global levels we find significant cointegration of both the regional and global markets.

Having addressed the existence of integration we analyze the setup of the long-term equilibrium and short-term dynamics for each route. We find similarity for both long-term structure and short-term dynamics among all integrated routes. However, we also find significant differences regarding the roles of prices and freight rates in the long-term relationship and the speed of adjustment. We conclude that while the coal market has achieved a significant amount of global integration, it still exhibits rigidities by route, with the system achieving equilibrium more rapidly on some routes than on others, both within and across basins.

With respect to the overall development of the market, our results suggest that market participants should be prepared to deal with an increasingly global coal market, whereas previous thinking was dominated by regional approaches. Overall our results also suggest intensified competition in steam coal markets, leaving less room for the abuse of market dominance. However, the exceptions we find to the general trend also suggest that “pockets” of markets with different characteristics and behavior remain, so that regional market power remains an issue. The findings also suggest that local events, such as the recent flood in Australia leading to substantial upheaval in the production chain, may affect not only local or regional markets, but have repercussions on transportation routes around the world.

We suggest that additional research should address spatial price competition, taking into account transportation limitations (e.g., Panama Canal) as well as differences in coal qualities. Furthermore, the use of steam coal mainly for electricity generation has direct repercussions for the prices of emissions allowances, at least in Europe. In addition, interfuel competition may be affected, so that adding the prices of additional fuels and emissions allowances to the analysis should extend our findings. Another fruitful avenue for further research is to analyze the precise role of logistics in the pricing of transportation costs.

Chapter 5

The Dynamics of Global Crude Oil Production

5.1 Introduction

Oil is for apparent reasons one of the global commodities most studied by economists. Key areas of interest include price formation, i.e. the role of speculation versus fundamental drivers; the interaction of prices with other economic variables such as exchange rates and GDP; and the drivers of oil supply. While there has been much empirical work on the determinants of OPEC production, less effort has been devoted to a systematic investigation of global oil production. In this chapter we take a naïve approach and estimate models to identify the relationship between country-specific oil production decision and world oil market prices as well as price volatility, while controlling for other important determinants of oil production decisions. By including lags of our explanatory variables that range from a decade ago to today we can analyze the response of oil production to specific influences over time.

In general, oil production has been analyzed from two perspectives. Since a major feature of fossil fuels is their nature, namely their exhaustibility and their geologic attributes, one stream of literature investigates whether oil production develops according to economic models of exhaustible resources based on Hotelling (1931), or whether oil production more closely relates to the question of worldwide oil depletion as suggested by Hubbart (1956). This stream of literature has produced mixed results given that the assumptions required in each model, such as the geographic scope of production, determine the predicted production pattern to some degree.

A second stream of literature examines the strategic behavior of the major oil producers. For example, the focus is on competition (i.e. MacAvoy, 1982) and revenue targets (i.e. Teece, 1982) in examining OPEC. Followers of the cartel hypothesis test if OPEC is a monopoly, an oligopoly, or if it acts as a dominant firm. Griffin's seminal chapter (1985) is the starting point for numerous contributions to the cartel hypothesis and also analyzes the potential mechanisms used to steer production, mostly based on current price and production data. One conclusion is that production in non-OPEC and OPEC countries reacts differently to current price changes, yet there are also differing interpretations about the exact nature of the potentially strategic interactions. Some authors (Griffin, 1985, Jones 1990) claim that OPEC acts as a cartel or a bureaucratic syndicate (Smith, 2005), others (Alhajji and Huettner, 2000) find that market results can be explained by Saudi Arabia's dominant role, and a few researchers promote the "target revenue hypothesis" (Griffin, 1985, Ramcharran, 2002, Alhajji and Huettner, 2000), and the existence of a quota system (Kaufmann et al., 2008).

The empirical stream of literature disregards the importance of a range of prices prior to the current period for future oil production. However, oil production follows physical investment with a significant time lag of seven to ten years (Wurzel et al., 2009). Investments in R&D can take even longer to result in actual oil production. Therefore, short-run adjustments in oil supply due to price changes differ significantly from long-run adjustments determined by investment decisions. In addition, limited competition in oil production leads to a scenario in which investment decisions are a potentially strategic instrument just like actual production decisions.

Structurally, the global oil market has changed substantially since 1974. Whereas OPEC dominated the market until the early 1980s in terms of prices and quantities, several private companies have invested heavily in exploration and development. Recent figures suggest that non-OPEC production accounted for roughly 60% in 2009 (BP, 2010). Most remarkable is the increase of oil production from non-OECD/non-OPEC countries, which increased their share in global production from 29% in 1994 to 34% in 2009, at the same time the share of OECD producers decreased from 32% to 25%. We are interested in the major determinants of production in all countries, i.e. the high prices triggering exploration activities; financial crises implying economic downturns and hence negative growth in oil consumption; terrorist attacks delaying or even alienating investments, etc.

This chapter analyzes in detail the effect of a range of current and past alterations in prices and price volatility on oil production in three groups of oil producing countries while controlling for the output effects of additional explanatory variables, such as investment, real economic activity, price volatility, strength of the U.S. dollar, etc. We base our analysis on an extensive sample of monthly data which allow for the inclusion of a rich lag structure. The remainder of the chapter is organized as follows. Section II introduces the corresponding data and methodology. Section III presents and discusses our results. Section IV gives our conclusions and suggestions for future research.

5.2 Data and Model Specification

5.2.1 Data and Basic Intuition

The existing literature shows that a number of global and local factors may affect oil production in individual countries. Among the key global variables are the price of oil, price volatility, the state of the overall macroeconomic environment, and the strength of the U.S. dollar. Two significant local variables are the amount of investment in oil exploration and production and a country's own institutional quality. Table 5.1 provides summary statistics for the variables used in our analysis.

In order to capture the supply side of the global oil market as fully as possible we compile a comprehensive dataset at monthly frequency which encompasses the majority of countries and virtually all global crude oil production. We use monthly crude oil production data for the period 1994-2009 as provided by the U.S. Energy Information Agency (EIA). Our daily data on the key benchmark crude oil spot price, WTI, covering the period 1986-2009 from which we compute monthly averages also derives from the EIA. As a measure of oil price volatility we compute the monthly standard deviation of daily log returns based on the WTI price.

We control for the state of the macroeconomic environment by using a comprehensive global real economic activity index proposed by Kilian (2009) and used by He et al. (2010) which captures important developments while avoiding shortcomings of the obvious alternative measures, such as GDP or industrial production. These alternatives may either not be available on a global level or may not be comparable across countries due to different methodologies and standards in the various national statistics offices. Exchange rate effects also may distort these measures.

Future production possibilities are closely related to current and past investment activities. We use country-level rig count data obtained from Baker Hughes as a proxy for investment in oil exploration and production (Ringlund et al., 2008). A country's institutional set-up, while only changing very slowly, is a strong determinant of overall economic success in the long term (Acemoglu et al, 2001; Faria et al, 2010). Including institutional quality indicators is novel in the literature on energy economics and allows us to control for time-varying country individual effects.[1]

5.2.2 Descriptive Statistics

We allocate the countries in our sample to three main groups: OPEC[2], OECD and non- OPEC/non-OECD. This division is in contrast to most of the related literature, e.g., Griffin (1985) and subsequent studies, which only distinguish between OPEC and non-OPEC. While the distinction of crude oil producing countries into OPEC and non-OPEC may have been appropriate in the past, we believe that a further subdivision of non-OPEC countries is warranted.

Table 5.1 indicates significant diversity between the local explanatory variables for the three country groups. Rig count activity differs substantially, particularly

[1] We include the mean of the World Bank's six country-level governance indicators: i) voice and accountability, ii) political stability and absence of violence/terrorism, iii) government effectiveness, iv) regulatory quality, v) rule of law and vi) control of corruption, which are available at annual frequency. The indicators are defined to range from -2.5 to 2.5, with higher values indicating higher quality in the respective category (Kaufmann et al., 2009). Values above zero indicate above-average performance on that particular indicator.

[2] We follow the IEA's definition of OPEC membership (IEA, 2009), so that we treat Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the UAE and Venezuela as OPEC members throughout the sample period. Thus, e.g., Indonesia is considered a non-OPEC country throughout.

regarding its variation around mean activity. OPEC has both the lowest number of rigs and the smallest variation around the mean. The OECD region exhibits the most pronounced dynamics, driven by U.S. and Canadian rig activity, in terms of both the mean number of rigs and the extent of variation around the mean. The non-OECD/non-OPEC group exhibits intermediate variation in its investment activity. Since rig count is not a perfect proxy for investment, we need to assume a direct relationship between rig activity and investment in oil production and a stable relationship across countries. While this may be a strong assumption, we believe that including the rig count is preferable to not including it, given the lack of available data on investment.

Governance indicators also differ across country groups and are highest for the OECD group and lowest for OPEC. However, based on the institutional indicators, with values above zero indicating above-average performance relative to the other countries, both OPEC and non-OECD/non-OPEC countries are positioned lower than the median country.

Table 5.1: Descriptive Statistics

Global Variables							
Variable	Obs.	From	To	Mean	SD	Min	Max
WTI spot price (real 2005 U.S. dollars)	284	Jan 86	Aug 09	36	18	14	119
WTI price volatility	284	Jan 86	Aug 09	0.023	0.013	0.007	0.110
Kilian real activity index	284	Jan 86	Aug 09	-3.5	23.6	-57.5	55.2
Exchange rate IMF Special Drawing Right (SDR) - U.S. dollar	332	Jan 82	Aug 09	0.75	0.10	0.61	1.04
Local variables by region							
OPEC							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	31,130	2,914	26,308	36,412
Rig count	332	Jan 82	Aug 09	192	43	105	303
Institutional quality	156	1996	2008	-0.49	0.04	-0.61	-0.45
OECD							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	22,457	978	19,043	24,012
Rig count	332	Jan 82	Aug 09	1,739	738	698	5,174
Institutional quality	156	1996	2008	1.19	0.03	1.14	1.23
non-OECD/non-OPEC							
Variable	Obs.	From	To	Mean	SD	Min	Max
Crude oil production (thousand barrels per day)	188	Jan 94	Aug 09	23,988	2,783	19,566	28,562
Rig count	332	Jan 82	Aug 09	431	88	247	591
Institutional quality	156	1996	2008	-0.43	0.03	-0.46	-0.38

Sources: Crude oil production and the WTI price are from the U.S. Energy Information Agency; the real activity index is from Kilian (2009); the U.S. dollar-SDR exchange rate is from Thompson Datastream; the rig count is from Baker Hughes; and the governance indicators are from the World Bank.
Prices are deflated by the 2005 U.S. CPI. Crude oil production is in thousand barrels per day. The institutional quality index ranges from -2.5 to 2.5, with higher numbers indicating better governance outcomes. The governance indices are available at annual frequency. Missing years 1997 and 1999 are completed through linear interpolation.

Figure 5.1 plots the evolution of oil output against the development of WTI prices and indicates that oil production differs across the three country groups over the sample period. In particular, the development of oil output of the OECD and non-OECD/non-OPEC groups are dissimilar in terms of longer-term development and short-term dynamics. We observe that total OECD output has declined by about 14% since the turn of the century, with Norway and the U.K. accounting for most of the group's overall decline. Non-OECD/non-OPEC output has increased steadily over the entire sample period. Figure 5.1 also suggests that OECD oil output is more volatile in the short run compared to non-OECD/non-OPEC output, whose increase has been fairly smooth and almost monotonic over the sample period. In contrast, OPEC output roughly followed the evolution and steady increase of the WTI price, although with a certain delay, which suggests that OPEC output might be more closely related to the development of global crude oil prices than the output of the two other country groups.

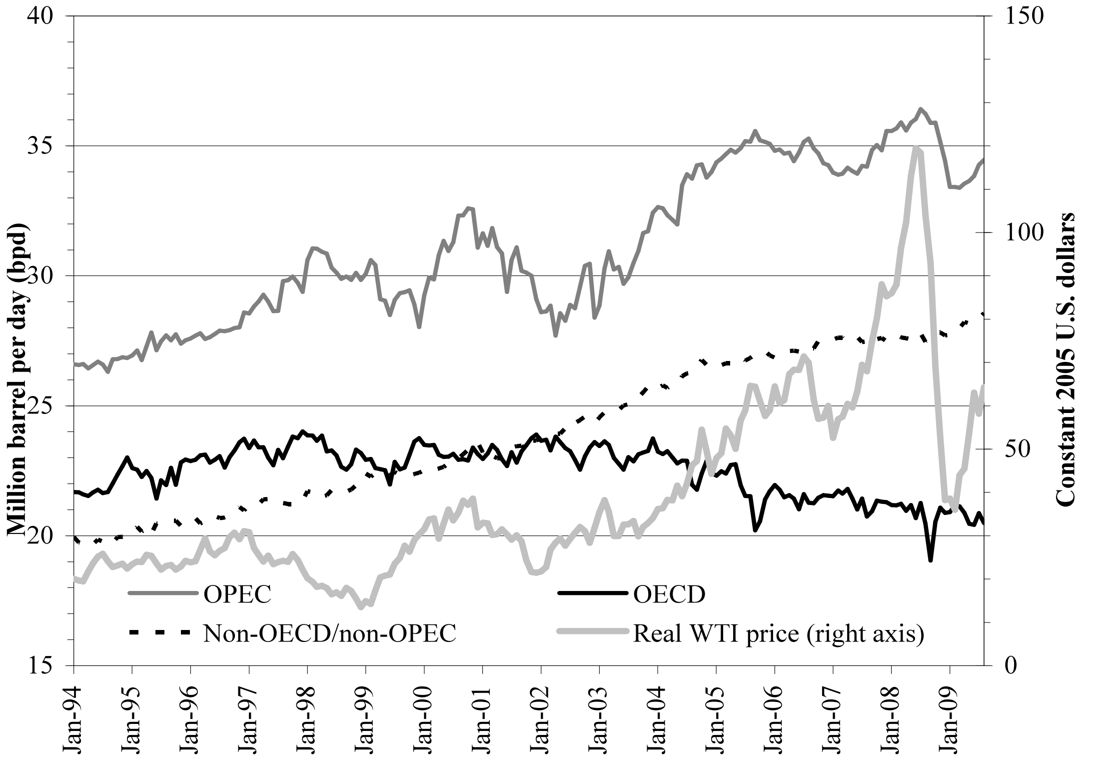

Figure 5.1: Production by Region and Real WTI Price.

5.2.3 Intra-Group Dynamics in Oil Production – Principal Component Analysis

Following our descriptive analysis we now evaluate the variation in our dependent variable, oil production, on a country level. Our intention is to better understand the rise of "new" producing countries, the decrease in OECD production and the role of OPEC. We use principal component analysis (PCA) to investigate the structure of the production data in a naïve manner. A graphical representation of the major principal components allows us to evaluate the degree of similarity among the production decisions of various countries over time. While we are not necessarily able to interpret principal components in a structural way, PCA is useful for achieving deeper insights about the set-up of our dependent variable without having to resort to parametric estimation techniques.

We conduct the PCA for all of OPEC, except for Iraq and Libya, and for the major producers from the other two groups.[3] For illustrative purposes we select three time periods to explore the relationship among key dimensions of oil production, given their varying behavior of the equilibrium price: the entire sample period; 1994-1998, a period of stagnating prices; and 2002-2006, a period of increasing prices.

Table 5.2: PCA Major Producers, First Differences - Eigenvalues and Proportion of Total Variation Explained by Sample Period

Sample period	Principal component number	Eigenvalue	Proportion of total variation explained
1994-2009	1	2.7	8.6%
	2	1.9	6.2%
1994-1998	1	4.0	13.0%
	2	2.9	9.3%
2002-2006	1	3.2	10.4%
	2	2.5	8.2%

Table 5.2 shows that the first two principal components have eigenvalues clearly in excess of 1 in the three periods. The moderate proportion of variation explained differs by sample period. When there are more homogenous price developments eigenvalues are higher and a greater proportion of variation is explained compared

[3] To be consistent with our quantitative analysis we conduct the PCA using differenced production data.

to the entire period.

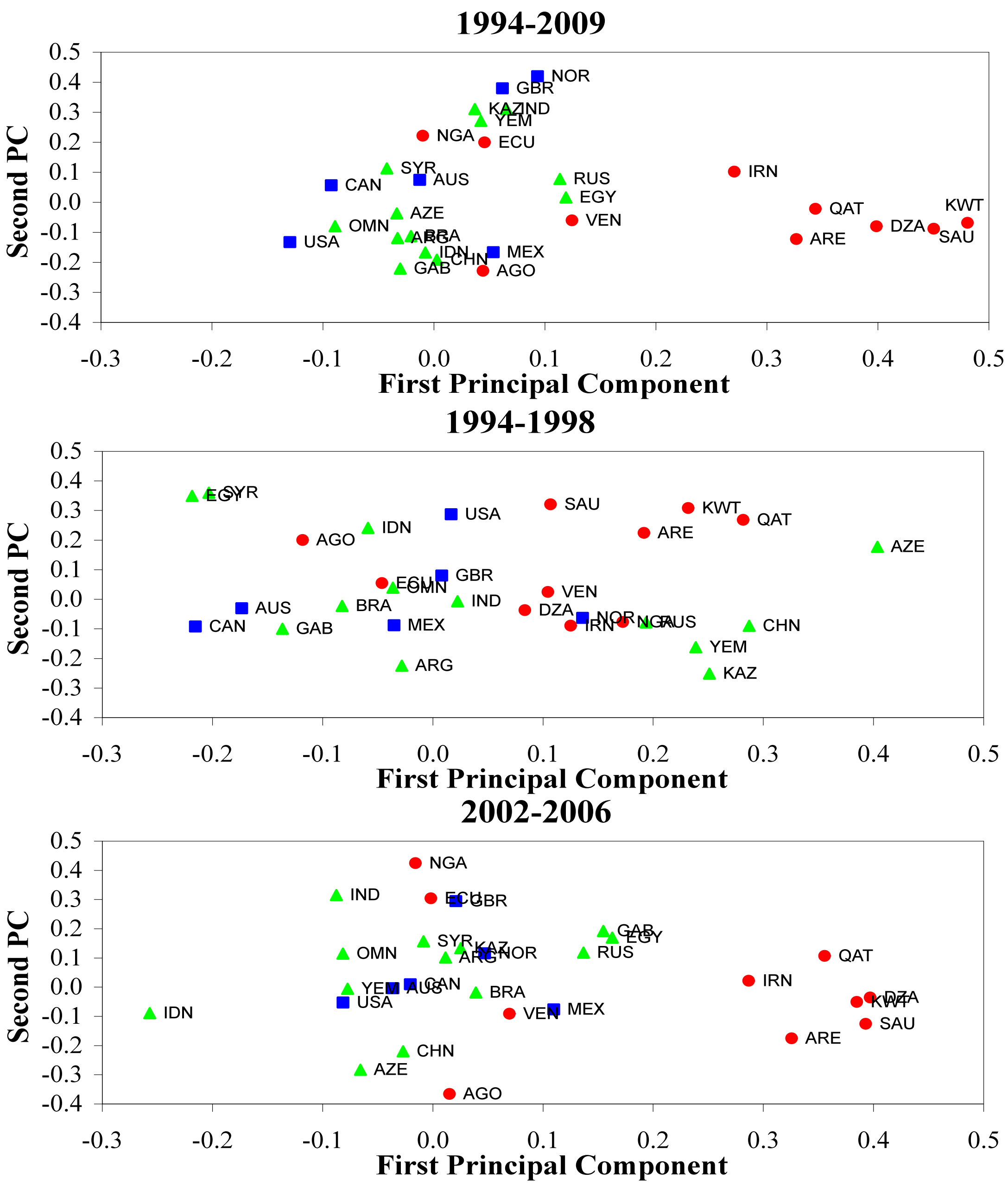

Figure 5.2: Principal Component Analysis, Major Producers, First Differences: Various Sample Periods

Figure 5.2 plots the distribution of the individual countries' production pattern over the two-dimensional space spanned by the first two principal components for the three periods.[4] When considering the pattern of oil production over the entire

[4]OPEC countries are depicted as circles, OECD as squares and non-OECD/non-OPEC countries as triangles. Country labels correspond to the World Bank's country coding system.

period (Figure 5.2, top panel), we notice a relatively high degree of similarity of output variation within the OPEC group, particularly among its Middle Eastern and North African members. However, Latin American and Sub-Saharan African OPEC members are significantly removed from this pattern. There is also a high degree of overlap between the OECD and non-OECD/non-OPEC groups

During the low-price period 1994-1998 (Figure 5.2, middle panel), cohesion within the three country groups diminishes and there is much more overlap. For OPEC, some countries from the so-called OPEC core (Smith, 2005) now also show signs of divergence.

During the high-price period 2002-2006 the WTI price tripled in real terms and we see greater similarity among OPEC members' output compared to the entire period (Figure 5.2, bottom panel). Output decisions appear to be well coordinated among the Middle Eastern and North African OPEC members, whereas Nigeria, Angola, Venezuela and Ecuador clearly diverge. Variations in the output of the main OECD producers also become more similar than in 1994-1998 and in the entire period. Only the non-OECD/non-OPEC group is less coherent than during the entire period.

While we cannot readily interpret the results of the PCA in economic terms, they support our findings from the previous descriptive analysis, strongly suggesting that a substantial amount of heterogeneity exists in the dynamics of oil output by country group, on the level of individual countries, and over time. Thus, we can derive two hypotheses which we discuss in the following sections:

Hypothesis 1: Crude oil production responds to prices and price volatility. A significant response is expected to come for both the current and previous periods along a lag-structure from the very short to the longer term.

Hypothesis 2: The reaction of crude oil production to changes in prices and price volatility is heterogeneous among country groups as well as among members within the groups.

5.2.4 Methodology

Much of the existing literature based on Griffin (1985) uses logarithms of prices and quantities, however, the price and quantity variables especially are clearly non-stationary over the sample period under consideration, thus providing spurious results in unadjusted OLS regressions.[5] Therefore, Kaufmann et al. (2008) adapt their estimation to the presence of non-stationarity by using an error correction approach. Their VEC estimation finds more than one cointegration relationship in each case, which leads to multiple sets of estimation results and unclear interpretations.

Therefore, we decide to trade off information content in favor of analytical clarity. We leave the real activity index and the standard deviation of log returns on oil unchanged, since both are stationary. We also leave the governance index in levels. We take first differences of the remaining variables to ensure covariance stationarity of our data.

We aim to identify the effects of prices and price volatility on crude oil production based on the estimation of the following model:

$$\begin{aligned}\Delta Q_{t,i} &= \alpha_i + \sum_{k=0}^{K} \beta_{k,i} \Delta P_{t-k} + \sum_{l=0}^{L} \phi_{l,i} SD(\Delta P_t)_{t-l} + \sum_{m=0}^{M} \gamma_{m,i} REAL_{t-m} \\ &+ \sum_{n=1}^{N} \delta_{n,i} \Delta RIG_{t-n,i} + \sum_{p=0}^{P} \theta_{p,i} \Delta EX(USD)_{t-p} + \lambda_i INST_{t,i} \\ &+ \sum_{j=1}^{11} \rho_j D_{t,j} + \epsilon_{t,i} \qquad (5.1)\end{aligned}$$

where $Q_{t,i}$ is crude oil output by group or country and P_t is the CPI-deflated WTI oil price[6], while $SD(\Delta P_t)_t$ is the monthly standard deviation of daily log returns of the WTI, our measure of volatility. $REAL_t$ is the real activity index constructed by Kilian (2009), $RIG_{t,j}$ is the rig count, our proxy for investment in oil exploration and production, and $EX(USD)_t$ is the exchange rate between the Special Drawing Right (SDR) and the U.S. dollar issued by the International Monetary Fund and

[5] Unit root tests reveal non-stationarity for a number of variables under consideration, while first differences are I(1).

[6] We also perform our analysis using key regional crude oil prices. The results are essentially unchanged, which provides additional evidence in favor of the oil market's global integration (Bachmeier and Griffin, 2006).

represents a basket of major global currencies. Thus, this exchange rate measures the value of the U.S. dollar in a global context. $INST_{t,i}$ is the mean of the six WGI governance indicators and D_t is a full set of monthly dummy variables to control for seasonality, such as potentially decreased oil production or rig activity due to adverse weather conditions.

Heteroskedasticity and autocorrelation are accounted for by using Newey-West corrected standard errors in the main regression model, with a generous autocorrelation specification of a lag up to 80 months. Since we do not include lagged output as an explanatory variable, residual autocorrelation will not affect the consistency of our estimations.

We include nine years of lags for oil price, price volatility, real activity, rig count, and U.S. dollar exchange rate to explore the full dynamics of the spectrum of lags. For prices we include monthly lags for the first quarter, then lags at quarterly frequency for the remainder of the first year and yearly averages beyond the first year, to analyze short-term, medium-term and longer term responses of crude oil production to price changes. To maintain relative parsimony for our model we include quarterly averages for the first year for the remaining explanatory variables and yearly averages thereafter.

5.3 Results and Discussion

We present our analysis by major country group. We first describe the results for the aggregated group-level regressions and then focus on some major individual countries in each group to evaluate our hypotheses at the country level.

Note that while having included CIS member countries and China when presenting descriptive statistics, we do not consider them in the group-wise analysis due to either missing or incomplete data on rig count.[7] We do present results for China and Russia for a specification of our model that excludes rig count, given that they represent a large proportion of non-OECD/non-OPEC oil output.

[7]However, running the group-wise regression based on the entire sample while excluding the rig count variable does not significantly change our results for most variables.

Table 5.3: Determinants of Crude Oil Production, Group-Wise Analysis

	(1) OPEC	(2) OECD	(3) Non-OECD/non-OPEC
Real WTI price, monthly average	0.717	4.850	4.021
	(0.967)	(0.590)	(0.174)
Real WTI price, monthly average (-1)	43.93**	-11.31*	3.136
	(0.014)	(0.094)	(0.121)
Real WTI price, monthly average (-2)	37.34***	-22.10*	-0.503
	(0.001)	(0.070)	(0.921)
Real WTI price, quarterly average (-1)	55.29	-107.8**	3.588
	(0.416)	(0.018)	(0.834)
Real WTI price, quarterly average (-2)	42.46	-47.73	9.095
	(0.377)	(0.318)	(0.534)
Real WTI price, quarterly average (-3)	6.723	-22.28	27.82*
	(0.921)	(0.631)	(0.074)
Real WTI price, yearly average (-1)	-227.6	-18.76	152.5**
	(0.466)	(0.954)	(0.034)
Real WTI price, yearly average (-2)	-281.7	-69.29	136.5**
	(0.150)	(0.885)	(0.012)
Real WTI price, yearly average (-3)	-283.5	-317.9	85.02
	(0.378)	(0.496)	(0.360)
Real WTI price, yearly average (-4)	-342.0	181.3	-25.65
	(0.302)	(0.441)	(0.699)
Real WTI price, yearly average (-5)	-667.0***	111.6	28.06
	(0.004)	(0.692)	(0.488)
Real WTI price, yearly average (-6)	-801.0***	164.5	60.31
	(0.000)	(0.694)	(0.205)
Real WTI price, yearly average (-7)	-593.1***	-148.8	66.75**
	(0.010)	(0.552)	(0.043)
Real WTI price, yearly average (-8)	-537.9***	-108.0	33.23
	(0.005)	(0.644)	(0.284)
Real WTI price, yearly average (-9)	-128.2	-169.3	96.08***
	(0.467)	(0.292)	(0.000)
Std. dev. (log price returns), quarterly average	-2280.5	-31416.4*	3571.9
	(0.892)	(0.091)	(0.179)
Std. dev. (log price returns), quarterly average (-1)	-28300.0*	-19445.4	3814.2**
	(0.053)	(0.200)	(0.012)
Std. dev. (log price returns), quarterly average (-2)	-4256.9	-45361.2	5832.1**
	(0.812)	(0.190)	(0.035)
Std. dev. (log price returns), quarterly average (-3)	-12222.5	-51857.0***	7602.3**
	(0.645)	(0.009)	(0.047)
Std. dev. (log price returns), yearly average (-1)	-68432.4	-112561.3*	35889.9***
	(0.446)	(0.068)	(0.007)
Std. dev. (log price returns), yearly average (-2)	-42727.4	-12441.7	22982.0***
	(0.640)	(0.850)	(0.004)
Std. dev. (log price returns), yearly average (-3)	5948.3	-77540.3	38218.6**
	(0.941)	(0.243)	(0.010)
Std. dev. (log price returns), yearly average (-4)	-31194.9	-5763.1	46136.3***
	(0.535)	(0.928)	(0.000)
Std. dev. (log price returns), yearly average (-5)	-85231.9**	-73120.4	24259.2*
	(0.041)	(0.357)	(0.076)
Std. dev. (log price returns), yearly average (-6)	-94699.2*	-28556.9	24664.7**
	(0.070)	(0.588)	(0.016)
Std. dev. (log price returns), yearly average (-7)	-73456.5*	-58790.9	34260.1*
	(0.087)	(0.148)	(0.055)
Std. dev. (log price returns), yearly average (-8)	-136500.9***	-16146.6	17953.7
	(0.008)	(0.576)	(0.104)
Std. dev. (log price returns), yearly average (-9)	-60660.6**	-42324.9*	4168.7
	(0.035)	(0.085)	(0.362)
Constant	13692.3	11141.8	-3740.0**
	(0.283)	(0.270)	(0.028)
Observations	156	156	156

*,**,*** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

Additionally, we omit Iraq and Libya from OPEC for the group-wise analysis.[8]

[8] In Iraq, political factors strongly impacted the oil industry over the entire sample period. For

While including a number of control variables in our regressions, we are mainly interested in the results for prices and price volatility.[9]

5.3.1 OPEC

Column 1 in Table 6.1 shows that an increase in prices leads to an increase in production at the group level. This output reaction is consistent with the pursuit of OPEC's stated price stabilization objective. However, in the medium to long term, the relationship reverses, which suggests significant revenue smoothing over a longer time horizon. The country level in Table 5.4 shows a more mixed picture, although it broadly confirms the impression from the group level regression. A notable exception is Nigeria, which exhibits revenue smoothing from the short to medium term. For some countries, particularly Iran and the UAE, we also observe that while oil output positively relates to price changes in the short term, there is no significant reaction in the medium to longer term. The country-level regressions also reveal that oil output appears to respond more strongly to prices for certain countries, especially for Saudi Arabia and Venezuela, which appears to drive the result on the group level.

OPEC as a group exhibits significant aversion to price risk, as evidenced by the negative reaction of production changes to increases in price volatility. This observation is borne out on the country level, where a majority of OPEC countries exhibit a negative relationship between changes in output and increases in price volatility across the lag spectrum. Past increases in volatility have strong negative effects on future output although with significantly differing time lags. While Saudi Arabia's output decline takes place immediately, Angola's output decreases in the medium term, and the UAE's output only reacts in the longer term.

Overall, our results regarding OPEC suggest a significant amount of coordination among OPEC members regarding their output reaction to changes in prices and price volatility. However, the coordination is imperfect, confirming the literature,

Libya data on the rig count was only available after 2002. For Iran data on the rig count ceased in 2006; given that Iran represents a significant share of OPEC production and that its rig count is available for the greatest part of the sample period, we included it in the OPEC group.

[9] The full results are available in Appendix A.2.

e.g., Smith (2005), that OPEC seems to act like a bureaucratic cartel.

5.3.2 OECD

The group level regression for the OECD (Table 6.1, column 2) reveals a substantial amount of revenue smoothing for prices in the short term, while on the country level significant heterogeneity becomes apparent (Table 5.5, columns 1-4). We find revenue smoothing behavior especially for Norway and the U.S., and a positive relationship between changes in output and price in Canada and the U.K. The country level results suggest that aggregate results should be treated with caution, since the group level results may be driven by a subset of producer countries, in this case by the U.S.

OECD also shows signs of aversion to price risk on the group level, although to a lesser degree than OPEC. On the country level it becomes clear that the majority of the major OECD producers seem to be risk averse with respect to price volatility, the clear exception being Norway, which exhibits a strong positive relationship between the level of price volatility and changes in the growth of output across most of the lag spectrum.

Overall our results on the country level show that OECD producers constitute a heterogeneous group with respect to both prices and price volatility.

Table 5.4: Determinants of Crude Oil Production, OPEC Producers

	(1) Algeria	(2) Angola	(3) Iran	(4) Kuwait	(5) Nigeria	(6) Saudi Arabia	(7) UAE	(8) Venezuela
Real WTI price, monthly average	-0.752	2.554	-2.276	1.945	-1.399	2.689	0.0340	2.735
	(0.216)	(0.158)	(0.799)	(0.294)	(0.757)	(0.573)	(0.992)	(0.522)
Real WTI price, monthly average (-1)	-0.555	2.719*	5.716	4.540**	-6.719***	22.39**	10.39*	23.10
	(0.271)	(0.058)	(0.153)	(0.018)	(0.000)	(0.017)	(0.078)	(0.126)
Real WTI price, monthly average (-2)	1.124	0.519	11.69*	3.461	-9.811***	29.24***	6.468***	31.44
	(0.193)	(0.787)	(0.073)	(0.115)	(0.001)	(0.000)	(0.008)	(0.104)
Real WTI price, quarterly average (-1)	-0.351	4.075	22.69	1.649	-34.14***	84.54***	26.71	44.77
	(0.846)	(0.355)	(0.438)	(0.678)	(0.006)	(0.001)	(0.162)	(0.264)
Real WTI price, quarterly average (-2)	-2.364	9.330	32.24	0.232	-44.40***	83.91***	27.90	51.27
	(0.265)	(0.127)	(0.355)	(0.970)	(0.000)	(0.000)	(0.409)	(0.449)
Real WTI price, quarterly average (-3)	-4.701**	8.590	46.00*	-0.771	-36.19***	51.67*	26.95	48.04
	(0.035)	(0.402)	(0.060)	(0.931)	(0.006)	(0.100)	(0.391)	(0.471)
Real WTI price, yearly average (-1)	-23.70***	32.61	107.6	13.03	-95.97*	65.65	146.7	-17.37
	(0.006)	(0.262)	(0.252)	(0.639)	(0.064)	(0.588)	(0.235)	(0.929)
Real WTI price, yearly average (-2)	-33.02***	-19.06	350.5	-4.970	-120.9**	14.72	161.1	-133.1
	(0.001)	(0.311)	(0.107)	(0.844)	(0.037)	(0.900)	(0.273)	(0.336)
Real WTI price, yearly average (-3)	-41.62**	-24.77	182.1	-46.63	-87.95*	-122.8	101.7	-167.7
	(0.038)	(0.306)	(0.459)	(0.371)	(0.069)	(0.123)	(0.202)	(0.385)

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Table 5.4: Determinants of Crude Oil Production, OPEC Producers – continued from previous page

	(1) Algeria	(2) Angola	(3) Iran	(4) Kuwait	(5) Nigeria	(6) Saudi Arabia	(7) UAE	(8) Venezuela
Real WTI price, yearly average (-4)	-8.455	-28.50**	145.5	-36.23	48.87	-158.1	74.71	-260.7*
	(0.543)	(0.049)	(0.359)	(0.378)	(0.578)	(0.180)	(0.156)	(0.080)
Real WTI price, yearly average (-5)	-25.67**	-23.66*	112.8	-28.98	36.52	-460.1**	102.2	-279.5*
	(0.028)	(0.099)	(0.313)	(0.493)	(0.585)	(0.029)	(0.216)	(0.094)
Real WTI price, yearly average (-6)	-32.68***	-35.63*	107.6	-40.01	106.5	-512.7***	55.37	-454.9***
	(0.005)	(0.053)	(0.190)	(0.203)	(0.175)	(0.002)	(0.594)	(0.001)
Real WTI price, yearly average (-7)	-14.53	-27.20**	43.50	10.82	5.056	-297.8***	23.03	-244.8**
	(0.201)	(0.024)	(0.407)	(0.645)	(0.868)	(0.000)	(0.704)	(0.023)
Real WTI price, yearly average (-8)	-18.73	15.91	-41.30	-3.776	54.87*	-232.5***	-32.06	-78.99
	(0.102)	(0.504)	(0.187)	(0.735)	(0.067)	(0.002)	(0.505)	(0.546)
Real WTI price, yearly average (-9)	-11.53***	13.65	-93.43	29.51**	14.46	-44.53	-11.81	-3.567
	(0.007)	(0.309)	(0.161)	(0.026)	(0.408)	(0.430)	(0.651)	(0.965)
Std. dev. (log price returns), quarterly average	-293.3	1639.9	-4957.9	161.1	-1575.5	-6724.1	-2646.5	10271.7**
	(0.611)	(0.291)	(0.334)	(0.925)	(0.658)	(0.456)	(0.534)	(0.048)
Std. dev. (log price returns), quarterly average (-1)	-1089.1***	-1435.4	793.2	-1087.7	-6629.2***	-13393.5***	-1825.0	3932.9
	(0.003)	(0.265)	(0.848)	(0.528)	(0.005)	(0.000)	(0.394)	(0.615)
Std. dev. (log price returns), quarterly average (-2)	1473.0*	-2162.4	1560.0	4103.7	-8441.8***	1365.7	847.1	3912.7
	(0.091)	(0.154)	(0.854)	(0.210)	(0.006)	(0.897)	(0.777)	(0.695)
Std. dev. (log price returns), quarterly average (-3)	-706.9	-172.9	-6347.2	2271.0	-5428.9***	-8890.4	148.8	892.9
	(0.509)	(0.913)	(0.611)	(0.570)	(0.010)	(0.458)	(0.970)	(0.932)
Std. dev. (log price returns), yearly average (-1)	1998.5	-3460.0	-87263.5	5565.4	-13538.0	-47047.2	-14209.2	1817.3
	(0.489)	(0.241)	(0.220)	(0.722)	(0.255)	(0.199)	(0.185)	(0.972)
Std. dev. (log price returns), yearly average (-2)	3016.5**	-1045.6	-67133.2*	-6821.2	-9931.9**	14037.5	-12562.6	-36828.3
	(0.039)	(0.659)	(0.070)	(0.304)	(0.041)	(0.587)	(0.157)	(0.444)
Std. dev. (log price returns), yearly average (-3)	-439.1	2815.3	-50087.4**	899.7	-19575.1**	38247.1	-1330.9	20717.3
	(0.692)	(0.510)	(0.050)	(0.882)	(0.034)	(0.111)	(0.840)	(0.470)
Std. dev. (log price returns), yearly average (-4)	3004.9*	-10036.5**	2283.0	12837.3*	-21909.5	24133.3	729.9	-23904.2
	(0.074)	(0.049)	(0.945)	(0.084)	(0.103)	(0.235)	(0.896)	(0.456)
Std. dev. (log price returns), yearly average (-5)	820.9	-9938.5	17811.6	-3407.3	-15008.1	-4076.9	-2336.7	22027.0
	(0.623)	(0.159)	(0.489)	(0.664)	(0.290)	(0.699)	(0.823)	(0.461)
Std. dev. (log price returns), yearly average (-6)	-423.3	-9860.9*	5607.3	-4973.3	-7555.9	5651.9	-355.2	-10853.1
	(0.852)	(0.057)	(0.681)	(0.113)	(0.644)	(0.763)	(0.957)	(0.280)
Std. dev. (log price returns), yearly average (-7)	1671.0	-5423.4*	-5272.7	-4128.0	-7958.3	1233.0	2617.6	-8418.5
	(0.568)	(0.097)	(0.770)	(0.182)	(0.654)	(0.954)	(0.864)	(0.608)
Std. dev. (log price returns), yearly average (-8)	1865.9	-4390.5**	28219.3***	-7769.5***	-755.8	-13014.7	-16457.5**	-67611.6**
	(0.511)	(0.015)	(0.003)	(0.002)	(0.944)	(0.380)	(0.025)	(0.043)
Std. dev. (log price returns), yearly average (-9)	874.9	-110.5	14092.5	1268.7	-11045.6**	18205.8	-3153.6	-60934.3*
	(0.447)	(0.952)	(0.124)	(0.793)	(0.020)	(0.237)	(0.716)	(0.056)
Constant	52.26	1119.9**	2873.1	199.2	3308.7	-281.2	944.8	-1052.8
	(0.880)	(0.046)	(0.472)	(0.788)	(0.114)	(0.943)	(0.485)	(0.772)
Observations	156	156	125	156	156	156	156	156
Mean share in group production	5.5%	3.3%	12.4%	7.4%	7.1%	31.3%	8.4%	9.6%

*,**,*** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

Table 5.5: Determinants of Crude Oil Production, OECD and non-OECD/non-OPEC Producers

	OECD				Non-OECD/non-OPEC			
	(1) Canada	(2) Norway	(3) United Kingdom	(4) United States	(5) Brazil	(6) Indonesia	(7) Russia	(8) China
Real WTI price, monthly average	0.274	3.667	2.638	-11.97*	4.433*	-0.774	-2.512	-1.885
	(0.951)	(0.586)	(0.505)	(0.068)	(0.059)	(0.184)	(0.242)	(0.289)
Real WTI price, monthly average (-1)	1.206	5.800	-4.471	-13.11*	5.409***	-2.656***	-3.401***	2.593
	(0.501)	(0.405)	(0.474)	(0.058)	(0.002)	(0.001)	(0.000)	(0.285)
Real WTI price, monthly average (-2)	-2.409	2.162	-1.676	-34.09***	1.177	-1.898*	-3.719	3.381*
	(0.500)	(0.809)	(0.859)	(0.003)	(0.589)	(0.068)	(0.311)	(0.074)
Real WTI price, quarterly average (-1)	20.80	-42.04	-26.20	-143.5***	2.086	-7.645**	-18.82*	10.39
	(0.108)	(0.236)	(0.422)	(0.006)	(0.736)	(0.012)	(0.050)	(0.271)
Real WTI price, quarterly average (-2)	24.17**	-83.84*	20.78	-120.1**	6.631	-4.029	-27.91*	19.72**
	(0.045)	(0.059)	(0.495)	(0.011)	(0.242)	(0.395)	(0.058)	(0.028)

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Table 5.5: Determinants of Crude Oil Production, OECD and non-OECD/non-OPEC Producers – continued from previous page

	(1) Canada	(2) Norway	(3) United Kingdom	(4) United States	(5) Brazil	(6) Indonesia	(7) Russia	(8) China
Real WTI price, quarterly	26.61*	-145.0***	51.35*	-104.9***	11.58*	-5.384	-35.60*	27.28**
average (-3)	(0.071)	(0.000)	(0.078)	(0.007)	(0.066)	(0.295)	(0.086)	(0.018)
Real WTI price, yearly aver-	166.4*	-684.9***	172.0*	-150.2	46.34*	-8.912	-135.4*	123.4***
age (-1)	(0.066)	(0.000)	(0.071)	(0.392)	(0.078)	(0.641)	(0.082)	(0.003)
Real WTI price, yearly aver-	102.1	-445.7***	2.979	-141.1	30.46*	-7.797	-85.35	100.3**
age (-2)	(0.379)	(0.004)	(0.984)	(0.606)	(0.077)	(0.620)	(0.253)	(0.029)
Real WTI price, yearly aver-	132.2	-436.5***	-78.05	-347.6	-5.502	-12.05	-43.17	94.15**
age (-3)	(0.225)	(0.002)	(0.638)	(0.401)	(0.830)	(0.540)	(0.192)	(0.049)
Real WTI price, yearly aver-	81.46	-132.7	25.43	-45.85	-31.83	-3.263	41.19	58.88
age (-4)	(0.311)	(0.164)	(0.757)	(0.819)	(0.304)	(0.869)	(0.327)	(0.133)
Real WTI price, yearly aver-	67.33	-286.0***	84.34	313.2	-25.45	26.73*	-13.44	11.59
age (-5)	(0.432)	(0.007)	(0.234)	(0.324)	(0.195)	(0.080)	(0.872)	(0.683)
Real WTI price, yearly aver-	50.10	-90.21	108.6**	71.21	-7.361	30.94***	13.01	3.501
age (-6)	(0.568)	(0.312)	(0.023)	(0.822)	(0.723)	(0.002)	(0.818)	(0.867)
Real WTI price, yearly aver-	-12.70	-233.7**	51.86	-12.62	-0.607	29.56**	-17.20	12.93
age (-7)	(0.859)	(0.022)	(0.423)	(0.950)	(0.972)	(0.011)	(0.611)	(0.629)
Real WTI price, yearly aver-	-23.84	34.37	72.92**	-168.2	1.964	10.27	-1.023	30.73***
age (-8)	(0.604)	(0.598)	(0.032)	(0.280)	(0.890)	(0.203)	(0.976)	(0.005)
Real WTI price, yearly aver-	-20.21	12.24	4.559	-89.63	39.74**	-5.945	-42.45**	12.54
age (-9)	(0.471)	(0.886)	(0.917)	(0.274)	(0.039)	(0.313)	(0.017)	(0.175)
Std. dev. (log price returns),	783.0	12707.9***	1870.5	-29338.3**	1955.5	-403.5	-1468.6	339.8
quarterly average	(0.679)	(0.007)	(0.637)	(0.035)	(0.118)	(0.629)	(0.604)	(0.842)
Std. dev. (log price returns),	-1089.0	9212.3**	-3565.7	-30572.8**	-68.47	-529.7	-2018.4	1383.6
quarterly average (-1)	(0.713)	(0.012)	(0.311)	(0.017)	(0.942)	(0.731)	(0.142)	(0.370)
Std. dev. (log price returns),	-2555.5	5762.6	-1769.0	-20783.8	595.5	281.9	-1669.4	2340.7
quarterly average (-2)	(0.682)	(0.386)	(0.512)	(0.380)	(0.777)	(0.839)	(0.330)	(0.257)
Std. dev. (log price returns),	944.8	1955.5	-5636.8	-39457.5*	1361.4	-1271.6	-3172.5	-64.29
quarterly average (-3)	(0.857)	(0.748)	(0.456)	(0.096)	(0.510)	(0.467)	(0.269)	(0.980)
Std. dev. (log price returns),	-5371.3	-4061.8	8283.8	-54445.3	5094.9	-64.49	-6210.9	1939.9
yearly average (-1)	(0.826)	(0.843)	(0.807)	(0.415)	(0.559)	(0.987)	(0.625)	(0.717)
Std. dev. (log price returns),	-4339.0	15954.4	7381.0	-21645.9	-1923.3	-3678.4**	1991.4	2594.7
yearly average (-2)	(0.858)	(0.462)	(0.577)	(0.358)	(0.831)	(0.044)	(0.693)	(0.519)
Std. dev. (log price returns),	-1369.2	22639.5	-32129.7***	-125878.2***	6637.0	-7656.3***	-2976.4	-2510.1
yearly average (-3)	(0.940)	(0.472)	(0.000)	(0.000)	(0.578)	(0.002)	(0.497)	(0.665)
Std. dev. (log price returns),	-6587.4	56011.4***	-4073.1	-105285.9***	12025.6*	437.0	-493.8	6338.3
yearly average (-4)	(0.716)	(0.000)	(0.701)	(0.006)	(0.055)	(0.924)	(0.947)	(0.185)
Std. dev. (log price returns),	-10943.8	45704.6***	-1921.7	-79307.2***	4586.2	2756.6	870.2	-1099.7
yearly average (-5)	(0.574)	(0.000)	(0.925)	(0.003)	(0.644)	(0.561)	(0.877)	(0.862)
Std. dev. (log price returns),	-5005.0	40151.9***	16694.8	-80911.3***	6351.8	1765.2	7888.9**	7989.3*
yearly average (-6)	(0.706)	(0.000)	(0.441)	(0.000)	(0.510)	(0.560)	(0.018)	(0.081)
Std. dev. (log price returns),	-4445.1	29229.8*	33174.1**	-101743.1***	9322.9	-207.6	2087.5	11842.0***
yearly average (-7)	(0.668)	(0.087)	(0.017)	(0.002)	(0.321)	(0.913)	(0.507)	(0.003)
Std. dev. (log price returns),	-16241.9**	35996.2***	26486.5*	-24464.9	3348.1	2752.8	5075.2**	4194.6
yearly average (-8)	(0.017)	(0.005)	(0.086)	(0.489)	(0.604)	(0.366)	(0.030)	(0.222)
Std. dev. (log price returns),	-2444.7	4469.4	-3550.4	2176.3	5549.3	2046.0**	-749.3	-4890.8
yearly average (-9)	(0.777)	(0.676)	(0.664)	(0.925)	(0.326)	(0.038)	(0.798)	(0.182)
Constant	1248.6	1725.9	-2125.4*	18149.5***	-1191.1	249.3	219.7	-850.0
	(0.549)	(0.531)	(0.090)	(0.000)	(0.371)	(0.652)	(0.698)	(0.305)
Observations	156	156	156	156	156	156	156	156
Mean share in group production	12.9%	13.5%	10.5%	39.8%	6.9%	5.7%	32.4%	14.6%

*,**,*** indicate significance at the 10%, 5% and 1% level, respectively; robust p-values in parentheses.

5.3.3 Non-OECD/Non-OPEC

The non-OECD/non-OPEC group exhibits a positive relationship between changes in output and changes in price growth in the medium term. Again, this relationship is less clear when considering the country level (Table 5.5, columns 5-8). While oil output in China and Brazil shows a positive reaction to price changes, Russia exhibits significant revenue smoothing with respect to prices, and Indonesia is an intermediate case.

Only the non-OECD/non-OPEC group shows a positive relationship between price volatility and changes in output on the group level, possibly because the group represents producers which are less risk averse and may therefore increase production when price volatility rises. The results are less clear when considering the country level, especially for Indonesia. However, overall positive and significant coefficients dominate.

Thus, while exhibiting substantial heterogeneity in the reaction of output to price changes, the non-OECD/non-OPEC group seems to be more homogenous than OECD in responding to price volatility. The lower degree of risk aversion sets it apart from the others, further validating our division of the non-OPEC countries into OECD and non-OECD/non-OPEC groups.

5.4 Summary and Conclusions

In this chapter we contribute to the empirical literature on the global crude oil market by providing a substantive empirical analysis of the dynamics of global production. We analyze the response of oil production to key global and local determinants of oil producers' output decisions, such as prices, price volatility, investment, real economic activity, the strength of the U.S. dollar and indicators of institutional quality, based on a rich dataset covering global crude oil production at monthly frequency. However, while controlling for important explanatory factors, we focus our analysis on oil prices and price volatility. We conduct the analysis for the three country groups, OPEC, OECD and non-OECD/non-OPEC, and for selected countries representing the majority of each group's oil production.

Based on a descriptive analysis we motivate the division of the countries in our sample into the three groups and then derive two hypotheses. To the best of our knowledge this is the first contribution that separates non-OPEC producers and provides individual analyses for all three groups. Our first hypothesis states that the proper modeling requires a dynamic model specification, since crude oil production responds to crude oil prices and price volatility not only in the current period, but over a range of lags, varying from the short term to the longer term. The second hypothesis states that the output response varies among the three groups of countries, as well as within each country group. Having specified a generous lag structure ranging from the current period to a lag of nine years, we find that oil output reacts to the entire lag spectrum of current and past prices and volatilities, which confirms the first hypothesis. Furthermore, substantial heterogeneity exists in the response of oil output in most cases, which confirms the second hypothesis.

Specifically, we find that OPEC production is consistent with price stabilization in the short term and with revenue smoothing in the medium to longer term. We also find strong evidence for price risk aversion in the oil output decisions of OPEC countries. The group of OECD countries exhibits a significantly higher degree of heterogeneity among its major oil producers. We find substantial evidence of revenue smoothing with respect to the oil price in the short to medium term. We also find a significant amount of aversion to price risk, with the exception of Norway. We find a largely positive reaction of output to price changes across the major producers in the non-OECD/non-OPEC group. Furthermore, third group exhibits the least amount of aversion to price risk of our three groups.

In conclusion, OPEC output decisions appear to be better coordinated than those of either OECD or non-OECD/non-OPEC, although we note the coordination is imperfect. Also, substantial differences in the response of oil output, particularly its reaction to price volatility, validate separating the non-OPEC countries into two groups.

The implication for further research is straightforward. Oil production differs across countries, regardless of OPEC membership and thus, findings should not be generalized. We suggest that researchers should closely examine the rise of developing and non-industrialized countries for lessons learned. Finally, from a technical perspective, a simultaneous equation approach may be a useful step forward.

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Chapter 6

Appendices

6.1 Appendix A.1: Appendix to Chapter 2: List of Variables

Dependent variables

Quantitative variables

- ln(Value of inter-firm exports): Value of EUA flows that leave the firm, drawn from CITL transactions data. We use the average EUA spot price in Euro for each compliance year to compute the value of this and the other value variables.

- ln(Value of inter-firm imports): Value of EUA flows that enter the firm, drawn from CITL transactions data.

- ln(Value of intra-firm exports): Value of EUA flows that leave one installation and enter another installation of the same firm in the same year, drawn from CITL transactions data.

Categorical variables

- Participation: Inter-firm exports: = 1 if the firm's value of inter-firm exports > 0 in a particular compliance year; and = 0 otherwise.

- Participation: Inter-firm imports: = 1 if the firm's value of inter-firm imports > 0 in a particular compliance year; and = 0 otherwise.

- Participation: Intra-firm exports: = 1 if the firm's value of intra-firm exports > 0 in a particular compliance year; and = 0 otherwise.

Independent Variables

Quantitative variables

- ln(Value of EUA stock): Natural logarithm of the value of each firm's EUA stock in Euro, as available for trading in each compliance year. This variable is based on CITL transactions data, and thus may differ from the firm's NAP allocation, e.g. due to delays in some national registries becoming operational (Poland and Italy are cases in point).

- ln(Turnover): Natural logarithm of the firm's annual turnover as reported in AMADEUS, in Euro.

- Value of EUA stock / turnover: Ratio of the value of the firm's EUA stock to its turnover.

- Return on assets: Return on assets as reported in AMADEUS, in percent.

Categorical variables

- Government-owned: = 1 if the firm is controlled by a government; and = 0 otherwise. Based on AMADEUS data.

- Person-owned: = 1 if the firm is controlled by a single person or a family; and = 0 otherwise. Based on AMADEUS data.

- EUA position: long: = 1 if the firm's allocation is larger than its verified emissions in that compliance year, based on CITL compliance data; and = 0 otherwise.

- Industry: = 1 if the majority of the firm's emissions were generated in installations classified outside of the combustion category based on the main activity codes from the CITL compliance data; and = 0 otherwise.

- New EU members: = 1 if the firm is based in a country that became an EU member in 2004; and = 0 otherwise. Based on AMADEUS data.

6.2 Appendix A.2: Appendix to Chapter 5: Full Set of Estimation Results

Table 6.1: Group Level Regressions

	(1) OPEC	(2) OECD	(3) Non-OECD/non-OPEC
Real WTI price, monthly average	0.717	4.850	4.021
	(0.967)	(0.590)	(0.174)
Real WTI price, monthly average (-1)	43.93**	-11.31*	3.136
	(0.014)	(0.094)	(0.121)
Real WTI price, monthly average (-2)	37.34***	-22.10*	-0.503
	(0.001)	(0.070)	(0.921)
Real WTI price, quarterly average (-1)	55.29	-107.8**	3.588
	(0.416)	(0.018)	(0.834)
Real WTI price, quarterly average (-2)	42.46	-47.73	9.095
	(0.377)	(0.318)	(0.534)
Real WTI price, quarterly average (-3)	6.723	-22.28	27.82*
	(0.921)	(0.631)	(0.074)
Real WTI price, yearly average (-1)	-227.6	-18.76	152.5**
	(0.466)	(0.954)	(0.034)
Real WTI price, yearly average (-2)	-281.7	-69.29	136.5**
	(0.150)	(0.885)	(0.012)
Real WTI price, yearly average (-3)	-283.5	-317.9	85.02
	(0.378)	(0.496)	(0.360)
Real WTI price, yearly average (-4)	-342.0	181.3	-25.65
	(0.302)	(0.441)	(0.699)
Real WTI price, yearly average (-5)	-667.0***	111.6	28.06
	(0.004)	(0.692)	(0.488)
Real WTI price, yearly average (-6)	-801.0***	164.5	60.31
	(0.000)	(0.694)	(0.205)
Real WTI price, yearly average (-7)	-593.1***	-148.8	66.75**
	(0.010)	(0.552)	(0.043)
Real WTI price, yearly average (-8)	-537.9***	-108.0	33.23
	(0.005)	(0.644)	(0.284)
Real WTI price, yearly average (-9)	-128.2	-169.3	96.08***
	(0.467)	(0.292)	(0.000)
Std. dev. (log price returns), quarterly average	-2280.5	-31416.4*	3571.9
	(0.892)	(0.091)	(0.179)
Std. dev. (log price returns), quarterly average (-1)	-28300.0*	-19445.4	3814.2**
	(0.053)	(0.200)	(0.012)
Std. dev. (log price returns), quarterly average (-2)	-4256.9	-45361.2	5832.1**
	(0.812)	(0.190)	(0.035)
Std. dev. (log price returns), quarterly average (-3)	-12222.5	-51857.0***	7602.3**
	(0.645)	(0.009)	(0.047)
Std. dev. (log price returns), yearly average (-1)	-68432.4	-112561.3*	35889.9***
	(0.446)	(0.068)	(0.007)
Std. dev. (log price returns), yearly average (-2)	-42727.4	-12441.7	22982.0***
	(0.640)	(0.850)	(0.004)
Std. dev. (log price returns), yearly average (-3)	5948.3	-77540.3	38218.6**
	(0.941)	(0.243)	(0.010)
Std. dev. (log price returns), yearly average (-4)	-31194.9	-5763.1	46136.3***
	(0.535)	(0.928)	(0.000)
Std. dev. (log price returns), yearly average (-5)	-85231.9**	-73120.4	24259.2*
	(0.041)	(0.357)	(0.076)
Std. dev. (log price returns), yearly average (-6)	-94699.2*	-28556.9	24664.7**
	(0.070)	(0.588)	(0.016)
Std. dev. (log price returns), yearly average (-7)	-73456.5*	-58790.9	34260.1*
	(0.087)	(0.148)	(0.055)
Std. dev. (log price returns), yearly average (-8)	-136500.9***	-16146.6	17953.7
	(0.008)	(0.576)	(0.104)
Std. dev. (log price returns), yearly average (-9)	-60660.6**	-42324.9*	4168.7
	(0.035)	(0.085)	(0.362)
Real activity, quarterly average	-30.84*	19.45	3.885**
	(0.050)	(0.102)	(0.024)
Real activity, quarterly average (-1)	14.25*	-20.75**	-0.0951

Continued on next page

Table 6.1: Group Level Regressions – continued from previous page

	(1) OPEC	(2) OECD	(3) Non-OECD/non-OPEC
	(0.086)	(0.031)	(0.970)
Real activity, quarterly average (-2)	-6.917	-6.858	-2.468
	(0.608)	(0.340)	(0.428)
Real activity, quarterly average (-3)	17.16**	-16.65**	-1.147
	(0.025)	(0.012)	(0.430)
Real activity, yearly average (-1)	35.14	-5.184	-0.861
	(0.143)	(0.866)	(0.833)
Real activity, yearly average (-2)	42.35***	-2.144	-4.356
	(0.000)	(0.940)	(0.439)
Real activity, yearly average (-3)	12.53	-1.479	13.35**
	(0.516)	(0.962)	(0.019)
Real activity, yearly average (-4)	-8.208	27.50*	8.995
	(0.621)	(0.051)	(0.110)
Real activity, yearly average (-5)	-10.11	-23.52	10.63**
	(0.689)	(0.412)	(0.026)
Real activity, yearly average (-6)	-23.27	-9.147	10.55
	(0.542)	(0.832)	(0.128)
Real activity, yearly average (-7)	6.399	-39.81**	13.49*
	(0.648)	(0.011)	(0.052)
Real activity, yearly average (-8)	16.04	34.05	5.579
	(0.723)	(0.290)	(0.549)
Real activity, yearly average (-9)	22.84	-29.57	-1.244
	(0.175)	(0.326)	(0.847)
Rig count, quarterly average (-1)	0.101	3.384*	-6.156***
	(0.993)	(0.059)	(0.001)
Rig count, quarterly average (-2)	6.340	5.323	-8.559***
	(0.657)	(0.110)	(0.000)
Rig count, quarterly average (-3)	-6.063	3.214	-8.290***
	(0.875)	(0.232)	(0.003)
Rig count, yearly average (-1)	24.90	22.29	-36.02***
	(0.891)	(0.227)	(0.001)
Rig count, yearly average (-2)	45.55	23.80	-29.21*
	(0.847)	(0.272)	(0.082)
Rig count, yearly average (-3)	130.2	13.80	-31.25
	(0.565)	(0.279)	(0.192)
Rig count, yearly average (-4)	19.40	15.83	-16.35
	(0.924)	(0.234)	(0.349)
Rig count, yearly average (-5)	-146.0	24.43	-15.56
	(0.432)	(0.325)	(0.259)
Rig count, yearly average (-6)	-101.6	22.80	-32.55***
	(0.563)	(0.501)	(0.002)
Rig count, yearly average (-7)	-87.31	15.12	-35.14*
	(0.531)	(0.419)	(0.080)
Rig count, yearly average (-8)	-244.3*	14.34	-38.14***
	(0.090)	(0.473)	(0.000)
Rig count, yearly average (-9)	-15.89	4.672	-18.99***
	(0.873)	(0.548)	(0.002)
SDR/U.S. dollar exchange rate, quarterly average	32449.7	1767.8	6530.2*
	(0.158)	(0.822)	(0.054)
SDR/U.S. dollar exchange rate, quarterly average (-1)	15469.7	-4320.5	3666.6
	(0.109)	(0.857)	(0.487)
SDR/U.S. dollar exchange rate, quarterly average (-2)	17669.5	7655.0	582.0
	(0.336)	(0.714)	(0.933)
SDR/U.S. dollar exchange rate, quarterly average (-3)	3569.1	-6074.5	2652.6
	(0.857)	(0.873)	(0.787)
SDR/U.S. dollar exchange rate, yearly average (-1)	35816.1	-62019.6	3692.6
	(0.754)	(0.703)	(0.933)
SDR/U.S. dollar exchange rate, yearly average (-2)	-10687.8	3371.8	-2805.8
	(0.938)	(0.985)	(0.945)
SDR/U.S. dollar exchange rate, yearly average (-3)	143527.6*	37223.9	1712.7
	(0.072)	(0.735)	(0.963)
SDR/U.S. dollar exchange rate, yearly average (-4)	63539.3	38759.7	10529.9
	(0.551)	(0.674)	(0.656)
SDR/U.S. dollar exchange rate, yearly average (-5)	5065.8	52369.2	22934.3
	(0.954)	(0.512)	(0.191)

Continued on next page

Table 6.1: Group Level Regressions – continued from previous page

	(1) OPEC	(2) OECD	(3) Non-OECD/non-OPEC
SDR/U.S. dollar exchange rate, yearly average (-6)	104441.1	73593.6	30716.1***
	(0.123)	(0.193)	(0.006)
SDR/U.S. dollar exchange rate, yearly average (-7)	41771.7	27321.2	22737.1
	(0.550)	(0.634)	(0.238)
SDR/U.S. dollar exchange rate, yearly average (-8)	-49638.1	11491.2	14362.9**
	(0.362)	(0.777)	(0.024)
SDR/U.S. dollar exchange rate, yearly average (-9)	-26237.7	1705.1	15290.5**
	(0.530)	(0.952)	(0.020)
Institutional Quality	-2080.3	282.7	6741.1**
	(0.669)	(0.964)	(0.023)
February	-0.322	175.2	9.090
	(0.998)	(0.453)	(0.828)
March	113.6	55.98	-45.20**
	(0.391)	(0.706)	(0.028)
April	-148.7	-121.2	-2.701
	(0.469)	(0.706)	(0.888)
May	-20.60	-359.4	-24.66
	(0.825)	(0.207)	(0.614)
June	156.4	-103.4	27.23
	(0.152)	(0.524)	(0.608)
July	45.10	730.5**	7.362
	(0.678)	(0.037)	(0.862)
August	-112.0	109.7	45.02
	(0.148)	(0.713)	(0.523)
September	-272.6***	489.6**	78.74
	(0.005)	(0.027)	(0.114)
October	-153.2*	1175.1**	32.90
	(0.063)	(0.038)	(0.627)
November	-141.6	1077.0*	20.89
	(0.296)	(0.059)	(0.724)
December	-62.91	648.2	11.34
	(0.592)	(0.160)	(0.843)
Constant	13692.3	11141.8	-3740.0**
	(0.283)	(0.270)	(0.028)
Observations	156	156	156

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; p-values in parentheses.

Table 6.2: Country Level Regressions – OPEC

	(1) Algeria	(2) Angola	(3) Iran	(4) Kuwait	(5) Nigeria	(6) Saudi Arabia	(7) UAE	(8) Venezuela
Real WTI price, monthly average	-0.752	2.554	-2.276	1.945	-1.399	2.689	0.0340	2.735
	(0.216)	(0.158)	(0.799)	(0.294)	(0.757)	(0.573)	(0.992)	(0.522)
Real WTI price, monthly average (-1)	-0.555	2.719*	5.716	4.540**	-6.719***	22.39**	10.39*	23.10
	(0.271)	(0.058)	(0.153)	(0.018)	(0.000)	(0.017)	(0.078)	(0.126)
Real WTI price, monthly average (-2)	1.124	0.519	11.69*	3.461	-9.811***	29.24***	6.468***	31.44
	(0.193)	(0.787)	(0.073)	(0.115)	(0.001)	(0.000)	(0.008)	(0.104)
Real WTI price, quarterly average (-1)	-0.351	4.075	22.69	1.649	-34.14***	84.54***	26.71	44.77
	(0.846)	(0.355)	(0.438)	(0.678)	(0.006)	(0.001)	(0.162)	(0.264)
Real WTI price, quarterly average (-2)	-2.364	9.330	32.24	0.232	-44.40***	83.91***	27.90	51.27
	(0.265)	(0.127)	(0.355)	(0.970)	(0.000)	(0.000)	(0.409)	(0.449)
Real WTI price, quarterly average (-3)	-4.701**	8.590	46.00*	-0.771	-36.19***	51.67*	26.95	48.04
	(0.035)	(0.402)	(0.060)	(0.931)	(0.006)	(0.100)	(0.391)	(0.471)
Real WTI price, yearly average (-1)	-23.70***	32.61	107.6	13.03	-95.97*	65.65	146.7	-17.37
	(0.006)	(0.262)	(0.252)	(0.639)	(0.064)	(0.588)	(0.235)	(0.929)
Real WTI price, yearly average (-2)	-33.02***	-19.06	350.5	-4.970	-120.9**	14.72	161.1	-133.1
	(0.001)	(0.311)	(0.107)	(0.844)	(0.037)	(0.900)	(0.273)	(0.336)
Real WTI price, yearly average (-3)	-41.62**	-24.77	182.1	-46.63	-87.95*	-122.8	101.7	-167.7
	(0.038)	(0.306)	(0.459)	(0.371)	(0.069)	(0.123)	(0.202)	(0.385)
Real WTI price, yearly average (-4)	-8.455	-28.50**	145.5	-36.23	48.87	-158.1	74.71	-260.7*
	(0.543)	(0.049)	(0.359)	(0.378)	(0.578)	(0.180)	(0.156)	(0.080)
Real WTI price, yearly average (-5)	-25.67**	-23.66*	112.8	-28.98	36.52	-460.1**	102.2	-279.5*
	(0.028)	(0.099)	(0.313)	(0.493)	(0.585)	(0.029)	(0.216)	(0.094)
Real WTI price, yearly average (-6)	-32.68***	-35.63*	107.6	-40.01	106.5	-512.7***	55.37	-454.9***
	(0.005)	(0.053)	(0.190)	(0.203)	(0.175)	(0.002)	(0.594)	(0.001)
Real WTI price, yearly average (-7)	-14.53	-27.20**	43.50	10.82	5.056	-297.8***	23.03	-244.8**
	(0.201)	(0.024)	(0.407)	(0.645)	(0.868)	(0.000)	(0.704)	(0.023)
Real WTI price, yearly average (-8)	-18.73	15.91	-41.30	-3.776	54.87*	-232.5***	-32.06	-78.99
	(0.102)	(0.504)	(0.187)	(0.735)	(0.067)	(0.002)	(0.505)	(0.546)
Real WTI price, yearly average (-9)	-11.53***	13.65	-93.43	29.51**	14.46	-44.53	-11.81	-3.567
	(0.007)	(0.309)	(0.161)	(0.026)	(0.408)	(0.430)	(0.651)	(0.965)
Std. dev. (log price returns), quarterly average	-293.3	1639.9	-4957.9	161.1	-1575.5	-6724.1	-2646.5	10271.7**
	(0.611)	(0.291)	(0.334)	(0.925)	(0.658)	(0.456)	(0.534)	(0.048)
Std. dev. (log price returns), quarterly average (-1)	-1089.1***	-1435.4	793.2	-1087.7	-6629.2***	-13393.5***	-1825.0	3932.9
	(0.003)	(0.265)	(0.848)	(0.528)	(0.005)	(0.000)	(0.394)	(0.615)
Std. dev. (log price returns), quarterly average (-2)	1473.0*	-2162.4	1560.0	4103.7	-8441.8***	1365.7	847.1	3912.7
	(0.091)	(0.154)	(0.854)	(0.210)	(0.006)	(0.897)	(0.777)	(0.695)
Std. dev. (log price returns), quarterly average (-3)	-706.9	-172.9	-6347.2	2271.0	-5428.9***	-8890.4	148.8	892.9
	(0.509)	(0.913)	(0.611)	(0.570)	(0.010)	(0.458)	(0.970)	(0.932)
Std. dev. (log price returns), yearly average (-1)	1998.5	-3460.0	-87263.5	5565.4	-13538.0	-47047.2	-14209.2	1817.3
	(0.489)	(0.241)	(0.220)	(0.722)	(0.255)	(0.199)	(0.185)	(0.972)
Std. dev. (log price returns), yearly average (-2)	3016.5**	-1045.6	-67133.2*	-6821.2	-9931.9**	14037.5	-12562.6	-36828.3
	(0.039)	(0.659)	(0.070)	(0.304)	(0.041)	(0.587)	(0.157)	(0.444)
Std. dev. (log price returns), yearly average (-3)	-439.1	2815.3	-50087.4**	899.7	-19575.1**	38247.1	-1330.9	20717.3
	(0.692)	(0.510)	(0.050)	(0.882)	(0.034)	(0.111)	(0.840)	(0.470)
Std. dev. (log price returns), yearly average (-4)	3004.9*	-10036.5**	2283.0	12837.3*	-21909.5	24133.3	729.9	-23904.2
	(0.074)	(0.049)	(0.945)	(0.084)	(0.103)	(0.235)	(0.896)	(0.456)
Std. dev. (log price returns), yearly average (-5)	820.9	-9938.5	17811.6	-3407.3	-15008.1	-4076.9	-2336.7	22027.0
	(0.623)	(0.159)	(0.489)	(0.664)	(0.290)	(0.699)	(0.823)	(0.461)
Std. dev. (log price returns), yearly average (-6)	-423.3	-9860.9*	5607.3	-4973.3	-7555.9	5651.9	-355.2	-10853.1
	(0.852)	(0.057)	(0.681)	(0.113)	(0.644)	(0.763)	(0.957)	(0.280)
Std. dev. (log price returns), yearly average (-7)	1671.0	-5423.4*	-5272.7	-4128.0	-7958.3	1233.0	2617.6	-8418.5
	(0.568)	(0.097)	(0.770)	(0.182)	(0.654)	(0.954)	(0.864)	(0.608)
Std. dev. (log price returns), yearly average (-8)	1865.9	-4390.5**	28219.3***	-7769.5***	-755.8	-13014.7	-16457.5**	-67611.6**
	(0.511)	(0.015)	(0.003)	(0.002)	(0.944)	(0.380)	(0.025)	(0.043)
Std. dev. (log price returns), yearly average (-9)	874.9	-110.5	14092.5	1268.7	-11045.6**	18205.8	-3153.6	-60934.3*
	(0.447)	(0.952)	(0.124)	(0.793)	(0.020)	(0.237)	(0.716)	(0.056)
Real activity, quarterly average	-0.140	-1.564*	-2.774	-0.124	6.461**	-24.73***	-5.568***	-28.61
	(0.664)	(0.057)	(0.461)	(0.856)	(0.010)	(0.000)	(0.004)	(0.145)
Real activity, quarterly average (-1)	-0.287	0.735	6.141	1.695	-3.412*	7.900	1.633	8.667**
	(0.615)	(0.229)	(0.267)	(0.150)	(0.097)	(0.174)	(0.256)	(0.014)
Real activity, quarterly average (-2)	0.464	-2.217	8.055	-2.821**	3.634**	0.967	-1.095	-12.77*
	(0.323)	(0.157)	(0.279)	(0.041)	(0.047)	(0.896)	(0.674)	(0.093)

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Table 6.2: Country Level Regressions – OPEC – continued from previous page

	(1) Algeria	(2) Angola	(3) Iran	(4) Kuwait	(5) Nigeria	(6) Saudi Arabia	(7) UAE	(8) Venezuela
Real activity, quarterly average (-3)	0.959	-0.399	-6.992	-1.349	1.546	-1.050	-7.613**	-6.366
	(0.193)	(0.680)	(0.359)	(0.108)	(0.563)	(0.817)	(0.037)	(0.277)
Real activity, yearly average (-1)	0.625	0.629	-21.51*	5.095	0.0157	1.552	-1.477	-27.05
	(0.687)	(0.521)	(0.068)	(0.119)	(0.998)	(0.890)	(0.857)	(0.241)
Real activity, yearly average (-2)	2.581	-0.249	-6.579	-1.221	4.313	5.213	-0.159	7.603
	(0.128)	(0.898)	(0.425)	(0.664)	(0.375)	(0.394)	(0.937)	(0.570)
Real activity, yearly average (-3)	-1.323	0.558	-30.83*	2.234	-5.767	-7.398	3.296	23.75**
	(0.150)	(0.646)	(0.098)	(0.196)	(0.117)	(0.481)	(0.292)	(0.019)
Real activity, yearly average (-4)	1.629***	-4.006**	-23.20	-0.271	-0.407	-10.70	1.410	-2.411
	(0.003)	(0.024)	(0.201)	(0.941)	(0.962)	(0.126)	(0.590)	(0.676)
Real activity, yearly average (-5)	1.336	-4.786*	-5.651	-1.243	-3.834	-12.97	-4.372	3.917
	(0.263)	(0.062)	(0.780)	(0.640)	(0.511)	(0.143)	(0.147)	(0.622)
Real activity, yearly average (-6)	1.592*	-3.111**	0.317	0.911	-11.89**	5.046	-8.853	-79.68
	(0.056)	(0.017)	(0.985)	(0.865)	(0.010)	(0.809)	(0.144)	(0.127)
Real activity, yearly average (-7)	1.837**	1.626	-16.98	-0.0743	-7.832	6.319	-1.112	-68.94*
	(0.045)	(0.364)	(0.441)	(0.992)	(0.133)	(0.646)	(0.872)	(0.093)
Real activity, yearly average (-8)	2.021	-3.965*	26.97**	4.352**	-1.235	3.894	-3.266	-86.47
	(0.161)	(0.094)	(0.043)	(0.038)	(0.667)	(0.758)	(0.495)	(0.106)
Real activity, yearly average (-9)	1.145	-2.566	19.83	5.159	-18.20***	20.23*	5.720	-12.16
	(0.148)	(0.344)	(0.305)	(0.142)	(0.004)	(0.069)	(0.313)	(0.355)
Rig count, quarterly average (−1)	1.113	-2.406	76.34***	0.970	-13.04*	-15.45	57.56	22.15
	(0.483)	(0.704)	(0.000)	(0.935)	(0.055)	(0.666)	(0.114)	(0.272)
Rig count, quarterly average (−2)	0.838	8.176*	91.42	3.047	-34.02**	-16.29	59.89	46.43
	(0.860)	(0.070)	(0.120)	(0.894)	(0.013)	(0.737)	(0.120)	(0.117)
Rig count, quarterly average (−3)	1.867	7.556*	107.2	21.32	-23.36	10.98	48.22	43.57*
	(0.641)	(0.051)	(0.269)	(0.405)	(0.303)	(0.781)	(0.124)	(0.059)
Rig count, yearly average (−1)	-10.36	8.285	424.2	128.1	-133.3**	328.8*	79.91	316.7*
	(0.443)	(0.624)	(0.228)	(0.325)	(0.016)	(0.092)	(0.438)	(0.100)
Rig count, yearly average (−2)	-14.58	-24.87	312.5	139.0	-32.20	410.8**	85.84	324.2*
	(0.395)	(0.339)	(0.238)	(0.243)	(0.715)	(0.023)	(0.310)	(0.053)
Rig count, yearly average (−3)	5.650	-50.65*	354.2	161.8**	-26.55	326.2	221.9*	225.2*
	(0.736)	(0.072)	(0.155)	(0.045)	(0.647)	(0.180)	(0.057)	(0.071)
Rig count, yearly average (−4)	-11.03	-32.68	108.9	96.08	38.13	398.1*	-39.52	136.1
	(0.511)	(0.469)	(0.498)	(0.336)	(0.592)	(0.061)	(0.622)	(0.254)
Rig count, yearly average (−5)	-13.43	-20.52	12.77	-39.61	30.16	21.62	-74.41	69.61
	(0.540)	(0.665)	(0.931)	(0.672)	(0.693)	(0.910)	(0.531)	(0.496)
Rig count, yearly average (−6)	-0.916	5.985	-40.03	-43.31	87.94	-49.20	-100.8	239.1*
	(0.955)	(0.892)	(0.750)	(0.582)	(0.159)	(0.808)	(0.393)	(0.067)
Rig count, yearly average (−7)	4.878	11.45	-51.28	-95.74**	91.27*	-185.4	-139.1	334.9**
	(0.817)	(0.739)	(0.573)	(0.037)	(0.073)	(0.545)	(0.338)	(0.043)
Rig count, yearly average (−8)	-18.22*	-8.547	10.30	-166.8***	76.90**	-164.9	-100.0	316.4**
	(0.052)	(0.816)	(0.876)	(0.000)	(0.033)	(0.532)	(0.314)	(0.038)
Rig count, yearly average (−9)	-6.546	8.497	121.6***	-36.36*	79.92**	12.14	-58.19	141.5*
	(0.423)	(0.624)	(0.006)	(0.083)	(0.013)	(0.940)	(0.318)	(0.053)
SDR/U.S. dollar exchange rate, quarterly average	-75.99	1865.2**	-603.9	4520.9*	-5094.6***	10789.2**	3895.4***	12212.6
	(0.923)	(0.011)	(0.827)	(0.099)	(0.003)	(0.016)	(0.007)	(0.288)
SDR/U.S. dollar exchange rate, quarterly average (-1)	-621.8	100.6	10902.1	-686.3	-1609.3	65.12	5381.4*	3869.4
	(0.626)	(0.957)	(0.246)	(0.799)	(0.640)	(0.992)	(0.054)	(0.717)
SDR/U.S. dollar exchange rate, quarterly average (-2)	31.32	-1598.1	6426.3	-1271.6	4813.5	1598.7	-324.2	11973.0
	(0.980)	(0.517)	(0.642)	(0.743)	(0.226)	(0.858)	(0.928)	(0.413)
SDR/U.S. dollar exchange rate, quarterly average (-3)	1020.9	-4367.3	12124.0	-4333.5	14090.7	-3425.6	-2270.5	-12674.7
	(0.225)	(0.258)	(0.490)	(0.455)	(0.124)	(0.752)	(0.709)	(0.281)
SDR/U.S. dollar exchange rate, yearly average (-1)	7755.1*	-20268.1	23421.4	-11207.5	51956.1	-35241.7	-11186.3	-64044.1
	(0.056)	(0.327)	(0.734)	(0.661)	(0.188)	(0.615)	(0.656)	(0.117)
SDR/U.S. dollar exchange rate, yearly average (-2)	4386.5	-20786.5	49962.7	-16752.1	42453.7	-98999.9	-13857.7	-41043.5
	(0.266)	(0.276)	(0.497)	(0.407)	(0.210)	(0.201)	(0.613)	(0.155)
SDR/U.S. dollar exchange rate, yearly average (-3)	4872.2	-14779.0	-8984.6	-11713.7	62757.2*	-13243.6	3624.8	12454.5
	(0.321)	(0.271)	(0.841)	(0.583)	(0.087)	(0.812)	(0.808)	(0.694)
SDR/U.S. dollar exchange rate, yearly average (-4)	2606.9	-10771.3	11101.8	-17702.7	48121.8*	-51311.7	-11097.6	38826.1
	(0.560)	(0.313)	(0.800)	(0.417)	(0.073)	(0.416)	(0.544)	(0.444)
SDR/U.S. dollar exchange rate, yearly average (-5)	1989.6	-8736.7	17121.8	-13908.4	46941.1**	-36053.3	-2102.1	-19640.2
	(0.556)	(0.117)	(0.582)	(0.443)	(0.029)	(0.318)	(0.849)	(0.501)

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Table 6.2: Country Level Regressions – OPEC – continued from previous page

	(1) Algeria	(2) Angola	(3) Iran	(4) Kuwait	(5) Nigeria	(6) Saudi Arabia	(7) UAE	(8) Venezuela
SDR/U.S. dollar exchange rate, yearly average (-6)	-322.5	-9227.0*	16192.5	-2421.4	33857.2**	5838.4	10685.0	48572.0
	(0.882)	(0.088)	(0.514)	(0.866)	(0.041)	(0.887)	(0.442)	(0.146)
SDR/U.S. dollar exchange rate, yearly average (-7)	4310.8***	-8658.6	2316.1	-4468.2	23194.3	-25851.5	-9361.1	30419.7
	(0.001)	(0.266)	(0.883)	(0.639)	(0.258)	(0.497)	(0.608)	(0.279)
SDR/U.S. dollar exchange rate, yearly average (-8)	-655.1	-2957.8	18199.6	-9889.3**	15895.4***	-48145.4*	-17458.8	24576.2
	(0.598)	(0.323)	(0.386)	(0.049)	(0.010)	(0.054)	(0.125)	(0.314)
SDR/U.S. dollar exchange rate, yearly average (-9)	-875.0	-411.9	-3428.0	-2765.9	5284.9	-14225.4	-14815.6	2567.2
	(0.334)	(0.848)	(0.695)	(0.411)	(0.291)	(0.197)	(0.181)	(0.877)
Institutional Quality	155.6	290.5**	277.4	-146.5	744.3*	333.9	-66.73	-1334.9
	(0.151)	(0.046)	(0.489)	(0.376)	(0.051)	(0.730)	(0.670)	(0.246)
February	-10.76*	-22.84	-29.74	-21.59**	39.88*	-2.409	-37.50	15.64
	(0.073)	(0.210)	(0.253)	(0.020)	(0.084)	(0.963)	(0.238)	(0.749)
March	-0.116	-24.88**	-29.50	-13.69	82.68***	3.187	-34.90	-11.43
	(0.984)	(0.028)	(0.421)	(0.274)	(0.003)	(0.935)	(0.197)	(0.896)
April	-2.154	-17.45	-152.1*	-49.29**	63.41***	-41.73	-87.00***	-37.39
	(0.851)	(0.196)	(0.073)	(0.028)	(0.000)	(0.592)	(0.000)	(0.640)
May	-16.35**	-13.69	-207.6**	-40.67***	32.71	21.29	-91.76***	51.88
	(0.015)	(0.307)	(0.025)	(0.000)	(0.308)	(0.831)	(0.005)	(0.306)
June	-8.562	-12.87	-215.3**	-28.99*	118.8***	-14.32	-58.21	21.22
	(0.607)	(0.566)	(0.035)	(0.058)	(0.000)	(0.853)	(0.173)	(0.723)
July	-8.112	24.31	-286.7*	-24.66**	102.3***	-16.63	-70.37	-60.44
	(0.559)	(0.590)	(0.056)	(0.011)	(0.000)	(0.823)	(0.122)	(0.269)
August	-13.64	20.73	-249.4*	-30.79**	106.2***	-128.0*	-41.85	-71.21
	(0.209)	(0.470)	(0.072)	(0.031)	(0.000)	(0.094)	(0.535)	(0.118)
September	-23.12*	14.62	-214.0	-21.32	115.0***	-203.1*	-29.54	-91.18*
	(0.072)	(0.680)	(0.195)	(0.202)	(0.001)	(0.065)	(0.763)	(0.064)
October	-27.66***	40.96	-191.1	-2.632	69.94***	-139.8	-23.74	63.06
	(0.002)	(0.205)	(0.207)	(0.845)	(0.000)	(0.198)	(0.741)	(0.323)
November	-29.45***	29.44	-146.2	-15.11	77.64***	-67.75	-101.1***	71.20
	(0.000)	(0.335)	(0.212)	(0.196)	(0.007)	(0.420)	(0.000)	(0.515)
December	-19.34***	39.50**	-111.4	23.47**	20.61	-2.853	25.39	-22.13
	(0.000)	(0.010)	(0.153)	(0.014)	(0.332)	(0.967)	(0.632)	(0.808)
Constant	52.26	1119.9**	2873.1	199.2	3308.7	-281.2	944.8	-1052.8
	(0.880)	(0.046)	(0.472)	(0.788)	(0.114)	(0.943)	(0.485)	(0.772)
Observations	156	156	125	156	156	156	156	156
Mean share in group production	5.5%	3.3%	12.4%	7.4%	7.1%	31.3%	8.4%	9.6%

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; p-values in parentheses.

Table 6.3: Country Level Regressions – OECD and non-OECD/non-OPEC

	OECD				**Non-OECD/non-OPEC**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Canada	Norway	United Kingdom	United States	Brazil	Indonesia	Russia	China
Real WTI price, monthly average	0.274	3.667	2.638	-11.97*	4.433*	-0.774	-2.512	-1.885
	(0.951)	(0.586)	(0.505)	(0.068)	(0.059)	(0.184)	(0.242)	(0.289)
Real WTI price, monthly average (-1)	1.206	5.800	-4.471	-13.11*	5.409***	-2.656***	-3.401***	2.593
	(0.501)	(0.405)	(0.474)	(0.058)	(0.002)	(0.001)	(0.000)	(0.285)
Real WTI price, monthly average (-2)	-2.409	2.162	-1.676	-34.09***	1.177	-1.898*	-3.719	3.381*
	(0.500)	(0.809)	(0.859)	(0.003)	(0.589)	(0.068)	(0.311)	(0.074)
Real WTI price, quarterly average (-1)	20.80	-42.04	-26.20	-143.5***	2.086	-7.645**	-18.82*	10.39
	(0.108)	(0.236)	(0.422)	(0.006)	(0.736)	(0.012)	(0.050)	(0.271)
Real WTI price, quarterly average (-2)	24.17**	-83.84*	20.78	-120.1**	6.631	-4.029	-27.91*	19.72**
	(0.045)	(0.059)	(0.495)	(0.011)	(0.242)	(0.395)	(0.058)	(0.028)
Real WTI price, quarterly average (-3)	26.61*	-145.0***	51.35*	-104.9***	11.58*	-5.384	-35.60*	27.28**
	(0.071)	(0.000)	(0.078)	(0.007)	(0.066)	(0.295)	(0.086)	(0.018)
Real WTI price, yearly average (-1)	166.4*	-684.9***	172.0*	-150.2	46.34*	-8.912	-135.4*	123.4***
	(0.066)	(0.000)	(0.071)	(0.392)	(0.078)	(0.641)	(0.082)	(0.003)
Real WTI price, yearly average (-2)	102.1	-445.7***	2.979	-141.1	30.46*	-7.797	-85.35	100.3**
	(0.379)	(0.004)	(0.984)	(0.606)	(0.077)	(0.620)	(0.253)	(0.029)
Real WTI price, yearly average (-3)	132.2	-436.5***	-78.05	-347.6	-5.502	-12.05	-43.17	94.15**
	(0.225)	(0.002)	(0.638)	(0.401)	(0.830)	(0.540)	(0.192)	(0.049)
Real WTI price, yearly average (-4)	81.46	-132.7	25.43	-45.85	-31.83	-3.263	41.19	58.88
	(0.311)	(0.164)	(0.757)	(0.819)	(0.304)	(0.869)	(0.327)	(0.133)
Real WTI price, yearly average (-5)	67.33	-286.0***	84.34	313.2	-25.45	26.73*	-13.44	11.59
	(0.432)	(0.007)	(0.234)	(0.324)	(0.195)	(0.080)	(0.872)	(0.683)
Real WTI price, yearly average (-6)	50.10	-90.21	108.6**	71.21	-7.361	30.94***	13.01	3.501
	(0.568)	(0.312)	(0.023)	(0.822)	(0.723)	(0.002)	(0.818)	(0.867)
Real WTI price, yearly average (-7)	-12.70	-233.7**	51.86	-12.62	-0.607	29.56**	-17.20	12.93
	(0.859)	(0.022)	(0.423)	(0.950)	(0.972)	(0.011)	(0.611)	(0.629)
Real WTI price, yearly average (-8)	-23.84	34.37	72.92**	-168.2	1.964	10.27	-1.023	30.73***
	(0.604)	(0.598)	(0.032)	(0.280)	(0.890)	(0.203)	(0.976)	(0.005)
Real WTI price, yearly average (-9)	-20.21	12.24	4.559	-89.63	39.74**	-5.945	-42.45**	12.54
	(0.471)	(0.886)	(0.917)	(0.274)	(0.039)	(0.313)	(0.017)	(0.175)
Std. dev. (log price returns), quarterly average	783.0	12707.9***	1870.5	-29338.3**	1955.5	-403.5	-1468.6	339.8
	(0.679)	(0.007)	(0.637)	(0.035)	(0.118)	(0.629)	(0.604)	(0.842)
Std. dev. (log price returns), quarterly average (-1)	-1089.0	9212.3**	-3565.7	-30572.8**	-68.47	-529.7	-2018.4	1383.6
	(0.713)	(0.012)	(0.311)	(0.017)	(0.942)	(0.731)	(0.142)	(0.370)
Std. dev. (log price returns), quarterly average (-2)	-2555.5	5762.6	-1769.0	-20783.8	595.5	281.9	-1669.4	2340.7
	(0.682)	(0.386)	(0.512)	(0.380)	(0.777)	(0.839)	(0.330)	(0.257)
Std. dev. (log price returns), quarterly average (-3)	944.8	1955.5	-5636.8	-39457.5*	1361.4	-1271.6	-3172.5	-64.29
	(0.857)	(0.748)	(0.456)	(0.096)	(0.510)	(0.467)	(0.269)	(0.980)
Std. dev. (log price returns), yearly average (-1)	-5371.3	-4061.8	8283.8	-54445.3	5094.9	-64.49	-6210.9	1939.9
	(0.826)	(0.843)	(0.807)	(0.415)	(0.559)	(0.987)	(0.625)	(0.717)
Std. dev. (log price returns), yearly average (-2)	-4339.0	15954.4	7381.0	-21645.9	-1923.3	-3678.4**	1991.4	2594.7
	(0.858)	(0.462)	(0.577)	(0.358)	(0.831)	(0.044)	(0.693)	(0.519)
Std. dev. (log price returns), yearly average (-3)	-1369.2	22639.5	-32129.7***	-125878.2***	6637.0	-7656.3***	-2976.4	-2510.1
	(0.940)	(0.472)	(0.000)	(0.000)	(0.578)	(0.002)	(0.497)	(0.665)
Std. dev. (log price returns), yearly average (-4)	-6587.4	56011.4***	-4073.1	-105285.9***	12025.6*	437.0	-493.8	6338.3
	(0.716)	(0.000)	(0.701)	(0.006)	(0.055)	(0.924)	(0.947)	(0.185)
Std. dev. (log price returns), yearly average (-5)	-10943.8	45704.6***	-1921.7	-79307.2***	4586.2	2756.6	870.2	-1099.7
	(0.574)	(0.000)	(0.925)	(0.003)	(0.644)	(0.561)	(0.877)	(0.862)
Std. dev. (log price returns), yearly average (-6)	-5005.0	40151.9***	16694.8	-80911.3***	6351.8	1765.2	7888.9**	7989.3*
	(0.706)	(0.000)	(0.441)	(0.000)	(0.510)	(0.560)	(0.018)	(0.081)
Std. dev. (log price returns), yearly average (-7)	-4445.1	29229.8*	33174.1**	-101743.1***	9322.9	-207.6	2087.5	11842.0***
	(0.668)	(0.087)	(0.017)	(0.002)	(0.321)	(0.913)	(0.507)	(0.003)
Std. dev. (log price returns), yearly average (-8)	-16241.9**	35996.2***	26486.5*	-24464.9	3348.1	2752.8	5075.2**	4194.6
	(0.017)	(0.005)	(0.086)	(0.489)	(0.604)	(0.366)	(0.030)	(0.222)
Std. dev. (log price returns), yearly average (-9)	-2444.7	4469.4	-3550.4	2176.3	5549.3	2046.0**	-749.3	-4890.8
	(0.777)	(0.676)	(0.664)	(0.925)	(0.326)	(0.038)	(0.798)	(0.182)
Real activity, quarterly average	-1.453	11.29**	5.370	29.12**	-0.124	2.789***	1.805	-0.713
	(0.374)	(0.045)	(0.270)	(0.037)	(0.915)	(0.000)	(0.129)	(0.565)
Real activity, quarterly average (-1)	-8.798***	2.800	-3.339**	0.815	1.629*	-1.086	-1.343*	-1.357
	(0.000)	(0.449)	(0.041)	(0.915)	(0.081)	(0.278)	(0.074)	(0.369)
Real activity, quarterly average (-2)	5.077*	9.692***	-8.756***	0.237	-3.993***	-0.320	1.874	-3.227***
	(0.069)	(0.001)	(0.000)	(0.969)	(0.000)	(0.737)	(0.236)	(0.000)

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Table 6.3: Country Level Regressions – OECD and non-OECD/non-OPEC – continued from previous page

	(1) Canada	(2) Norway	(3) United Kingdom	(4) United States	(5) Brazil	(6) Indonesia	(7) Russia	(8) China
Real activity, quarterly average (-3)	-4.462	6.998	-2.226	1.253	-3.898***	-0.412	3.910**	-3.706***
	(0.199)	(0.277)	(0.268)	(0.876)	(0.000)	(0.203)	(0.036)	(0.001)
Real activity, yearly average (-1)	0.279	-7.911*	-3.429	51.95***	2.793	1.439	-1.748	-3.774***
	(0.958)	(0.065)	(0.460)	(0.000)	(0.185)	(0.294)	(0.291)	(0.006)
Real activity, yearly average (-2)	-2.098	23.11***	-4.452	-16.49	-6.298***	-2.141**	2.850*	-5.339**
	(0.645)	(0.001)	(0.397)	(0.499)	(0.000)	(0.041)	(0.093)	(0.036)
Real activity, yearly average (-3)	-1.561	-7.904	-3.231	-5.701	3.928	0.521	-3.681	-4.113*
	(0.762)	(0.246)	(0.416)	(0.773)	(0.120)	(0.315)	(0.156)	(0.075)
Real activity, yearly average (-4)	0.974	18.92***	7.420	-27.40*	0.961	1.284	4.372	2.363
	(0.809)	(0.003)	(0.137)	(0.084)	(0.582)	(0.117)	(0.255)	(0.245)
Real activity, yearly average (-5)	-10.27	27.71***	-15.75**	-19.45	-0.00792	1.411	5.924*	-7.911***
	(0.271)	(0.001)	(0.014)	(0.231)	(0.998)	(0.342)	(0.071)	(0.004)
Real activity, yearly average (-6)	-6.063	37.86***	-14.06	17.34	3.311	1.406	0.930	-3.137
	(0.452)	(0.008)	(0.222)	(0.531)	(0.504)	(0.296)	(0.836)	(0.533)
Real activity, yearly average (-7)	-1.371	-6.301	-11.50	16.77	3.201	0.350	-8.488**	-7.654**
	(0.886)	(0.690)	(0.277)	(0.460)	(0.580)	(0.572)	(0.048)	(0.024)
Real activity, yearly average (-8)	-4.290	15.74**	-6.868	71.53***	-2.110	3.837***	2.617	-6.988***
	(0.349)	(0.016)	(0.152)	(0.000)	(0.306)	(0.001)	(0.697)	(0.001)
Real activity, yearly average (-9)	0.981	13.25**	-21.73*	17.77	-0.543	-0.366	-4.075	-7.988*
	(0.897)	(0.011)	(0.062)	(0.193)	(0.877)	(0.794)	(0.324)	(0.072)
Rig count, quarterly average (−1)	-0.712	6.298	-19.40*	-1.617	4.053	0.649	n/a	n/a
	(0.217)	(0.544)	(0.089)	(0.513)	(0.643)	(0.803)	n/a	n/a
Rig count, quarterly average (-2)	0.169	39.12*	-17.35	-2.444	2.431	5.010***	n/a	n/a
	(0.811)	(0.080)	(0.218)	(0.289)	(0.868)	(0.010)	n/a	n/a
Rig count, quarterly average (−3)	-0.735	64.41	-30.09	0.744	10.16	4.016*	n/a	n/a
	(0.371)	(0.186)	(0.164)	(0.773)	(0.607)	(0.079)	n/a	n/a
Rig count, yearly average (−1)	-0.573	345.3**	-163.4**	4.714	-16.63	18.92	n/a	n/a
	(0.937)	(0.045)	(0.027)	(0.594)	(0.839)	(0.194)	n/a	n/a
Rig count, yearly average (−2)	0.674	343.2***	-151.9***	38.40***	-26.23	16.68	n/a	n/a
	(0.836)	(0.000)	(0.000)	(0.001)	(0.590)	(0.164)	n/a	n/a
Rig count, yearly average (-3)	4.205	308.2***	-194.3***	47.04***	-25.37	10.17	n/a	n/a
	(0.334)	(0.001)	(0.000)	(0.000)	(0.630)	(0.345)	n/a	n/a
Rig count, yearly average (−4)	5.918***	311.7***	-84.18	45.82***	-41.46	5.566	n/a	n/a
	(0.003)	(0.002)	(0.165)	(0.003)	(0.328)	(0.489)	n/a	n/a
Rig count, yearly average (−5)	0.602	261.9***	41.02	58.62**	-27.90	-2.738	n/a	n/a
	(0.846)	(0.003)	(0.554)	(0.020)	(0.543)	(0.809)	n/a	n/a
Rig count, yearly average (−6)	-1.020	269.5***	78.07	44.01	-2.903	-1.701	n/a	n/a
	(0.845)	(0.001)	(0.235)	(0.112)	(0.937)	(0.813)	n/a	n/a
Rig count, yearly average (−7)	-1.059	111.1	60.31	24.03**	8.579	0.361	n/a	n/a
	(0.664)	(0.264)	(0.419)	(0.047)	(0.828)	(0.952)	n/a	n/a
Rig count, yearly average (−8)	-0.587	25.32	24.50	6.949	-26.71	-3.701	n/a	n/a
	(0.851)	(0.816)	(0.723)	(0.679)	(0.212)	(0.550)	n/a	n/a
Rig count, yearly average (−9)	-0.599	123.6	-5.344	-6.205	-13.30	-0.762	n/a	n/a
	(0.796)	(0.215)	(0.867)	(0.331)	(0.610)	(0.856)	n/a	n/a
SDR/U.S. dollar exchange rate, quarterly average	-5090.4	5766.2**	-914.2	420.4	5435.7***	-82.88	-1452.5	1547.1
	(0.180)	(0.013)	(0.826)	(0.969)	(0.001)	(0.850)	(0.475)	(0.111)
SDR/U.S. dollar exchange rate, quarterly average (-1)	-5112.8	7673.2*	-7378.2	3415.7	1689.2	1463.3	-1648.4	-24.86
	(0.329)	(0.089)	(0.353)	(0.752)	(0.410)	(0.175)	(0.706)	(0.982)
SDR/U.S. dollar exchange rate, quarterly average (-2)	-6945.4*	13443.5**	1275.1	20454.6	-632.4	1591.0	3417.5	-1329.6
	(0.077)	(0.016)	(0.866)	(0.295)	(0.727)	(0.116)	(0.363)	(0.606)
SDR/U.S. dollar exchange rate, quarterly average (-3)	-7261.3	12695.4	14621.1	18780.8	-2464.3	2108.5	6413.4	-811.3
	(0.145)	(0.314)	(0.234)	(0.335)	(0.417)	(0.165)	(0.120)	(0.846)
SDR/U.S. dollar exchange rate, yearly average (-1)	-30582.1	73462.8	41152.3	51252.8	-13291.0	12639.7	41322.0**	-9953.7
	(0.305)	(0.181)	(0.378)	(0.598)	(0.294)	(0.210)	(0.014)	(0.622)
SDR/U.S. dollar exchange rate, yearly average (-2)	-39237.3	85975.7	41865.0	72701.3	-19161.7	14395.2*	39367.3**	-9587.2
	(0.181)	(0.337)	(0.506)	(0.430)	(0.251)	(0.081)	(0.016)	(0.641)
SDR/U.S. dollar exchange rate, yearly average (-3)	-24460.2	68218.7	58350.9	47580.4	-7353.1	6664.3	38596.0**	-13747.2
	(0.471)	(0.129)	(0.259)	(0.659)	(0.499)	(0.179)	(0.029)	(0.480)
SDR/U.S. dollar exchange rate, yearly average (-4)	-31372.7	38926.8	58636.5	49754.4	-2811.4	8936.8**	25386.0*	-7201.2
	(0.356)	(0.243)	(0.184)	(0.597)	(0.697)	(0.018)	(0.070)	(0.621)
SDR/U.S. dollar exchange rate, yearly average (-5)	-12055.8	53791.2**	32859.7	37485.8	626.1	11015.2***	29818.0**	-16393.8*
	(0.594)	(0.040)	(0.318)	(0.639)	(0.918)	(0.000)	(0.031)	(0.064)

Continued on next page

Table 6.3: Country Level Regressions – OECD and non-OECD/non-OPEC – continued from previous page

	(1) Canada	(2) Norway	(3) United Kingdom	(4) United States	(5) Brazil	(6) Indonesia	(7) Russia	(8) China
SDR/U.S. dollar exchange rate, yearly average (-6)	-9059.9	27030.9	22968.7	6064.7	6098.0	8477.7***	26241.4*	-11773.4*
	(0.710)	(0.308)	(0.212)	(0.929)	(0.441)	(0.003)	(0.051)	(0.062)
SDR/U.S. dollar exchange rate, yearly average (-7)	-24791.9	20336.7	18495.7	34928.9	-2696.1	9312.9***	27916.6**	3114.6
	(0.178)	(0.519)	(0.261)	(0.564)	(0.679)	(0.000)	(0.026)	(0.651)
SDR/U.S. dollar exchange rate, yearly average (-8)	-27044.5**	42326.0*	19325.3	22556.8	573.5	7395.7***	16556.9***	259.4
	(0.011)	(0.081)	(0.107)	(0.578)	(0.897)	(0.001)	(0.000)	(0.956)
SDR/U.S. dollar exchange rate, yearly average (-9)	-15726.2***	9550.3	3343.4	28625.5	6166.7*	4064.8**	6542.6	2351.7
	(0.003)	(0.523)	(0.555)	(0.340)	(0.054)	(0.023)	(0.105)	(0.473)
Institutional Quality	-355.8	-3450.3***	157.9	-1166.9	576.2*	153.7	91.05	670.0
	(0.509)	(0.000)	(0.682)	(0.347)	(0.058)	(0.225)	(0.584)	(0.268)
February	88.86***	113.3***	58.80***	-41.00	6.138	-8.276	57.66***	-89.99**
	(0.000)	(0.010)	(0.003)	(0.799)	(0.517)	(0.111)	(0.008)	(0.015)
March	142.1***	-10.87	63.92*	-115.1	-18.99	-8.866	48.01***	-102.4***
	(0.005)	(0.786)	(0.079)	(0.490)	(0.256)	(0.140)	(0.000)	(0.000)
April	235.9*	56.15	39.32	-241.1	-1.168	-14.28***	42.64*	-110.5***
	(0.054)	(0.359)	(0.425)	(0.247)	(0.930)	(0.006)	(0.064)	(0.000)
May	197.2	-65.18	-54.96	-300.2	-5.371	-20.72***	62.56***	-73.11***
	(0.121)	(0.152)	(0.556)	(0.155)	(0.866)	(0.010)	(0.000)	(0.000)
June	152.5*	-91.19	77.05	-291.1	17.41	-0.172	121.8***	-78.37***
	(0.055)	(0.475)	(0.497)	(0.137)	(0.633)	(0.988)	(0.000)	(0.010)
July	140.6***	287.4***	239.4***	-243.1	27.27	-3.165	78.92*	-118.9***
	(0.006)	(0.000)	(0.000)	(0.170)	(0.430)	(0.766)	(0.075)	(0.000)
August	97.84**	-293.7***	95.01*	-38.55	25.41	-11.61	59.58***	-77.89**
	(0.029)	(0.000)	(0.064)	(0.824)	(0.496)	(0.543)	(0.000)	(0.039)
September	143.3***	-32.01	362.1***	-203.1	63.28*	3.788	55.90***	-78.03***
	(0.003)	(0.598)	(0.000)	(0.404)	(0.074)	(0.620)	(0.002)	(0.005)
October	301.5***	100.2*	295.8***	286.5***	34.18	1.004	17.29	-64.30*
	(0.000)	(0.050)	(0.000)	(0.000)	(0.200)	(0.925)	(0.176)	(0.053)
November	280.7***	76.67	130.1***	375.4***	68.41*	-18.17*	-5.665	-79.76***
	(0.001)	(0.181)	(0.000)	(0.003)	(0.071)	(0.063)	(0.785)	(0.000)
December	131.3**	71.05	110.5**	207.7***	76.14***	-19.01*	-4.959	-143.1***
	(0.011)	(0.163)	(0.011)	(0.006)	(0.001)	(0.063)	(0.634)	(0.002)
Constant	1248.6	1725.9	-2125.4*	18149.5***	-1191.1	249.3	219.7	-850.0
	(0.549)	(0.531)	(0.090)	(0.000)	(0.371)	(0.652)	(0.698)	(0.305)
Observations	156	156	156	156	156	156	156	156
Mean share in group production	12.9%	13.5%	10.5%	39.8%	6.9%	5.7%	32.4%	14.6%

*, **, *** indicate significance at the 10%, 5% and 1% level, respectively; p-values in parentheses.