Preliminary

Integration of the Global Emissions Trading Markets

Bruce Mizrach*
Rutgers University

September 2009

Abstract

Emissions markets have emerged in Europe, the U.S., and around the globe. This paper analyzes the market structure of trading in these instruments. Within the EU ETS, I find, after controlling for a structural break in April 2006, that spot markets in Europe are cointegrated. The futures markets are more weakly linked, and even many parts of the futures curve evolve nearly independently. CERs are also not yet integrated with EUA prices. The U.S. Acid Rain program, the oldest cap and trade scheme, auctions SO2 allowances annually, and I find the exchange traded futures efficiently predict the auction outcomes. The voluntary markets in the U.S. are cointegrated with EUA prices, and I estimate an implicit Kyoto adoption probability of 13.55%.

`Keywords`: carbon; emission allowances; cap and trade; cointegration;

`JEL Classification`: G13, G32, E44;

* Department of Economics, Rutgers University, e-mail: mizrach@econ.rutgers.edu, (732) 932-7363 (voice) and (732) 932-7416 (fax). http://snde.rutgers.edu. I would like to thank the European Climate Exchange, the London Energy Brokers Association, and Nordpool for providing data.

1. Introduction

There are now are large number of mechanisms for trading greenhouse gases. The largest is the European Union Emissions Trading Scheme (EU ETS), a cap and trade system that emerged out of the Kyoto Protocol. I estimate that 2,549 million tonnes of CO2 equivalent (mtCO2e) were traded in 2008 at the five most active exchanges in the EU ETS, with about 46% of that screen based. The essential unit traded is a European Union Allowance (EUA) which legally offsets the emission quotas.

Kyoto also created a Clean Development Mechanism (CDM) which provides incentives for developing countries to lower their carbon emissions. These projects, the majority of which are in China and India, are in principal substitutable for emissions in the EU ETS. The industry publication *New Carbon Finance* estimates that 381 mtCO2e in primary CDM was traded in 2008, with a market value of $5.8 billion. They estimate that about 79% of the trades were over-the-counter (OTC).

CDM credits trade in secondary markets as Certified Emission Reductions (CERs). The secondary market at the five major exchanges transacted a total volume of 618 mtCO2e. 30% of this volume was screen based.

The European Climate Exchange (ECX) has emerged as the major trading venue. In 2008, it handled 70.4% of the screen based EU ETS futures trading and 91.4% of the screen exchanged CER futures volume. There is an active EUA spot market, dominated currently by Bluenext, with a screen exchanged market share of 99.5%. Futures volume is more than ten times spot volume though, and the ECX plays a leading role in prime formation.

My statistical analysis centers on the fragmentation of these markets. I perform tests for cointegration, between the same instruments on different exchanges, and different futures maturities on the same exchange. This analysis is complicated by a structural break in the CDM mechanism in April 2006.

I find that the spot markets on Bluenext and Nordpool are cointegrated, but the futures markets still appears to be fragmented. Futures contracts, even in 2008, don't all move according to a single common trend.

A lingering policy question is whether the EUA and CER credits are equivalent. This has been hampered by issues regarding certification of projects in the developing world, and whether CERs would have value beyond 2012.

Progress has been made on the certification front with a more transparent registry system that began in October 2008, but my analysis indicates that CER and EUA prices are still not cointegrated.

Carbon is traded in a variety of forms around the world. There are voluntary and regional arrangements in the U.S. and smaller markets in Asia, Australia, and Latin America. I explore screen, OTC and auction markets in these areas, and again test for their integration with carbon prices in the EU ETS.

The U.S. Acid Rain program is the oldest cap and trade system, and it has been conducting annual emissions auction since 1993. I find that the forward prices of allowances are not rational predictors of the future spot auction prices, but the exchange traded SO2 futures in Chicago do predict the auction outcomes.

I do find a cointegrating relationship between the Chicago Climate Exchange voluntary reduction CFI futures index and the ECX EUA futures. These imply a risk neutral probability of 13.55% that the U.S. will adopt a system similar to the EU ETS.

Section 2 describes the Kyoto cap and trade scheme. Section 3 looks at the supply of CDM/JI projects. Section 4 begins with a description of the market architecture. Section 5 discusses recent trends in emission prices and relevant policy changes since Kyoto. Section 6 provides the development of the cointegration methods. Section 7 tests for cointegration across exchanges and maturities within the EU ETS. Section 8 examines spreads between secondary market CER prices and EUAs. Section 9 looks at the recent developments in the U.S., and Section 10 looks at markets outside North American and Europe. Section 11 concludes.

2. Kyoto Cap and Trade System

I cover first developments in Europe and North America that followed the adoption of the Kyoto Protocol. Figure 1 summarizes the current state of global Kyoto adoption.

[Insert Figure 1: Global Adoption and Implementation of Kyoto Treaty]

In Section 9, I examine developments in the U.S., some of which preceded Kyoto chronologically.

2.1 European Union ETS

In December 1997, the United Nations Framework Convention on Climate Change (UNFCC)

adopted the Kyoto Protocol. The European Union and its member states ratified the treaty on May 31, 2002. Directive 2003/87/EC, which entered into force on October 25, 2003, then established a scheme for emission trading within the European Community to "promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner." The goal was to decrease emissions 8% from their 1990 levels by 2012.

The scheme was based on the allocation of allowances to emit one tonne of carbon dioxide equivalent[1] during a specified period. This basic unit was called a European Union Allowance (EUA). 2003/87/EC called upon member states to create national plans for distributing the allowances. By December 2004, the European Commission had approved plans for all the major European economies[2] except Italy which was approved in May 2005.

The first phase was concerned only with CO2 and was limited to large plants in key industrial sectors like power generation, oil refining, steel, and pulp and paper. The national plans covered, by 2006, more than $10,000$ installations,[3] responsible for more than 45% of European carbon dioxide emissions.[4]

Implementation of this "cap and trade" system required a standardized system of registries. Commission Regulation (EC) No 2216/2004, passed on December 21, 2004, created a Community Independent Transaction Log (CITL) for this purpose.

Russia ratified the treaty in November 2004, pushing the emissions coverage over the threshold 55% needed for implementation, and Kyoto became legally binding on February 16, 2005. Exchange trading in Europe began not long after.

The European Union Greenhouse Gas Emission Trading Scheme (EU ETS) began operations in January 2005. The scheme began with a "warm-up" Phase I from 2005-2007, to be followed by successive 5-year periods. Phase II, from 2008-2012, coincides with the Kyoto compliance period.

2.2 North America

President Clinton had signed the Kyoto treaty in 1998, but the Senate never ratified it. The U.S.

[1] A tonne of "carbon dioxide equivalent" means one metric tonne of carbon dioxide (CO2) or an amount of any other greenhouse gas with an equivalent global-warming potential. Annex II of the 2003 Directive contains the conversion factors.

[2] Here are the dates of Commission approval. July 2004: Austria, Denmark, Germany, Ireland, the Netherlands, Slovenia, Sweden, and the UK. October 2004: Belgium, Estonia, Finland, France, Latvia, Luxembourg, Portugal, and the Slovak Republic. December 2004: Cyprus, Hungary, Lithuania, Malta and Spain. In 2005, the approve Poland (March), the Czech Republic (April), Italy (May), and Greece (June).

[3] See European Environmental Association (2006) p. 14.

[4] Betz and Misato (2006).

rejected the Kyoto treaty in March 2001, early in the Bush administration. At present, there are a number of regional and voluntary initiatives. The House also passed on June 26, 2009, the Waxman-Markey bill to implement a cap and trade system in the U.S. The legislation still awaits Senate approval as of this writing.

Canada also signed the treaty in 1998, but they were slow to pass enabling legislation. In April 2007, they produced a framework for mandatory greenhouse gas reductions called "The Action Plan to Reduce Greenhouse Gases and Air Pollution." Further details were provided in the "Turning the Corner" plan and mandatory targets are scheduled to begin on January 1, 2010. Limited exchange trading of Canadian permits has already begun.

3. Kyoto Demand and Supply

Demand for emission credits is determined by the aggressiveness of the National Allocation Plan. The Kyoto protocol has three avenues for creating supply of emission credits.

3.1 AAU

A potentially fatal loophole in the EU ETS are the Assigned Amount Units (AAUs). These are gaps between a country's stated emission goals, and their actual output. The majority of these credits come from transition countries, especially Russia and the Ukraine. Many have argued that these credits have not been legitimately earned because many of the carbon emitting factories would have been eliminated anyway. There is a similar concern about Joint Implementation projects which we discuss below.

Article 17 of Kyoto allows for trading excess credits, but the first trades did not take place until the fall of 2008. According to Point Carbon, 75 mtCO2e traded in the first half of 2009, with a value of €750m, up 74% from 43 mtCO2e with market value €330m in the second half of 2008.

3.2 Clean Development Mechanism (CDM)

Another potential achilles heel for the Kyoto Protocols was their treatment of developing countries. Particularly as India and China's growth accelerated in the late 1990s, incentives to lower emissions outside of the industrialized (Annex B) countries became vital. Article 12 created The Clean Development Mechanism (CDM) which provides certified emission reduction (CER) credits towards Kyoto targets for projects in developing nations. These credits are now refererred to as primary

CERs (pCER), and they trade at a discount to the second market sCERs. The UNFCC maintains a database of projects approved by the CDM executive board.

The first project approved was the Brazil NovaGerar Landfill Gas to Energy Project in November 2004. This was a large waste handling and disposal facility financed by the Netherlands which receives 0.670 mtCO2e per annum of credits. As of this writing, September 2009, $1,822$ projects have been approved[5] by the CDM executive board which produce an annual average of 318.1 million CERs. The distribution by originating country is in Figure 4.

[Insert Figure 2: Sources of CDM Projects]

India has more than 300 CDM projects which have produced more than 34 million CERs. Schwank and Guyer (2009) report that China has more than 286 CDM projects as November 2008. Brazil and Mexico round out the top four. The pipeline of projects exceeds the existing supply. China is expected[6] to produce 59% of the annual average CERs.

[Insert Table 1: Trading of CDM/JI projects]

The IETA (2007,2008) estimated that 382 mtCO2e of Certified Emissions Reductions (CERs), were transacted at a value of $2.894 billion in 2005, and 537 mtCO2e with a market value $5.804 billion in 2006. Less than 1% of these transactions, 35 mtCO2e, in 2005-6, were conducted in the secondary market though. There were 552 mtCO2e of primary CDM transactions in 2007, and secondary market volume rose to 240 mtCO2e to 30% of the total.

Momentum slowed in the new project market for the first time in 2008. Primary CDM projects fell to 389 mtCO2e. The secondary market picked up the slack though, with volumes rising to $1,072$.

The basic question from a market integration perspective is whether the offsets, officially 1:1, trade at similar prices in the EU ETS. I will consider this question in the empirical analysis below.

3.3 Joint Implementation

Article 6 of the Kyoto Protocol, allows Annex B countries to earn emission reduction units (ERUs) from joint projects in other Annex B countries. This program, called Joint Implementation (JI), has, in practice, consisted almost entirely of projects in former Eastern Bloc countries. To issue ERUs the host country must cancel an equivalent number of AAUs from its national registry.

[5] The process of approval seems to be getting tougher. In September 2009, the UN only reistered 3 of 31 projects under review.

[6] http://cdm.unfccc.int/Statistics/Registration/AmountOfReductRegisteredProjPieChart.html

[Insert Table 2: Host region/country for JI]

As can be seen in Table 2, 120 of the 185 approved projects have been in Russia and the Ukraine. Another 54 are in former Eastern Bloc countries.

In January 2008, the EU commission restricted CDM/JI usage to 5.6% of the national allocation from 2008-2020. The CDM registry announced[7] the connection of EU registries and CITL to the ITL on October 22, 2008. This moved CERs from temporary holding accounts into the national registry. I will look for a CER supply shock on both of these dates.

3.4 Net Demand

With the global recession reducing industrial production, there has been a significant decline in Annex B demand for carbon credits. Røine and Tvinnereim (2009) estimated in March that Annex B countries have a net Kyoto deficit of 544 mtCO2e, down 39% from September 2008. The largest demand will come from Japan, with a deficit of 220 mtCO2e, Spain (89 mtCO2e) and Austria (52 mtCO2e). Meanwhile, the supply from CDM and JI initiatives has, they note, fallen by 6% in 2009, as credit conditions have delayed many projects. Point Carbon estimates this will result in a net increase of 20% in carbon trading, to 5,900 mtCO2e, in 2009.

Emissions permit trading takes place at registered carbon exchanges and through over-the-counter (OTC) transactions. I discuss each in turn.

4. Market Architecture-Europe and N. America

The vast majority of trading in the emissions allowance market consists of spot, futures and options trading in EUA and CERs.

[Insert Figure 3: Market Overview]

The largest trading venue is the European Climate Exchange (ECX). EUA spot and derivatives contracts are listed on 9 other exchanges in North America and Europe: Bluenext; Chicago Climate Exchange; Climex; The European Energy Exchange/Eurex (EEX); Energy Exchange Austria (EXAA); Green Exchange/NYMEX; Gestore del Mercato Elettrico (GME/IPEX); and Montreal Climate Exchange (MCeX); and Nordpool.

There are 8 major OTC brokers: CantorCO2e; Evolution Markets; GFI Group; ICAP; MF

[7] See http://cdm.unfccc.int/ Registry/index.html.

Global Energy; Spectron; TFS Energy; Tullet Prebon;

The contracts they trade are summarized in Table 3.

[Insert Table 3: Overview of Contracts Traded]

The EU ETS is unusual in that the most liquid instruments are futures contracts. The ECX dominates the trading of derivative securities, leaving the spot market to Bluenext and Nordpool.

Trading in CERs only took off in June 2007 when Nordpool introduced a forward contract. The ECX responded in 2008, offering futures (March 14) and options (May 16). Bluenext began to trade a spot instrument in August 2008. It faces minimal competition at the moment from Climex and Nordpool. The Chicago Climate Exchange, the U.S. relative of the ECX, also offers CER trading.

I turn first to the exchanges and then to the OTC brokers.

4.1 Exchanges

There are 9 exchanges. I begin with the largest, the European Climate Exchange, and then describe the rest alphabetically.

4.1.1 European Climate Exchange

The European Climate Exchange[8] (ECX) is part of Chicago Environmental plc, the London based parent of both the ECX and the Chicago Climate Exchange. It has traded on the Alternative Investment Market (AIM) of the London Stock Exchange since September 2003 under the symbol *CLE*. Its market capitalization based on the December 21, 2008 prices of 845p is £391.10mn.

In March 2005, the European Emissions Trading System futures contracts are launched on ECX under a revenue sharing agreement with the ICE Futures in London. They trade futures and options. Contract specifications are in Table ECX.

[Insert Table 4: ECX Contracts]

This is the largest exchange, dominating screen based trading in both EUAs and CERs.

4.1.2 BlueNext

BlueNext[9], a joint venture of NYSE Euronext (60%) and Caisse des Depot (40%), a French govern-

[8] http://www.ecx.eu
[9] http://www.bluenext.eu/

ment financial institution, launched on December 21, 2007. It builds upon the Powernext carbon business, acquired by Euronext when they sold their stake in Powernext. Powernext had been a market leader in spot EUA trading since its debut in June 2005,

BlueNext continues to hold a commanding share in exchange trading of spot EUA. It added spot CER trading on August 12, 2008.

[Insert Table 5: BlueNext Contracts]

BlueNext also trades EUA and CER futures. Delivery is made in the made in the Swiss registry.

BlueNext was in the headlines in June 2009 over a scandal involving value added taxes. A surge of trading volume in May and early June led to suspicions of value added tax (VAT) fraud . BlueNext halted trading, first for "technical reasons" and then explicitly, from from June 4th to 9th, and re-opened on the 10th. Rather than delving into what appears to have been a long-standing failure to pay the VAT, France and the Netherlands, and then the U.K. chose to exempt carbon transactions from the tax.

4.1.3 Chicago Climate Exchange

The Chicago Climate Exchange[10] (CCX), a sister company to the much larger ECX, operates a cap and trade system for the voluntary emissions reduction (VER) market in North America. CCX emitting members make legally binding commitments to meet emission targets. They range from electric power generators like Manitoba Hydro, to Abbott Pharmaceutical, to the state of New Mexico.

If members are able to reduce their emissions below the targets, they generate Exchange Allowances to bank or sell to those who emit above the them. Similar to CERs, there are also Exchange Offsets which are generated by approved offset projects. DuPont Chemical for example has an approved offset project for hydroflourocarbon destruction in Arizona. CCX has arranged a verification procedure administered by the Financial Industry Regulatory Authority (FINRA).

The allowances traded on CCX are Carbon Financial Instrument (CFI) contracts, each of which represents 100 mtCO2e. CFI contracts are comprised of Exchange Allowances and Exchange Offsets.

[10] http://www.chicagoclimatex.com

[Insert Table 6: CCX Contracts]

Spot CFI contracts trade on the CCX, and futures and options trade on Chicago Climate Futures Exchange (CCFE), a wholly owned subsidiary of the CCX. CCFE is regulated by the CFTC, with market surveillance from the National Futures Association, and clearing through the The Clearing Corporation. The CCX also trades a number of other GHG contracts like nitrogen, sulfur, and also weather related derivatives. The exchange began offering CER futures trading in August 2007.

4.1.4 Climex

Climex is a Dutch venture[11] that originally offered trading in nitrogen oxides (NOx) for the local market.[12] In March 2005, the CO2 market opened up, and it now offers spot trading in EUAs and CERs, and conducts, in collaboration with the Asia Carbon Exchange (ACX-Change), regular auctions in CER and VER.

Trading on Climex is anonymous: buyers and sellers are not disclosed to each other. APX, a California based company which is a registry provider and administrator, originate, serves as the clearinghouse for spot trading, taking on all the counterparty risk.

4.1.5 EEX/Eurex

The European Energy Exchange[13] (EEX), founded in 2002 from the merger of LPX Leipzig Power Exchange and European Power Exchange, provides spot and derivatives markets for power, natural gas and emission rights. Eurex made an initial investment in December 2007, and then purchased Nordpool's stake in February 2008, raising their total ownership to 34.7%, greatly expanding the distribution of pricing information through the use of the Eurex system.

[Insert Table 7: EEX Contracts]

EEX/Eurex offers EUA (since 05-Dec-2007) and CER (26-Mar-2008) futures and options (14-Apr-2008) on EUA futures. The EEX operates an established clearing house specializing in energy markets: the European Commodity Clearinghouse (ECC), which is a fully owned subsidiary of

[11] http://www.climex.com. The platform was originally called New Values. It was founded in 2003 by Axel Posthumus and Tames Rietdijk, with shareholders Rabobank and TenneT.

[12] The Dutch Environmental Management Act (EMA) provides a framework of emissions trading of both NOx and CO2. The NOx system is based on relative caps that are tied to the energy usage of the facility. The legislation defines a *performance standard rate* based on the number of grams of NOx per joule.

[13] http://www.eurexchange.com

EEX.

4.1.6 EXAA

The Energy Exchange Austria[14] (EXAA), which opened in March 2002 and is based in Vienna, is a small energy and emissions trading market that began spot trading in EUAs in June 2005. EXAA relies on a novel combination of a closed order book auction with two market makers, EGL and since June 2006,

More details on the auction procedure are described in Table 6.

[Insert Table 8: EXAA Auction]

I analyze whether auctions at EXAA and in the U.S. produce unbiased outcomes below.

4.1.7 Green Exchange

The NYMEX Green Exchange[15], subsidiary of NYMEX Holdings Inc., is now part of the Chicago Mercantile Exchange (CME) Group following the CME's acquisition of NYMEX in August of 2008. They trade options and futures on EUAs and CERs. It also has a set of futures and option contracts for NOx and SOx for the North American market, including allowances for the RGGI. Trading can be done on the NYMEX trading floor, or through the CME Globex electronic platform, with clearing through ClearPort. There is physical settlement through the UK registry. NYMEX added in-delivery month contracts in July 2009 for September 2009.

[Insert Table 9: Green Exchange Contracts]

Trading volumes remain quite modest. Open interest on all EUA futures totaled less than 1,500 contracts as of September 16, 2009, and CERs were only slightly more popular with an open interest in the futures just above 4,000 contracts.

I analyze the implicit transfer prices of EUA and RGGI and try to infer an implicit probability of the U.S. joining the Kyoto system.

4.1.8 GME

Many of the exchanges that trade emissions began as wholesale electricity markets, and GME[16]

[14] http://en.exaa.at/
[15] http://nymex.greenfutures.com
[16] http://www.mercatoelettrico.org

(Gestore del Mercato Elettrico) opened the first wholesale power market, often called the Italian Power Exchange (IPEX) in March 2004. GME's Emissions Trading Market provides Italian and foreign operators that have a holding account in the National Registry[17] or in other European Registries, an opportunity to buy and sell emission permits "under certain and predefined rules: (i) competition between operators; (ii) anonymity of trades; (iii) transparency of transactions; (iv) efficiency in price formation; (v) security of transactions."

GME's electronic platform manages spot-delivery trades of both Phase I and Phase II EUAs. "The platform is also designed for the trading of credits accrued from CDM (Clean Development Mechanism) and JI (Joint Implementation) projects, i.e. CERs (Certified Emission Reductions) and ERUs (Emission Reduction Units), respectively, as per Directive 2004/101/EC (or Linking Directive)."

4.1.9 Montreal Climate Exchange

In April 2007, Canada, in accordance with their requirements under the Kyoto treaty, adopted a new regulatory framework for greenhouse gases. The framework mandated 18% reductions in emissions intensity below 2006 levels by 2010, with 2% continuous improvements thereafter.

The Montreal Climate Exchange (MCeX), a joint venture of the Montreal Exchange Inc. and the Chicago Climate Exchange (CCX)[18], began trading claims on Canadian carbon dioxide equivalents. The contracts trade on the Montreal Exchange electronic SOLA platform and clear through the Canadian Derivatives Clearing Corporation. The market is as of September 2009 very thin, with open interest of only 263 contracts on four expiries out to 2012.

4.1.10 Nord Pool

The Nord Pool group[19] was started by the Nordic electricity grid companies and provides spot (Nord Pool Spot AS) and derivatives trading (Nord Pool ASA). Nord Pool ASA operates the world's largest power derivatives exchange and among Europe's largest carbon exchanges for trade in EUAs and CERs. The company has more than 400 members from 21 countries. Nord Pool ASA, owned by Statnett and Svenska Kraftnät, holds the exchange license and Nord Pool Clearing ASA, owned by NASDAQ OMX, handles the back end.

[17] In Italy, it is called the ISPRA, "Istituto Superiore per la Protezione e la Ricerca Ambientale," environmental protection and research institute, under law 133/2008.
[18] http://www.mcex.ca
[19] http://www.nordpoolspot.com/about/Product_group/

Nord Pool was the first exchange to list EUAs as standardized exchange contracts in January 2005. In June 2007, Nord Pool was the first exchange to trade CERs.

NASDAQ OMX has acquired all of the shares in Nord Pool International, Nord Pool Clearing ASA and Nord Pool Consulting. The latter contains Nord Pool's international products, including CO2 products and power generation. NASDAQ OMX paid 2,182 million NOK (approximately 325 million USD) for the shares.

4.2 OTC Brokers

There are 9 major over-the-counter (OTC) brokers. APX Power UK; CantorCO2e; Evolution Markets; GFI Group; ICAP; MF Global Energy; Spectron; TFS Energy; Tullet Prebon. Cantor, GFI, ICAP and Tullet Prebon are large interdealer brokers with a global presence in numerous commodity and financial market. All but MF Global are members of the London Energy Brokers Association (LEBA).[20] By their nature, broker level data on trading volumes is hard to come by, but I describe some features of each in alphabetical order. I then analyze aggregate LEBA data at the end of this section.

4.2.1 APX Power UK

APX is an Anglo-Dutch brokerage with a strong presence in power and natural gas. It also provides clearing for carbon spot trading on the Climex platform.

4.2.2 Cantor CO2e

Cantor is a broker dealer best known for its trading activity in the fixed income market. Nonetheless, Cantor has had an environmental division since 1992, and now brokers trades in the EU ETS, and the U.S. mandatory and voluntary markets.

4.2.3 Evolution Markets

Evolution Markets[21] is a specialist brokerage firm with strengths in JI/CDM and the voluntary emissions market. They were voted "Best Broker" in these two categories by *Environmental Finance*, a trade publication. They also have a strong position in trading of non-carbon greenhouse gases in the U.S. market.

The company advertises a number of milestones for the emissions market which I record in

[20] http://www.leba.org.uk/index.php
[21] http://new.evomarkets.com/

Table 10.

[Insert Table 10: Evolution Carbon Market Firsts]

Evolution conducted the first brokered trade of EU carbon allowances, and the first indexed-CER trade. They were also among the designers of the RGGI, and brokered the first ever sale of carbon offsets for compliance under the RGGI program.

4.2.4 GFI Group

Formed in 1987, GFI[22] provides inter-dealer brokerage services in the US, UK and Singapore. They trade a range of voluntary and compliance environmental products including EUAs, CERs, ERCs and VERs.

4.2.5 ICAP Energy

ICAP plc[23] is a London based broker dealer with a strong market presence in Treasury bonds (BrokerTec) and foreign exchange (EBS). They claim to be the largest broker dealer in the world, and their shares trade on the London Stock exchange. They have made an aggressive move into the energy and emission markets through their ICAP Energy subsidiary. They trade offsets in the EU ETS (both EUAs and CERs) and were named "Carbon Emissions Broker of the Year" by *Point Carbon*, a leading industry research group.

4.2.6 MF Global

MF Global Ltd.[24] is a global derivatives broker that is listed on the New York Stock Exchange (NYSE: MF). Their energy subsidiary acts as both a general clearing member and inter-dealer broker in EUAs and CERs. It is also a brokers trades and initiates projects for the voluntary carbon market.

4.2.7 Spectron

Spectron[25] began brokering North American Environmental Products in January 2006. It brokers Renewable Energy Credits (RECs), SO2 Allowances, seasonal and annual NOx Allowances, New York State NOx & SO2, Reclaim, Houston-Galveston Area (HGB) MECTP NOx allowances,

[22] http://www.gfigroup.com/markets/commodities/emissions.aspx
[23] http://www.icap.com/
[24] http://www.mfglobalenergy.com
[25] http://www.spectrongroup.com/

Emission Reduction Credits (ERCs), Voluntary Greenhouse Gas and Biofuels. Spectron is a participant member of the CCX.

Spectron market innovations, which I list in Table 9, include brokering the first OTC CO2 option settled against the CCX and the first 2012 CO2 trade.

[Insert Table 11: Spectron Market Firsts]

Spectron is also a market leader in the brokering of European CO2 allowances (EUAs). Spectron offers spot and forward OTC trading of EUAs via its integrated electronic/phone broking system. OTC clearing is available through various exchanges. Furthermore, Spectron is also actively involved in the CDM (Clean Development Mechanism) and JI (Joint Implementation) market as well as working on developing emerging markets, such as Mercury and Northeast Greenhouse Gas in the US.

4.2.8 TFS

Tradition Financial Services[26] (TFS), founded in 1985 and now a subsidiary of Compagnie Financière Tradition (SSE: CFT) based in Lausanne, is a market leader in the inter-dealer brokering of OTC physical and derivative products. Compagnie Financière Tradition reaffirms its position as a world leader with consolidated turnover reaching 786.1 million euro in 2003. Both TFS and CFT are subsidiaries of VIEL & Cie[27], which is based in Paris, France, and is continental Europe's top financial brokerage firm.

Their energy subsidiary, TFS Energy, has specialized in CDM offsets and the U.S. voluntary market beginning in 2005. "TFS GreenScreen" was the first electronic emissions trading platform following the launch of the EU ETS.

4.2.9 Tullett Prebon

Tullett Prebon, a more than century old interdealer broker with an established reputation in fixed income, entered the environmental trading business in April 2008. Tullett is trying to leverage its presence in energy trading, a brokerage that was ranked first in the 2009 survey by *Energy Risk*.

Before turning to my formal analysis of greenhouse gas market integration, I summarize the recent price behavior of the dominant European market.

[26] http://www.tfsgreen.com/
[27] http://www.viel.com

4.3 OTC trading volumes

In 2003-4, project based trading dominated the over-the-counter market. IETA estimated 78 mtCO2e were exchanged in 2003 and 107 mtCO2e in 2004. Over-the-counter transactions begin to be placed and/or cleared on the registered carbon exchanges in 2005.

I have data on OTC transactions only from ECX and Nordpool. Industry estimates indicate that these two represent more than 97% of the total exchange based OTC trading.[28] I have a second source for OTC transactions, the London Energy Brokers Association (LEBA) which reports totals from 7 major brokers.

OTC trading volumes are totaled in Table 12. There is double counting in these totals as many of the LEBA transactions are processed through the ECX and Nordpool.

[Insert Table 12: EUA OTC Trading 2005-08]

Exchange traded volumes nearly reach OTC volumes in 2008 for the first time. ECX is slightly more dominant in this table, but this may reflect the relative paucity of data.

5. Trends in EU Emission Prices

EUA prices for the active December 2005 futures contract opened at €16.85 on April 22, 2005. The peak 2005 price for this contract reached €29.10 on July 8, 2005. The December 2006 contract surpassed this level on April 18, 2006 rising to €30.45. I graph the full series of the ECX near term futures contract in Figure 4.

[Insert Figure 4: EUA Futures Prices 2005-2008]

As has been documented by Ellerman and Buckner (2007), the number of allowances distributed in 2005-6 exceeded emissions by about eighty million tons or about 4% of the total EU cap. A selloff began when, according to industry reports[29] greenhouse emissions audits of the Czech Republic and The Netherlands' were revealed to be lower than forecast by 15% and 7%, respectively. Prices collapsed by almost 40%, with heavy volume of 65 mtCO2e, falling from €29.85 on April 24 to €19.05 on May 24, 2006. Alberola, Chevallier, and Cheze (2008) confirm a structural break in

[28] Michael Szabo of Thomson Reuters estimates 7,619 mtCO2e in spot trading at BlueNext and Climex, 20,626 mtCO2e in futures trading at EXAA in 2008 that I don't report here. This represents less than 2.5% of the volume I report in Table 2.

[29] See e.g. carbonpositive.net, "EUAs tumble to €20 and below," April 27, 2006.

their model for EUA prices at this time.

Prices continued to fall through the rest of 2006. Two policy rulings by the European Commission accelerated the slide. The first, emphasized by Alberola, Chevallier, and Cheze (2008), was the declaration in October 2006 by Stavros Dimas that national allocation plans for Phase II would have to be considerably below current emission levels. The second, highlighted by Frino, Kruk and Lepone (2008), was the rejection of a French-Polish proposal to allow Phase I allowances to be banked for Phase II.

On September 1, 2006, the spread between December 2008 (Phase II) and December 2006 (Phase I) EUA futures was €1.85 = €17.85 − €16.0. By the end of November, this had widened to €10.15 = €18.25− €8.10. August 2008 trading volume was 12.523 mtCO2e in the 2006 expiry versus 9.964 mtCO2e for the 2008. By November, this reverses to 28.659 mtCO2e for the 2008, and 15.650 mtCO2e for the 2006.

The December 2006 contract expired at a settlement price of e6.60, down 78% from the the peak. By February 2007, it became clear to the market that the 2005-2007 EUAs were not in any way binding, and prices for the December 2007 contract fell below €1.00 on February 19, 2007. The December contract expired at the token price of €0.01.

To bolster the prices of Phase II allowances, the European Commission did follow through on Dimas' promise. They set an EU-wide cap of $2,080$ mtCO2e for 2008-2012, giving member states 10% fewer allowances than they had requested in their second round of national plans. Reinaud and Philibert (2007) note that these limits represented a 6.5% reduction from verified 2005 emissions. Some countries found the new limits too stringent: Hungary, Latvia, Malta, Lithuania, Poland and the Czech Republic, challenged the new limits in court. Other countries, like the UK, one of the few countries to be net short EUAs under the Phase I allocation,[30] were happy to have their plans approved with no further reductions. Most states accepted the decision, realizing that without tighter limits the scheme for Phase II permits would collapse like the Phase I allowances.

The Phase II contracts retained their credibility. The December 2008 expiry ranged from a low of €12.25 on February 20, 2007 to a maximum of €25.15 on May 29, 2007. It closed out 2007 at €22.41.

Mansanet-Bataller, Pardo, and Valor (2007) show that, as expected, OTC and exchange prices

[30] Ellerman and Buckner (2007) estimate that the UK had the largest net short position in the Phase I allocation. They were given allowances of 205.3 mtCO2e compared to 2005-6 emissions of 246.7 mtCO2e, for an underallocation of −20.2%.

are highly correlated, but their analysis is limited to 2005 and does not test for cointegration. This calls for a more formal analysis which I begin in the next section.

6. Cointegration

Our primary analytical tool in the market structure analysis is cointegration. Cointegration is a statistical model that describes how markets, each of which involves in a random fashion during the day, may nonetheless be linked.

More intuition here.

6.1 Error correction representation

Let X_t be an $n \times 1$ vector of market prices,

$$X_t = (p_{1,t}, p_{2,t}, ..., p_{n,t})', \tag{1}$$

which has the following vector autoregressive data generating process,

$$X_t = \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} + u_t. \tag{2}$$

The coefficient estimates Π_i are an $n \times 1$ matrix and u_t is an $n \times 1$ vector of independent Gaussian disturbances. It is convenient to work with (2) in vector error correction form,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k+1} + \theta X_{t-k} + u_t, \tag{3}$$

where $\Gamma_s = -\sum_{j=s+1}^{k} \Pi_j \ , s = 1, 2, ..., k-1$, and $\theta = \sum_{j=1}^{k} (\Pi_j - I)$.

Assuming that each price has a unit root,

$$\Delta p_{i,t} = p_{i,t} - p_{i,t-1} = \varepsilon_{i,t}, \tag{4}$$

where $\varepsilon_{i,t} \tilde{} \ N(0, \sigma_\varepsilon^2)$, but some $r \times 1$ linear combination of the prices is stationary,

$$z_t = \beta' X_t, \tag{5}$$

then I can write (3) as

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k+1} - \alpha z_{t-1} + u_t, \tag{6}$$

where α and β are $n \times r$ matrices. The dimension of the cointegrating vector r, the weights in the linear combination β and the speeds of adjustment α are the crucial parameters in the analysis.

6.2 Hypothesis testing

Johansen (1991) describes a procedure for determining the rank of β using canonical correlations.

Denote the eigenvalues of this system by λ, he then defines the statistic,

$$-T \sum_{j=r+1}^{n} \log(1 - \lambda_j). \tag{7}$$

This tests the null that the matrix β has rank r (the system has $n-r$ unit roots) and is distributed asymptotically $\chi^2(r)$. I follow much of the literature and utilize a finite sample correction from Reimers (1992),

$$-(T + nk) \sum_{j=r+1}^{n} \log(1 - \lambda_j). \tag{8}$$

In practice, we will work our way up from $r = 0$ to $r = n$, stopping at the first value for r which fails to reject the null.

6.3 Estimation

Having established the rank of the cointegrating vector, I obtain estimates of the parameters using Johansen's (1991) maximum likelihood method. These estimates will tell us whether exchange prices are roughly equal over time, whether CERs and EUAs are stable substitutes, and a variety of other inferences about the cointegrating relationship.

Even when markets are cointegrated, I will be concerned about how quickly they adjust. The vector of adjustment coefficients α is equally important.

7. Integration of the EUA Market

Pilot screen trading of allowances began in 2003 with the anticipation of the Kyoto ratification. The International Emissions Trading Association (IETA) estimates[31] 0.65 MtCO2e was exchanged in 2003 and 9 MtCO2e in 2004.

With the implementation of the EU ETS, screen trading began in earnest.[32] The European Climate Exchange (ECX) quickly claimed nearly 2/3 of the market, with the next largest, in order of volume, Nordpool, Bluenext (formerly Powernext), the European Energy Exchange (EEX), Energy Exchange Austria (EXAA), and Climex.

Apart from the ECX, the other major platforms are energy trading platforms which had been

[31] International Emissions Trading Association, State and Trends of the Carbon Market (2005), p.32

[32] The IETA computes transaction volumes for 2005 that include exchange platform and OTC contracts. The EU ETS, they estimate, handled more than 97% of the global trading volume. The UK ETS, the New South Wales ETS, and Chicago Climate Exchanges collectively traded less than 9 mtCO2e.

adapted from the active markets in electricity. It was a natural complement to their existing businesses.

I have data from the largest exchanges: the ECX, Nordpool, Bluenext, EEX, and EXAA. I list their trading volumes in Table 13.

[Insert Table 13: EUA Screen Trading 2005-08]

ECXs market share runs from 63% to 80%. BlueNext has emerged in 2008 as the strong second market center, overtaking Nordpool.

7.1 Spot Market

I have data on the spot markets from both Bluenext and Nordpool covering the period October 2005 to March 2008 for the 2005-07 EUAs.[33] The data are plotted in Figure 5.

[Insert Figure 5: EUA Spot Prices 2005-2008]

The data display a sharp break downtrend beginning in April 2006. There appears to be a structural break there as prices fall from 24.30 to 15.70 between April 26 and 27, 2006. Prices appear to stabilize through October 2006 and then resume their downtrend. The spot price movements are consistent with Alberola et al. (2008) analysis, and I will later confirm the break statistically.

The first diagnostic test for cointegration is to test whether the spot series are $I(1)$. I will use the augmented Dickey-Fuller 1979) ADF test and the Phillips-Perron (PP, 1988) to detect the presence of unit roots.

Perron (1989) reminds us that unit root tests in the presence of structural breaks can be misleading, but his procedure assumes a known break point. I will instead test for a unknown structural break in the level and unit root simultaneously using the Zivot and Andrews (1992) test. The null in Zivot and Andrews is a unit root, and the alternative an $I(0)$ process with one structural break.

Their procedure searches through the sample for the minimum t-stat on θ_1, the coefficient on the lagged level in the regression,

$$\Delta p_{i,t} = \alpha_0 + \alpha_1 t + \alpha_2 D_t^B + \theta_1 p_{i,t-1} + \textstyle\sum_{j=1}^{k} \phi_j \Delta p_{i,t-j} + u_{i,t}. \tag{9}$$

t is a time trend, and D_t^B is a dummy variable that is zero prior to date B and equal to 1 thereafter.

[33] The 2008-12 EUAs are available only from April 1, 2008. The results are quite similar to those reported in the text.

The lags k are included from a maximum of 12 lags using a t-test criterion at the 10% level. Zivot and Andrews provide asymptotic critical values of -4.80 for a 5% test and -5.34 for a 1%.

For Bluenext, the t-test sets $k = 10$, and for Nordpool, $k = 11$. The strongest evidence for a structural break for both series comes on April 25, 2006 when $t(\theta_1) = -3.73$ which is well inside the critical values needed to reject the unit root.

I then estimate the cointegration model on the entire sample and report results in Table 14.

[Insert Table 14: EUA Spot Price Cointegration Analysis]

The trace test supports one common trend, $r = 1$, and this model is quite successful. I can't reject $\beta_2 = -1$, and both markets adjust prices towards their long run equilibrium. The Bluenext coefficient is significantly different from zero, and suggests a speed of adjustment of 1.73 days.

The fact that the two markets remain cointegrated through a period of substantial price variation is a reassuring reminder of the tight integration of the European markets.

7.2 Futures market

I have two questions of interest in examining the futures. First, I repeat the exercise of the integration across markets, and then I want to look at integration across the futures curve.

7.2.1 Integration across exchanges

I have daily closing futures prices from three exchanges: (1) the ECX; (2) Nordpool; and (3) Eurex. I first study the 2005-07 vintage of the EUA over the period October 2005 to November 2007. Results from the cointegration analysis are in Table 15.

[Insert Table 15: EUA Futures Cointegration Analysis]

The Zivot-Andrews test again places the greatest probability of a structural break at the date of April 25, 2006. It fails to reject the unit root for any of the three. The minimum t-stats on θ_1 are -3.138 for ECX, -3.182 for Nordpool, and -3.693 for Eurex.

I proceed with the cointegration analysis on the full sample. It appears that Eurex is redundant. I can't reject that $\beta_3 = 0$, indicating that Eurex, which averages only 5.66% of the volume during 2005-2007, could be dropped from the cointegrating vector. The error correction is also off. The ECX goes up when its prices are above those of Nordpool, $\alpha_1 = 0.701$, and Nordpool appears to overshoot, $\alpha_2 = 1.660$. If I start the sample in May 2006, the ECX error corrects, $\alpha_1 = -0.100$,

but the coefficient is insignificant.

I now explore whether the 2008-12 EUA futures have a tighter integration. I have data from the three exchanges from July 2006 to December 2008. Unit root tests for all three fail to reject. The cointegrating vector suggests including all three markets, but one can easily reject $\beta_1 = -\beta_2$ for ECX and Nordpool or any other pair of unitary coefficients. Nordpool and Eurex adjust significantly to this cointegrating relation, but I can't reject that α_1 for the ECX is zero. These results change little if I explore only 2008, and look at any pair of markets that includes the ECX.

The conclusion here is that the futures market is not completely integrated even at a daily frequency.

7.2.2 Integration along the futures curve

I now turn to market substitutes for EUA, first in Europe. I examine contracts from the ECX because it is the most liquid and to control for the non-integration across the exchanges I found in the previous section.

I examine five maturities for the 2008-12 EUA futures, the December expiries from 2008 to 2012. I have data from May 2006 to December 2008. The trace test for the five series, reported in Table 16, implies five common trends. Each series behaves like an independent random walk.

[Insert Table 16: ECX Futures Curve Cointegration Analysis]

I shorten the sample to 2008 to see if the markets became more closely integrated. That appears to be the case, as this time the trace test finds only two common trends. The model doesn't seem to have much economic interpretation though. The cointegrating vector does not imply that prices are similar apart from small basis adjustments, and none of the error correction coefficients are significant.

I now turn to markets that trade close substitutes for the EUA.

8. CER Spreads

Trading in secondary CERs occurs in most places that EUA instruments are traded. I report market share on secondary screen trading in CERs in Table 17.

[Insert Table 17: CER Screen Trading 2007-08]

The ECX arrived in this market in late March 2008, almost a year after Nordpool, but has still

managed to win a dominant market share of 91.43% of the 185.438 mtCO2e that was transacted in 2008.

Unlike the spot EUA and futures, the majority of CER trading volume remains over-the-counter. 617.88 mtCO2e was traded, but only 30.0% of that was screen traded.

OTC trading is also dominated by the ECX with a market share of 88.33%. This is remarkable because of their absence from this market segment in 2007.

[Insert Table 18: CER OTC Trading 2007-08]

LEBA volumes, 18 mtCO2e in 2007 and 325 mtCO2e, are fairly close to the exchange brokered OTC volumes.

I turn now to examine how tightly integrated are the EUA and CER contracts.

8.1 Cointegration of EUA and CERs

I have Nordpool data from June 1, 2007 and ECX begins trading a futures contract in April 2008. I graph the EUA-CER spread from June 2007 to December 2008 in Figure 5.

[Insert Figure 5: CER-EUA Spread]

I first look to see if the EUAs CERs spread appears stationary. The spread definitely narrows, especially after July 1, 2008. The average spread from July 1, 2007 to June 30, 2008 is €5.88 and this falls to €3.77 during the second half of 2008. Spreads narrow after the connection of the EU registries, but there is no sharp spike in the series on that date.

I test both the EUA and CER series for unit roots using the Zivot and Andrews test. I cannot reject a unit root in either series: the minimum $t(\theta_1)$ values are -2.69 for the Nordpool CER, and -3.68 for the ECX EUA futures contract. For both series, the greatest weight on a possible structural break is in late September 2008.

There is no pair of EUA and CER prices that the trace test rejects separate trends for each. Results are in Table 19.

[Insert Table 19: EUA-CER Cointegration Analysis]

For the longest series, the Nordpool CER and ECX EUA futures with 398 daily observations, the p-value is 0.34 on $r = 0$. Given the lack of integration across futures markets, I pair the ECX EUA and CER contracts in a second test. This spans most of 2008, but still fails to find any

common trends. Finally, I look to see if a cointegrating vector emerged after the consolidation of the CDM registries. Restricting the trace test to the sub-sample from October 23 to December 30, 2008, I still cannot reject that $r = 0$.

I now leave the EU ETS and begin to explore emissions markets in other parts of the world.

9. Developments in North America

The irony of the Kyoto system is that the U.S. had the first cap and trade system. It dates back to the acid rain problem in the Northeast from coal fired electric utilities.

I cover the Acid Rain Program from the Clean Air Act of 1990, recent regional initiatives in the U.S. and neighboring Canadian provinces, and the voluntary market.

9.1 Acid Rain Program

9.1.1 SO2

Title IV of the 1990 amendments to the U.S. Environmental Protection Agency's Clean Air Act establishes a cap and trade program to "reduce annual SO2 emissions by 10 million tons below 1980 levels." Section 7651 provides a market oriented framework of allowances and a transfer mechanism that enabled a trading market to emerge.

Phase I began in 1995 and was applied to mostly coal-burning electric utility plants located in 21 eastern and midwestern states. Phase II, which began in the year 2000, tightened the emissions limits further and extended them to over 2,000 units in all. Virtually every facility with more than 25 megawatts of generating capacity is now included.

Affected utility units are allocated allowances[34] based on their historic fuel consumption and a specific emissions rate. Each allowance permits a unit to emit one ton of SO2 during or after a specified year. Emission levels may not exceed Title I limits though. For each ton of SO2 emitted in a given year, one allowance is retired, that is, it can no longer be used. Phase II set a permanent ceiling (or cap) of 8.95 million allowances.

The EPA has judged the program to be a success. In 2007, SO2 emissions fell below the long term emission cap. Achieving this target, three years ahead of schedule, required a reduction of

[34] EPA allocated Phase I allowances at an emission rate of 2.5 pounds of SO2/mmBtu (million British thermal units) of heat input, multiplied by the unit's baseline fossil fuel consumption from 1985-87. In Phase II, allowances were lowered to a rate of 1.2 pounds of SO2/mmBtu.

6.8 million tons of SO2 emissions, a decrease of -43%.

9.1.2 Auction analysis

Allowances may be bought, sold, or banked and trade in an OTC secondary market with a dozen brokers.[35]. The EPA lists allowance transactions[36] but not prices.

The only publicly disseminated prices are from annual auctions which have been held since 1993. On March 24, 2009, 77 bids were entered for the spot auction. The $125,000$ allowances cleared at a market price of \$62.00. For the 7-year ahead auction, there were 25 bids with a clearing price of \$6.63. Figure 6 plots the market clearing spot prices since 1993.

[Insert Figure 6: EPA Acid Rain Program SO2 Auction Prices]

Spot prices have fluctuated substantially, between \$62.00 in the most recent auction on March 24, 2009 to over \$860 in the March 2006 auction. Forward rates have always traded at a discount to the spot. In Phase I, between 1993 and 1999, the discount averaged only -5.37%. From 2000 to 2009, in Phase II, the discount grew to an average -60.54%.

The first question of interest is whether forward auction prices predict future spot prices. Through 1997, the EPA conducted both 6 and 7-year ahead auctions. From 1998 on, these are 7-year ahead prices. There are a total of 16 forward prices between 1993 and 2003.

I regress the realized spot price τ periods ahead, $p_{t+\tau}$ on the τ-period head futures from time t, f_t^τ,

$$p_{t+\tau} = \alpha + \beta f_t^\tau \tag{10}$$

If the futures are unbiased predictors of the futures spot rates, I should find $\alpha = 0$ and $\beta = 1$. I estimate,

$$\widehat{p}_{t+\tau} = \underset{(208.38)}{102.26} + \underset{(1.83)}{1.53}\, f_t^\tau .$$

While I can't reject, using the standard errors in parentheses, that $\alpha = 0$ and $\beta = 1$, the regression fits poorly overall, with a R^2 of just above 5%.

A related question is whether market prices anticipate the auction results. Futures on SO2 emissions (SFI) have been trading on the Chicago Climate Futures Exchange since December 2004.

[35] The EPA website lists the following brokers: Air & Liquid Advisors; Amerex Energy; Cantor Fitzgerald Environmental; Chicago Climate Futures Exchange; Conservation Services Group; Element Markets LLC; Evolution Markets; GFI Group, Inc.; Natsource; New York Mercantile Exchange; Polaris Markets LLC; Spectron Energy; TFS Energy; United Power

[36] http://camddataandmaps.epa.gov/gdm/ index.cfm?fuseaction=allowances.wizard

These are contracts to allow 25 EPA SO2 allowances under the Acid Rain Program. While this is a relatively short interval, I do have five annual auctions to compare with the closing futures prices of the near-month contract on the last trading day prior to the auction. Fitting (10) to this data, I estimate

$$\widehat{p}_{t+\tau} = \underset{(10.89)}{-0.24} + \underset{(0.02)}{0.96} f_t^{\tau}.$$

The coefficient on the futures includes some basis adjustment as it is significantly different than one at the 95% level, but the futures explain 99% of the variation in the auction prices.

9.1.3 Integration of SO2 and CO2

A final question is whether the acid rain prices in Chicago are cointegrated with the EUA prices at the ECX. I create a series of rolling December expiry futures for both and test for cointegration. I use the sample period July 5, 2006 to December 31, 2008 and find no evidence of common trends. I obtain a similar result when I restrict the sample to 2008.

9.2 NOx

On March 10, 2005, the EPA initiated a program to deal with nitrogen oxide, another greenhouse gas emitted by manufacturing and power generating plants. EPA called it the Clean Air Interstate Rule (CAIR)[37], and it covers 28 eastern states and the District of Columbia.

In March 2006, EPA issued quotas on 2009-14 emissions as part of its Federal Implementation Plans (FIPS). On July 11, 2008 though, the U.S. Court of Appeals for the D.C. Circuit, in North Carolina v. EPA found flaws with EPA's allocation plans, and the status of the program remains in limbo.

9.3 Regional and State Level Programs

This section covers a variety of programs at the regional and state level that have emerged in the U.S. and Canada in the absence of a federal greenhouse gas program.

9.3.1 Regional Greenhouse Gas Initiative (RGGI)

The Regional Greenhouse Gas Initiative (RGGI) is a cooperative effort by ten Northeast and Mid-

[37] There is a similar program for mercury emissions called Clean Air Mercury Rule (CAMR) that effects (mostly) coal-generated electricity plants.

Atlantic states[38] to limit greenhouse gas emissions. Unlike the acid rain program, the RGGI is focused on CO2. The market-based CO2 emissions reduction program in the United States. The states have agreed to will CO2 emissions from the power sector, and then require a 10 percent reduction in these emissions by 2018. The key to the regional market is the ability to trade allowances to any facility within the region.

RGGI allowances trade at quarterly auctions. The first was on September 25, 2008. A sealed-bid, uniform price auction resulted in the sale of 12.565 mtCO2 at a clearing price of $3.07. There were 59 separate entities bidding for more than four times the available allowance. Bid prices ranged from $1.86 to $12.00, and the Herfindahl index of bid concentration, computed by Potomac Economics, was 446. The December 17, 2008 auction sold 31.506 mtCO2 at $3.38 and drew 69 participants.

RGGI futures have been trading on the Chicago Climate Exchange since August 15, 2008.

9.3.2 California

In September 2006, California passed the California Global Warming Solutions Act of 2006 (Assembly Bill 32)[39]. The goal of the legislation is to bring greenhouse gas emissions back to their 1990 levels by 2020. The California Air Resource Board (ARB) passed, in December 2008, a series of proposals to meet these goals called a "scoping" plan. The plan includes a cap and trade system that is scheduled to begin in 2012.

9.3.3 Western Climate Initiative

The Western Climate Initiative (WCI) began, in February 2007, as an agreement among Arizona, California, New Mexico, Oregon, and Washington to develop a regional target for reducing greenhouse gas emissions. It shares many features of Kyoto: a multi-state registry and a plan to develop a market-based program to reach the target. In August 2007, the WCI adopted the goal of reducing greenhouse gas emissions by 15% below 2005 levels by 2020.

British Columbia (March 2007), Utah (May 2007), Manitoba (June 2007), Montana (January 2008), Quebec (April 2008) and Ontario (July 2008) have signed on to the agreement.

[38] The ten states are: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.

[39] http://www.arb.ca.gov/cc/ab32/ab32.htm

9.3.4 Midwestern Greenhouse Gas Reduction Accord

The midwest is the manufacturing center of the U.S., and it was significant that, in November 2007, six U.S. states and one Canadian province (Iowa, Illinois, Kansas, Manitoba, Michigan, Minnesota, and Wisconsin) created the Midwestern Greenhouse Gas Reduction Accord (MWGGA)[40]. At present, the agreement is simply a statement of principals with a commitment to develop a detailed cap and trade system by 2010.

9.4 Emission Reduction Credits (ERCs)

A variety of state and regional groups have created a market in emission reduction credits (ERC). These are analogous to CERs under Kyoto.

Emission credits have been issued and traded, as McLean (1999) notes, for more than 20 years in the U.S., beginning with Title IV of the Clean Air Act of 1990. The second large market that emerged in 1993 was California's South Coast Air Quality Management District[41]. $15 million in ERC and short-term ERC (STERC) were transacted in July 2009 on a range of greenhouse gases and pollutants. Cantor Fitzgerald has brokered 90 transactions with a market value of nearly $3.5 million. A third continuing program is the Ozone Transport Commission[42] that began in 1994.

With the exception of the Clean Air Act, the lack of a national registry and difficulties in banking allowances have hampered the creation of a liquid marketplace.

9.5 Voluntary Emissions Reduction

In the absence of any national emission system, many companies, state and local governments and non-profits have started to develop cooperative, but legally binding arrangements to lower their greenhouse gas production. An OTC and exchange market has emerged in the U.S. and to a lesser extent globally.

The difficulty in growing this market is national and international cooperation on standards. Among those vying for the dominant role: (1) The Voluntary Carbon Standard (VCS) was established by The Climate Group, the International Emissions Trading Association (IETA) and the World Economic Forum Global Greenhouse Register in 2006. The standard has undergone

[40] http://www.midwesternaccord.org/
[41] http://www.aqmd.gov/permit/ERC.htm
[42] http://www.otcair.org/

several revisions[43] with the current VCS 2007.1 arrived at in November 2007. Project lists are maintained at both APX,[44] a U.S. based envornmental solutions company, and MarkIt,[45] a London based financial information provider. As of September 2009, APX lists 127 projects with an estimated annual output of 9.3 million VCU. MarkIt publicly lists 98 registered projects; (2) The Gold Standard, launched in May 2006, was initiated by the World Wildlife Foundation, South-SouthNorth and Helio International. The Gold Standard is a non-profit foundation under Swiss Law and funded by public and private donors; (3) The Climate Action Reserve[46] is a private non-profit organization originally formed by the State of California under Gray Davis back in October 2001; (4) The American Carbon Registry (ACR) was founded in 1997 as the GHG Registry by the Environmental Defense Fund (EDF) and Environmental Resources Trust (ERT). Hamilton, Sjardin, Shapiro, and Marcello (2009) note that 96% of voluntary offset credits were verified in 2008, and 79% of the verified OTC credits were documented by the top four registries. The most popular sources of carbon offsets, they note, were renewable energy projects (51%) and landfill gas (methane) projects (17%).

[Insert Table 20: Voluntary Market]

Hamilton et al. (2009) report that the OTC voluntary carbon market prices rose to $7.34 in 2008 from $6.10 in 2007 and $4.10 in 2006. Demand grew to 54 mtCO2e in 2008, up 26% over 2007. The near month CFI futures contract on the Chicago Climate Exchange traded at an average price of $3.95, a discount of 46.2% to the OTC prices. Chicago traded 69.2 mtCO2e in CFI contracts in 2008.

Trading in 2009 appears to have been hurt by moves toward a mandatory cap and trade system. Volumes in CFI contracts fell 44% to 259,034 from 462,228 in the first half of 2009 versus 2008.

9.6 Cointegration with the EU ETS

The Chicago Climate Exchange has been the leader in this market, having created CFI contracts. I compare CCX December 2008 CFI contracts with ECX December 2008 EUA contracts. Over the sample period, August 2007 to December 2008, CFI prices average $3.64 and the EUA futures

[43] http://www.v-c-s.org/docs/Voluntary%20Carbon%20Standard%202007_1.pdf
[44] http://www.apx.com/environmental/carbon-market-infrastructure.asp
[45] http://www.tz1market.com/vcspublic.php. The registry was originally started by TZ1 and was acquired by MarkIt in July 2009.
[46] http://www.climateactionreserve.org/. The California Climate Action Reserve and the Center for Climate Action operate through the Climate Action Reserve.

average €22.32.

I can't reject that either series has a unit root, and the trace test suggests a single common trend with cointegrating vector,

$$p_t^{EUA} - 5.33 p_t^{CFI}.$$

There is a slow but statistically significant error correction by the ECX that averages about four months.

I close this section with a crude, back of the envelope risk neutral probability of the United States adopting the Kyoto limits. Adjusting the U.S. dollar for the current exchange rate of $1.3845 US/€$, the cointegration relationship implies a 13.55% chance that the U.S. will place limits on CO2 equivalent to Europe.

10. Exchanges Around the Globe

I will report on these by either region or country. A summary table with major contracts and trading volume is in Table 21.

[Insert Table 21: Exchanges Outside Europe and North America]

I begin with Asia which has markets in India and China and in places with active financial centers like Singapore.

10.1 Asia

10.1.1 MCX

India has became a major source for CERs, and it is not surprising then that a Mumbai based company, the Multicommodity Exchange of India[47] (MCX), has entered the emissions trading business. Its stakeholders include the National Stock Exchange of India Ltd. (NSE), the Bank of India (BoI), Fidelity International, Citibank and Merrill Lynch. The MCX, which offers futures trading in 55 commodities, entered into a strategic alliance with CCX in September 2005 to initiate carbon trading in India.

In 2008, MCX traded 0.682 mtCO2e in CFI contracts with a market value of 877.04 million Rupees, and 1.861 mtCO2e in CERs with a market value of 12,753.07 million Rupees.

[47] http://www.mcxindia.com

10.1.2 NCDEX

The rival Mumbai based National Commodity and Derivatives Exchange (NCDEX)[48] also trades CERs. It's trading volumes lag behind the MCX. The market value of CERs transacted was 8,380.90 million Rupees in 2008.

10.1.3 Tianjin Emission Trading Exchange

China's first comprehensive emissions trading exchange, the Tianjin Climate Exchange[49], was set up on September 25, 2008. The Exchange was jointly established by the China National Petroleum Corp., Tianjin Property Rights Exchange and the Chicago Climate Exchange, with 53%, 22% and 25% stakes, respectively.

The exchange intends to implement the Binhai Comprehensive Reform Plan of March 2008 with the goals of supporting the Clean Development Mechanism and establishing a marketplace for greenhouse gases in China. Since 2006, Tianjin Binhai has been the location for experiments by the Chinese government in financial innovation.

10.1.4 ACX Asia

Asia Carbon Exchange (ACX-Change)[50], based in Singapore, claims to be the world's first CDM based online trading platform. Like many other exchanges, it helps to develop, finance and then market CDM projects. Since November 2005, they have transacted 4.5 million CERs with a market value of €43 million. They have offices in Australia, the Netherlands, Hong Kong, India, Indonesia, Malaysia, Thailand, UAE and Vietnam.

Asia Carbon Global, the exchange parent company, launched the trade of VERs in its platform during May 2007 and the first auction was conducted in June 2007. Thereon, ACX-Change conducts regular auction of VERs. Revenues have totaled €508,071 in the voluntary market.

10.1.5 JBIC Carbon Exchange

The Japan Bank for International Cooperation (JBIC) is the international wing of Japan Finance Corporation (JFC) established on October 1, 2008. It publishes a weekly set of prices called the Nikkei-JBIC carbon quotation index[51]. JBIC reports the average of indicative quotes from

[48] http://www.ncdex.com/
[49] http://www.tianjinclimateexchange.com/index-en.html
[50] http://www.asiacarbon.com/Carbon_Trading.html
[51] http://www.jbic.go.jp/en/about/press/2008/0421-01/index.html

Barclays Capital Japan Limited, EcoSecurities Japan, Fortis, JP Morgan, Marubeni Corporation, Natsource Japan, Orbeo/Rhodia Japan and Sumitomo Corporation.

There is very little trading volume going through the JBIC sponsored Carbon Credit Trading Platform[52], but the Bank is funding numerous CDM projects.

10.2 Australia

Australia was, along with the U.S., an unenthusiastic supporter of Kyoto. In June 2002, Conservative Prime Minister John Howard refused to sign the treaty following the rejection by the U.S. Nonetheless, the successor Labor government of Kevin Rudd, in his first act as PM, signed onto Kyoto. He then introduced the Carbon Pollution Reduction Scheme[53] in May 2009, and a series of bills was passed by the House in June 2009. As of this writing, the Senate rejected the legislation in August 2009, in part because of the global economic downturn and the opposition of powerful mining interests.[54] Each Australian produced 20.58 tonnes of carbon each year, against 19.78 tonnes for the United States and 4.5 tonnes for China, now the world's biggest greenhouse gas polluter overall.

10.2.1 ACX

The Australian Climate Exchange Limited (ACX)[55], which began operations in 2007, was the first electronic emissions trading platform in the country. It offers trading in VERs with a registry in Perth and Renewable Energy Certificates, a compliance instrument under the Australian Mandatory Renewable Energy Target[56].

10.2.2 NGAS

The NSW Greenhouse Gas Reduction Scheme (NGAS) is a mandatory greenhouse gas emissions trading schemes that commenced on January 1, 2003. GGAS aims to reduce greenhouse gas emissions associated with the production and use of electricity. It achieves this by using project-based activities to offset the production of greenhouse gas emissions.

McGill and Passey (2009) note that the market has been highly concentrated, with nearly 70%

[52] http://www.joi.or.jp/carbon/
[53] http://www.climatechange.gov.au/emissionstrading/index.html
[54] Australia is the largest per capita carbon producer in the world at 20.58 tonnes of carbon each year, against 19.78 tonnes for the United States and 4.5 tonnes for China, which has the largest overall total.
[55] http://www.climateexchange.com.au/Default.aspx
[56] http://www.orer.gov.au/publications/mret-overview.html

of the credits (NGACs) generated by three large market participants, Integral (46%), EDL (17%) and AGL (8.5%). The demand side has come almost entirely from NSW owned utilities. The scheme is scheduled to phase out once the CPRS is in place.

10.3 New Zealand

The New Zealand Carbon Exchange (NZCX)[57] is a partnership with Cantor Fitzgerald's environmental unit, Cantor CO2e. The New Zealand Emissions Trading Scheme (NZ ETS) was legislated through the Climate Change Response Act (2002). The standard NZ Unit (NZU) is the right to emit one ton of CO2e. It is by construction equivalent to one CER and should closely reflect the international price. In 2008, the NZ ETS began with the forestry sector, and will expand to include energy producers in 2010.

Poltical uncertainty in both Australia and New Zealand has hampered widespread trading.

10.4 Brazil

The Brazilian Carbon Market (MBRE) was the result of a joint initiative between the Brazilian Mercantile & Futures Exchange (BM&F) and the Brazilian Ministry of Development, Industry and Foreign Trade (MDIC). It is now linked to the Bovespa, the Sao Paulo equities market, that merged with BM&F in 2008. The market offers a carbon trading facility, BM&F Carbon Facility, and an online CER trading system.

In September 2008, the market held its second auction, consisting of 713,000 certified emission reductions (CERs) from landfill projects held by the São Paulo Municipal Government. Mercuria Energy Trading SA, from Geneva, bought the lot for €19.20 per metric ton of carbon emissions, paying a total of €13.689 million.

11. Conclusion

I have tried to describe the market architecture of global emissions trading. This study has been heavily biased toward the EU ETS where the majority of trading currently takes place.

My formal econometric analysis suggests that while the markets in Europe have matured only the spot market is fully cointegrated. Uncertainties about CERs have prevented their prices from sharing a common trend with the EUAs.

[57] http://www.nzcx.com/index.htm

The Acid Rain SO2 auctions show a market still in flux. Forward auction prices are not rational predictors of future spot prices, but daily SFI futures from Chicago do anticipate the annual auction outcomes.

A final surprising result is the cointegration of voluntary CFI prices in the U.S. with European EUA prices. From this relationship, I estimate a 13.55% chance that the U.S. will adopt a system similar to the EU ETS.

The Kyoto agreement expires in 2012, and negotiations are already under way for a follow-on treaty. With the Copenhagen gathering in December 2009 looming, the global economic downturn and the slow progress of legislation in the U.S. have generated pessimism about the control of greenhouse gases. Prices are currently singing this tune.

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Table 1
Trading of CDM and JI 2005-7

	2005		2006		2007		2008	
Program	**Volume (mtCO2e)**	**Value ($mn)**	**Volume (mtCO2e)**	**Value ($mn)**	**Volume (mtCO2e)**	**Value ($mn)**	**Volume (mtCO2e)**	**Value ($mn)**
Primary CDM	341	2,417	537	5,804	552	7,433	389	6,519
Secondary CDM	10	221	25	445	240	5,451	1,072	26,277
JI	11	68	16	141	41	499	20	294

The data are from the International Emissions Trading Association (IETA) and World Bank reports on the *State and Trends in the Carbon Market* for 2007-9.

Table 2
Joint Implementation Projects 2008

Country	Number	kERUs	2012 kERUs
Russia	90	42760.78	195182.8
Ukraine	30	10875.67	51895.02
Bulgaria	12	1000.893	4582.147
Czech Republic	1	33.441	167.205
Romania	7	2025.734	10004.77
Poland	10	3532.135	16459.38
Hungary	10	1667.789	8232.627
Estonia	4	246.657	1236.772
Latvia	1	5.337	26.685
Lithuania	8	1717.284	6535.149
Slovakia	1	12.5	62.5
Others	11	4569.605	17880.29
Germany	6	4199.71	16030.82
New Zealand	5	369.895	1849.475
Total JI countries	185	68447.83	312265.4

The data are from the The United Nations Environment Programme (UNEP) Risoe Centre on Energy, Climate and Sustainable Development pipline of JI projects: http://cdmpipeline.org/ji-projects.htm.

Table 3
Overview of Contracts Traded

	EUA			CER		
Exchanges	**Spot**	**Futures**	**Options**	**Spot**	**Futures**	**Options**
Bluenext	X	X		X		
Chicago Climate Exchange (CCX)					X	X
Climex	X			X		
European Climate Exchange		X	X		X	X
European Energy Exchange (EEX)/Eurex		X	X		X	X
Energy Exchange Austria (EXAA)	X					
Green Exchange/NYMEX		X	X		X	X
Gestore del Mercato Elettrico (GME)	X			X		
Nordpool	X	X		X	X	

Table 4
ECX Contracts

Features	**EUA Futures**	**EUA Options**
Unit of Trading	1,000 CO2 EUA.	One ICE ECX EUA Options Contract.
Price quotation	Euros (€.cc) per metric tonne	Euros (€.cc) per metric tonne
Contract months	December 2009-2014	Dec. 2009-2012
Expiry Day	Last Monday of the contract month.	3 days before futures
Trading system	ICE electronic platform	ICE electronic platform
Trading model	Continuous trading	Continuous trading
Trading hours	07:00 to 17:00 hours UK Time	07:00 to 17:00 hours UK Time
Settlement prices	Trade wtd. avg. 16:00 to 16:15	Trade wtd. avg. 16:00 to 16:15
Delivery	Physical delivery at LCH.Clearnet	Turn into futures contracts at expiry
Clearing	ICE Clear Europe central counterparty	ICE Clear Europe central counterparty
Margin	ICE Clear Europe margins	ICE Clear Europe margins

Source: http://www.ecx.eu/index.php/Contract-Specifications

Table 5
BlueNext Contracts

	Spot EUA 2008-2012	**Spot CER**	**EUA Futures Dec.08-12**
Underlying	EUA 2008-2012	CDM CERs	EUA 2008-2012
Price Tick	0.01 €/t	0.01 €/t	0.01 €/t
Volume Tick	1,000 tonnes	1,000 tonnes	1,000 tonnes
Trading System	Trayport (Global Vision)	Trayport (Global Vision)	Trayport (Global Vision)
Trading Hours	09:00-17:00 Paris M-F	09:00-17:00 Paris M-F	08:00-17:00 Paris M-F
Settlement	Real-time BlueNext	Real-time BlueNext	LCH.Clearnet SA

Source: Bluenext

Table 6
Chicago Climate Exchange Contracts

Symbol	Description
CER	Certified Emission Reduction Futures and Options
CFI	Carbon Financial Instrument Futures and Options
DJSI-W	Dow Jones Sustainability World Index Futures
ECO-Index	ECO-Clean Energy Index Futures
IFEX-ELF	IFEX Event Linked Futures (U.S. Tropical Wind)
IFEX-FLW	IFEX Event Linked Futures (Florida Tropical Wind)
IFEX-GCW	IFEX Event Linked Futures (Gulf Coast Tropical Wind)
NFI-A	Nitrogen Financial Instrument (Annual) Futures and Options
NFI-OS	Nitrogen Financial Instrument (Ozone Season) Futures
RGGI	Regional Greenhouse Gas Initiative Futures and Options
SFI	Sulfur Financial Instrument Futures and Options

Source: Chicago Climate Exchange.

Table 7
EEX/Eurex Emission Contracts

Products	**Product ID**	**Introduction**
EUA Futures	F2PE	05-Dec-2007
CER Futures	FCER	26-Mar-2008
Options on EUA Futures	O2PE	14-Apr-2008

Source: EEX

Table 8
EXAA Auction Procedure

Time	Action
08:00	Exchange trading day for trading in CO2 certificates
8:00-13:55	Trading in CO2 certificates is opened; sending, changing and deleting orders is possible
11:00	Purchase orders limited to the cas account
13:30	Cover test of sell order CO2 certificates
13:55	Trading in CO2 certificates is closed
13:55	Second coverage test
14:00	AUCTION: Calculation of the market clearing price (MCP) and volumes
14:05-14:10	Post-trading; trading in surplus orders
14:10	MCPs and volumes announced; trade confirmations are sent.
20:30	Key data for billing (invoices and credits) available

Source: http://en.exaa.at/spotmarket_CO2/marketplace/trading_concept.html

Table 9
Contracts Traded on the Green Exchange

Symbol	Commodity Name	Contract Unit	Min. Fluct.	Min. Value Chg.
RS	SO2 Emission Allowance	100 tons	0.25/ton	$25.00
RN	Seasonal NOX Emission Allowance - Curr.	10 tons	25.00/ton	$250.00
YI	Seasonal NOX Emission Allowance - 2009	10 tons	25.00/ton	$250.00
YJ	Seasonal NOX Emission Allowance - 2010	10 tons	25.00/ton	$250.00
YN	Seasonal NOX Emission Allowance - 2011	10 tons	25.00/ton	$250.00
YM	Seasonal NOX Emission Allowance - 2012	10 tons	25.00/ton	$250.00
WW	Annual NOX Emission Allowance - 2009	10 tons	25.00/ton	$250.00
YP	Annual NOX Emission Allowance - 2010	10 tons	25.00/ton	$250.00
YQ	Annual NOX Emission Allowance - 2011	10 tons	25.00/ton	$250.00
YR	Annual NOX Emission Allowance - 2012	10 tons	25.00/ton	$250.00
VA	Certified Emission Reduction (CER)	1,000 mt	0.01/mt	€10.00
RC	European Union Allowance (EUA)	1,000 mt	0.01/mt	€10.00
	Options			
AS	SO2 Emission Allowance	100 tons	0.05/ton	$5.00
AS	SO2 Emission Allowance	100 tons	0.05/ton	$5.00
AV	European Union Allowance (EUA)	1,000 mt	0.01/mt	€10.00
AV	European Union Allowance (EUA)	1,000 mt	0.01/mt	€10.00
VG	Certified Emission Reduction (CER)	1,000 mt	0.01/mt	€10.00
VG	Certified Emission Reduction (CER)	1,000 mt	0.01/mt	€10.00

Source: http://www.nymex.com/media/greenex_fut_sum.xls. All contracts have physical settlement at termination.

Table 10
Evolution Carbon Market Firsts

Date	Milestone
Dec. 2002	First Trade of Kyoto Allowances (green-AAUs)
Apr. 2003	First Brokered EU ETS Trade
Jun. 2004	First EU ETS Trades Using the ISDA Contract
Nov. 2004	First Large-Scale EUA Transaction (400K EUAs)
Nov. 2004	First EUA Trade for settlement in 2008
Sep. 2005	First Brokered EUA Option
Mar. 2006	First Indexed CER Trade
Mar. 2007	First "Phase Three" (Post-2012) EUA Trade

Source: http://new.evomarkets.com/index.php?page=About_Us-Evo_Firsts

Table 11
Spectron Market Developments

Milestone
Brokering the first OTC REC option in the US;
Brokering the first OTC CO2 option settled against the CCX;
Brokering the first 2012 OTC CO2 trade in EUAs;
Launching the first audited set of energy indices;
Brokering the first "clean" (emissions-related) spark spread.

Source: http://www.spectronenvironmental.com/about-us/category719.html

Table 12
EUA OTC Trading 2005-08 in mtCO2e

		Market Share		LEBA
	Volume	**ECX**	**Nordpool**	**Volume**
2005	66.664	77.88%	22.12%	22.703
2006	319.527	86.78%	13.22%	288.058
2007	716.950	91.25%	8.75%	874.938
2008	1,368.537	93.45%	6.55%	1,520.381

The volume totals are in millions of ton of CO2 equivalent (mtCO2e) and were collected directly from the two exchanges. Only ECX and Nordpool report their OTC transactions. The London Energy Brokers Association (LEBA) reports total trading volumes from 7 contributing brokers Cantor CO2e, GFI Brokers Limited, ICAP Energy, Spectron, Tullett Prebon, Tradition, and Evolution Markets.

Table 13
EUA Screen Trading 2005-08 in mtCO2e

		Market Share				
	Volume	**ECX**	**Nordpool**	**BlueNext**	**EEX**	**EXAA**
2005	55.838	63.57%	23.63%	7.81%	4.66%	0.33%
2006	233.893	72.33%	7.41%	13.27%	6.87%	0.13%
2007	451.000	83.30%	5.92%	5.26%	5.46%	0.06%
2008	1,180.883	70.42%	2.03%	20.87%	6.68%	0.01%

The volume totals are in millions of ton of CO2 equivalent (mtCO2e) and were collected directly from the five exchanges.

Table 14
EUA Spot Price Cointegration Analysis

Unit Root Tests		
	Zivot-Andrews	
Bluenext	-3.723	
	(0.130)	
Nordpool	-3.728	
	(0.129)	
Trace Tests		
	$r = 1$	$r = 0$
	234.249	1.554
	(0.00)	(0.21)
Coefficients		
	α	β
Bluenext	-0.576	1
	(0.00)	
Nordpool	0.296	-0.999
	(0.10)	(0.00)
Sample	25-Oct-05	31-Mar-08
Obs.	601	
Lags	2	

The sample of spot EUA prices from Bluenext and Nordpool runs from October 2005 to March 2008, a total of 601 observations. p-values are in parentheses. I interpolate from the Zivot-Andrews (1992) asymptotic critical values, -5.30 at 1% and -4.38 at 5%, to compute the p-values for unit root tests. The Schwarz criterion selects the lags in the VAR used in the Johansen trace test and estimation procedures. I utilize the finite sample corrected trace statistic and approximate p-values from Doornik (1998).

Table 15
EUA Futures Cointegration Analysis

Unit Root Tests		
	Zivot-Andrews	
ECX	-3.138	
	(0.173)	
Nordpool	-3.182	
	(0.170)	
Eurex	-3.693	
	(0.132)	
Trace Tests		
$r = 0$	$r = 1$	$r = 2$
941.679	316.359	1.063
(0.00)	(0.00)	(0.30)
Coefficients		
	α	β
ECX	0.701	1.000
	(0.00)	
Nordpool	1.660	-1.062
	(0.00)	(0.00)
Eurex	1.353	0.063
	(0.00)	(0.21)
Sample	04-Oct-05	29-Nov-07
Obs.	541	
Lags	1	

The sample of EUA futures prices runs from October 2005 to November 2007, a total of 541 observations. p-values are in parentheses. I interpolate from the Zivot-Andrews (1992) asymptotic critical values, -5.30 at 1% and -4.38 at 5%, to compute the p-values for unit root tests. The Schwarz criterion selects 1 lags in the VAR used in the Johansen trace test and estimation procedures. I utilize the finite sample corrected trace statistic and approximate p-values from Doornik (1998).

Table 16
ECX Futures Curve Cointegration Analysis

2006-05-05 to 2008-12-15					
			Unit Root Tests		
	Dec. 2008	Dec. 2009	Dec. 2010	Dec. 2011	Dec. 2012
ADF	-1.719	-1.719	-1.709	-1.697	-1.697
	(0.85)	(0.85)	(0.85)	(0.85)	(0.85)
PP	-1.738	-1.738	-1.738	-1.698	-1.680
	(0.85)	(0.85)	(0.85)	(0.85)	(0.84)
			Trace Tests		
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$
	394.491	176.516	55.031	13.202	3.608
	(0.00)	(0.00)	(0.00)	(0.11)	(0.06)
2008-01-02 to 2008-12-15					
	135.199	50.414	20.820	7.394	0.485
	(0.00)	(0.03)	(0.38)	(0.54)	(0.49)
			Coefficients		
	Dec. 2008	Dec. 2009	Dec. 2010	Dec. 2011	Dec. 2012
$\beta_{1,i}$	1.000	-4.067	7.697	-8.476	3.820
$\beta_{2,i}$	1.000	-1.615	0.133	-0.038	0.506
$\alpha_{1,i}$	-0.016	-0.012	-0.03	0.046	0.017
	(0.88)	(0.91)	(0.78)	(0.66)	(0.88)
$\alpha_{1,i}$	-0.399	-0.266	-0.309	-0.401	-0.419
	(0.34)	(0.53)	(0.48)	(0.36)	(0.36)

The table reports on cointegration diagnostics for December EUA futures expiries from the ECX. The first sample from May 2006 to December 2008 has a total of 541 observations, and the second, just for 2008, has 245.. p-values are in parentheses. ADF is the augmented Dickey-Fuller test and PP is the Phillips-Perron test. I use logistic interpolation from the asymptotic critical values to compute the p-values for the unit root tests. The Schwarz criterion selects the lags in the VAR used in the Johansen trace test and estimation procedures. I utilize the finite sample corrected trace statistic and approximate p-values from Doornik (1998).

Table 17
CER Screen Trading 2007-08 in mtCO2e

		Market Share				
	Volume	**ECX**	**Nordpool**	**BlueNext**	**EEX**	**EXAA**
2007	5.667	0.00%	100.00%	0.00%	0.00%	0.00%
2008	185.438	91.43%	4.23%	3.02%	1.32%	0.00%

The volume totals are in millions of ton of CO2 equivalent (mtCO2e) and were collected directly from the five exchanges.

Table 18
CER OTC Trading 2007-08 in mtCO2e

		Market Share					LEBA
	Volume	**ECX**	**Nordpool**	**BlueNext**	**EEX**	**EXAA**	**Volume**
2007	24.477	0.00%	100.00%	0.00%	0.00%	0.00%	18.055
2008	432.442	88.33%	11.58%	0.00%	0.10%	0.00%	325.441

The volume totals are in millions of ton of CO2 equivalent (mtCO2e) and were collected directly from the five exchanges. The London Energy Brokers Association (LEBA) reports total trading volumes from 7 contributing brokers Cantor CO2e, GFI Brokers Limited, ICAP Energy, Spectron, Tullett Prebon, Tradition, and Evolution Markets.

Table 19
Cointegration Analysis of EUA and CERs

				Trace Test	
Futures	**CER**	**Start**	**End**	$r = 0$	$r = 1$
ECX	Nordpool	01-Jul-07	30-Dec-08	9.307	3.156
				(0.34)	(0.08)
ECX	ECX	01-Apr-08	30-Dec-08	8.74	2.687
				(0.40)	(0.10)
ECX	ECX	23-Oct-08	30-Dec-08	11.315	2.724
				(0.20)	(0.10)

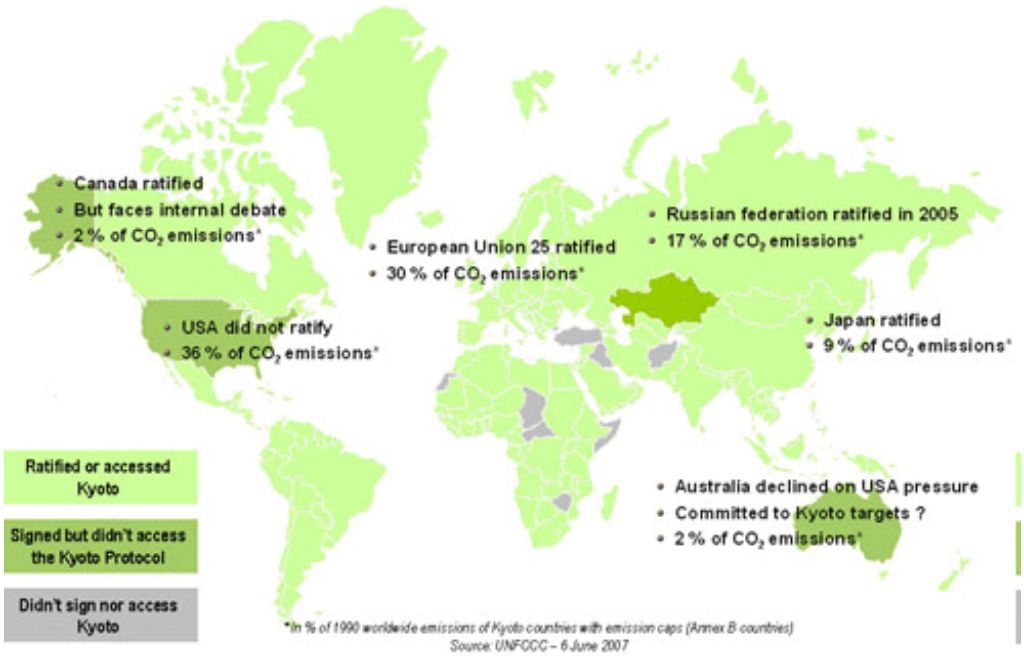
The Schwarz criterion selects the lags in the VAR used in the Johansen trace test. I utilize the finite sample corrected trace statistic and approximate p-values from Doornik (1998).

Table 20
Voluntary Emissions Market

	2007		2008	
Program	**Volume (mtCO2e)**	**Value ($mn)**	**Volume (mtCO2e)**	**Value ($mn)**
OTC	43	263	54	397
CCX (CFI)	22.9		69.2	

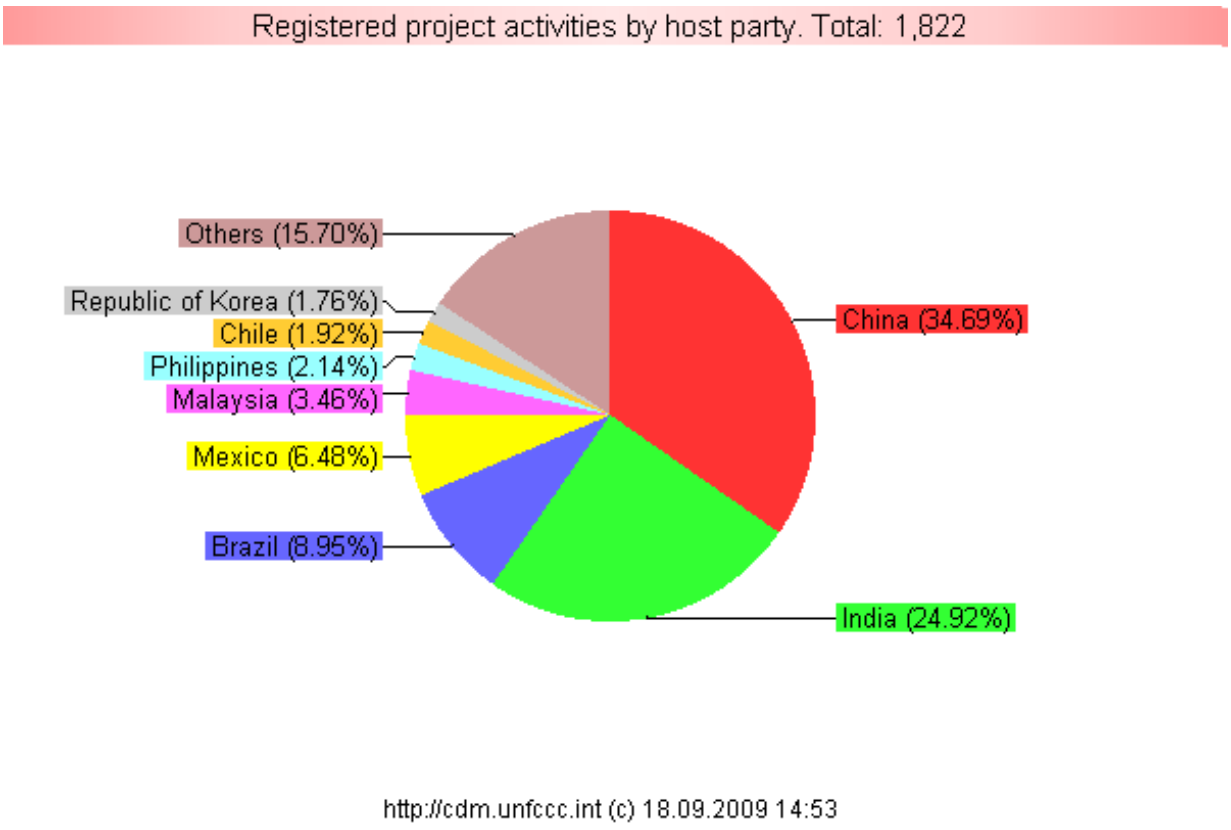
Source: OTC data are from the World Bank, *State and Trends in the Carbon Market* for 2009 for OTC projects. The CFI data are from the Chicago Climate Exchange website.

Figure 1
Status of Kyoto Protocol



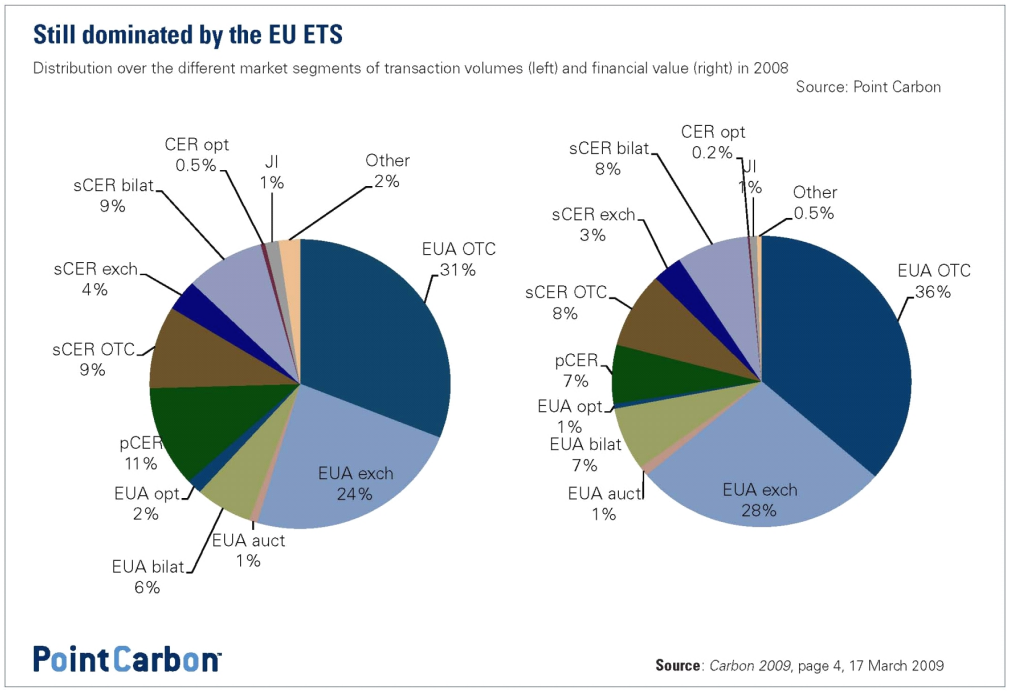
Source: http://greenpointenergy.net/Knowledge-Base/Kyoto-Protocol.html

Figure 2
Sources of Registered CDM Projects



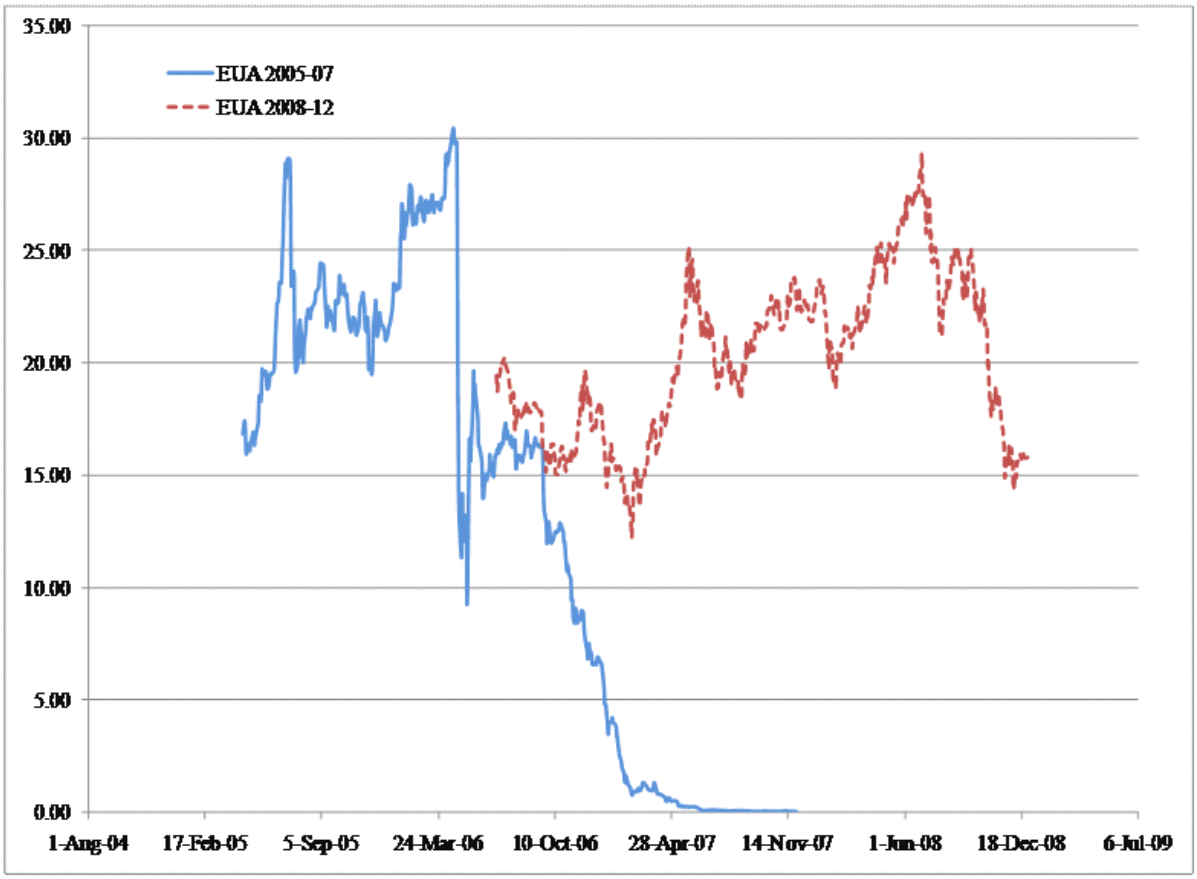
Source: UNFCC.

Figure 3
Market Overview



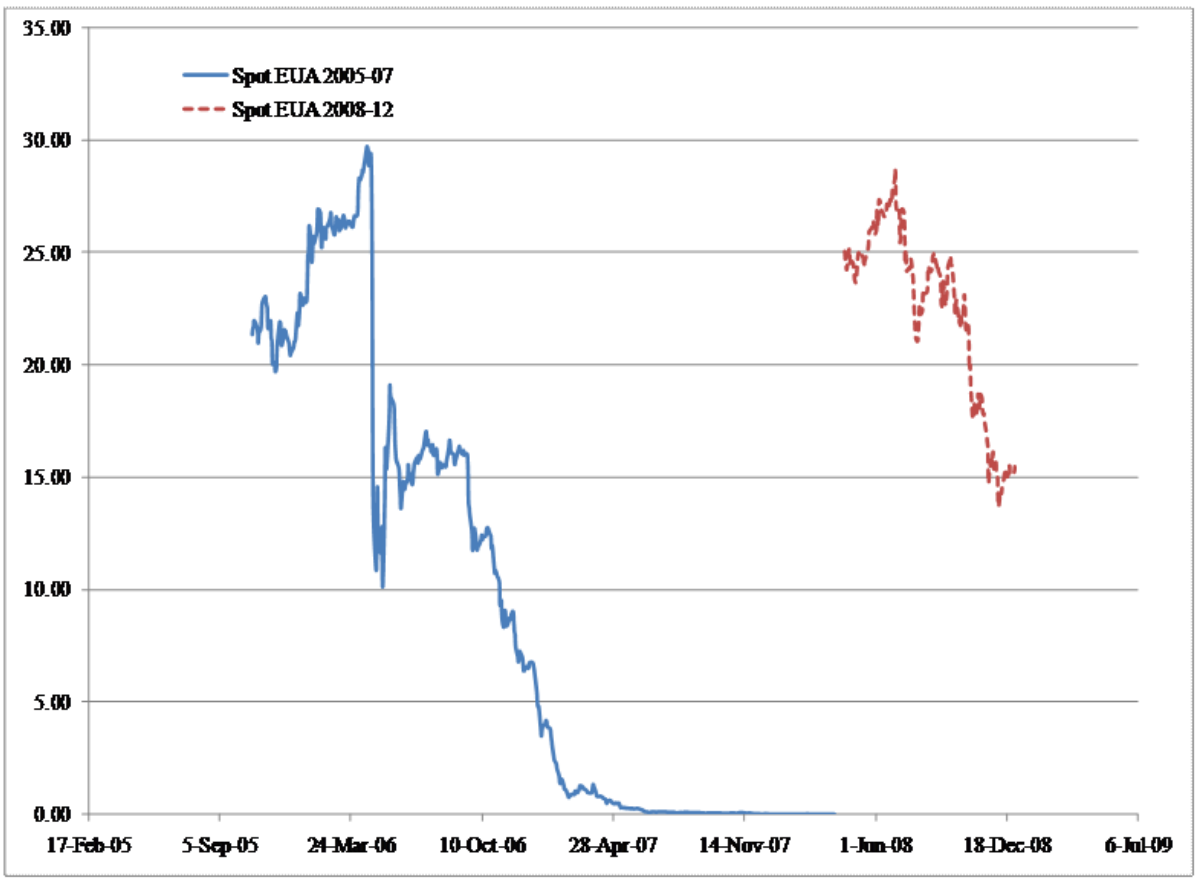
Source: Point Carbon.

Figure 4
EUA Futures Prices



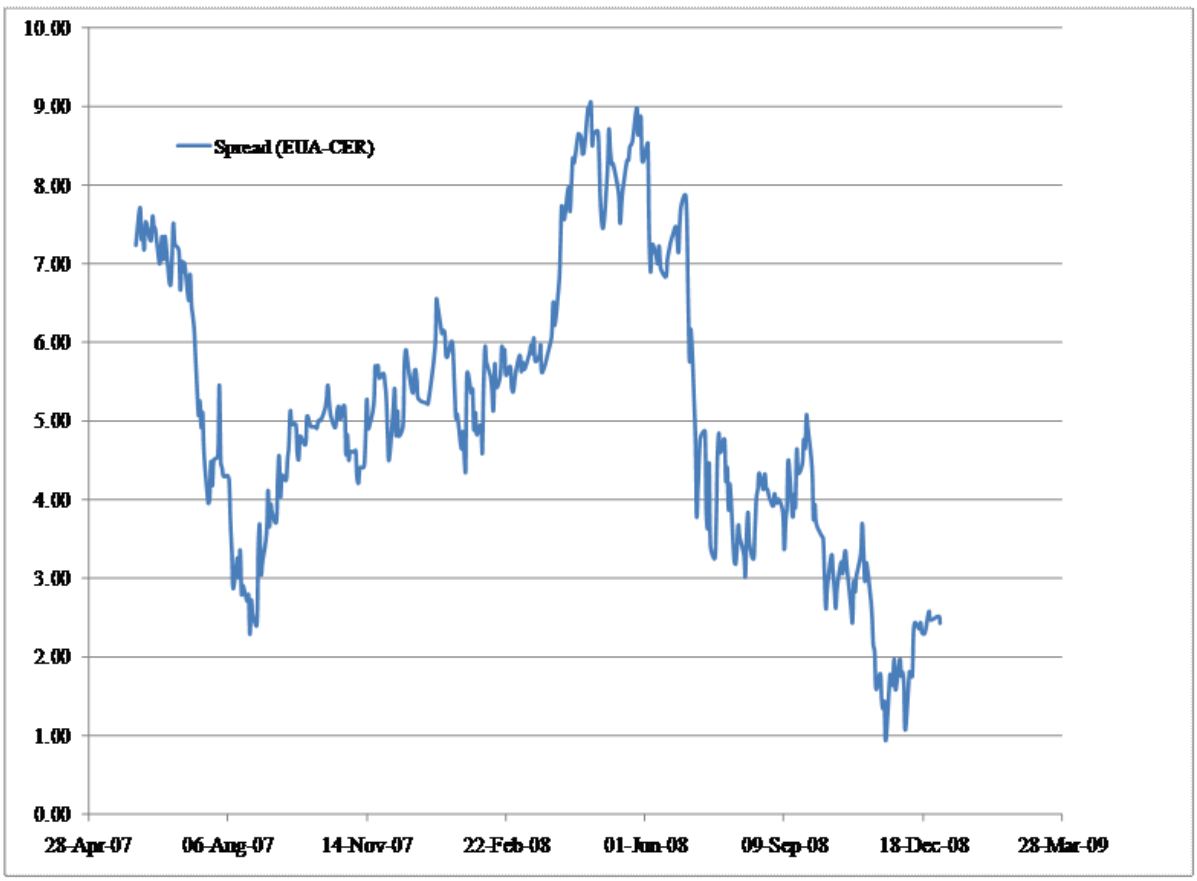
The data are from a rolling near month ECX contract. The EUA 2005-07 trades from March 2005 to November 2007. The EUA 2008-12 trades from March 2006 to December 2008.

Figure 5
EUA Spot Prices



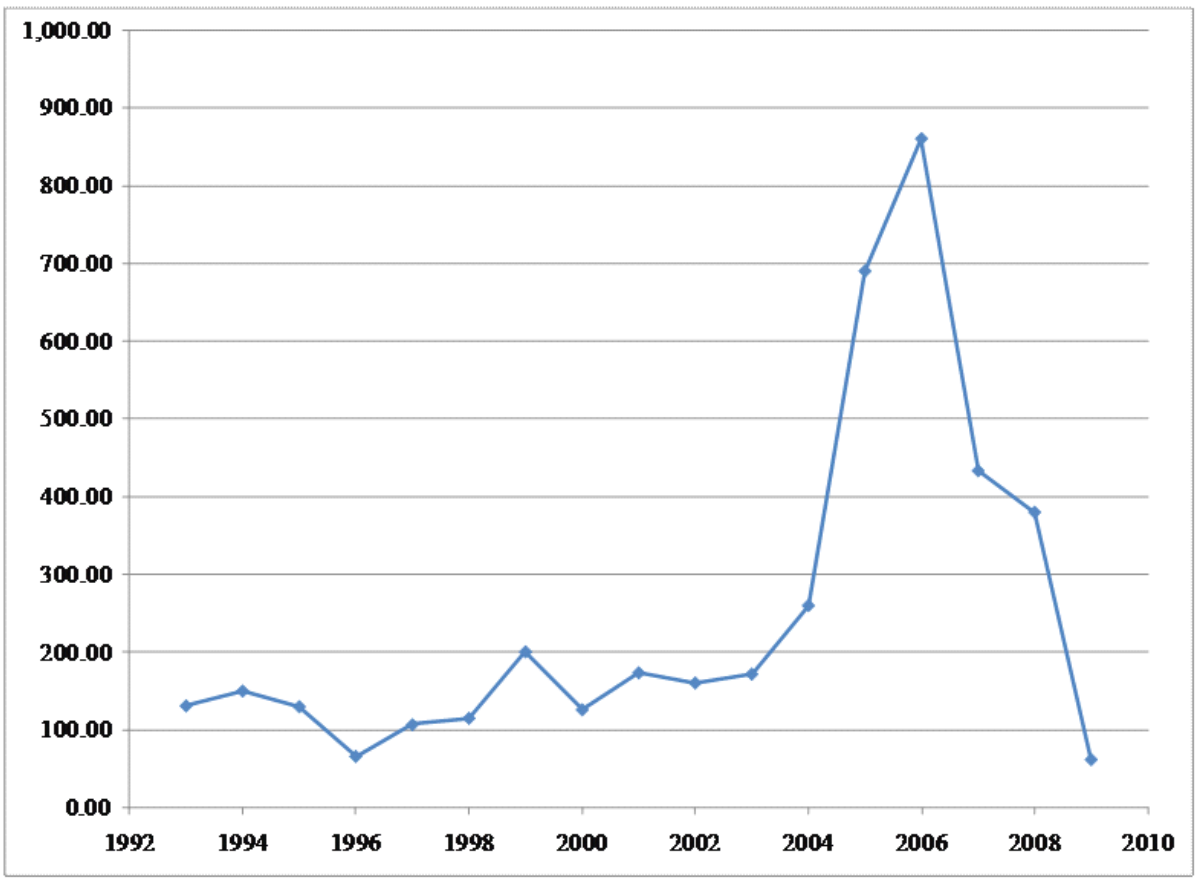
The data are from Bluenext and cover the period from October 2005 to March 2008 for the 2005-07 spot series and from April to December 2008 for the 2008-12 series.

Figure 6
EUA-CER Spread



The data are from Nordpool and cover the period from June 1, 2007 to December 31, 2008.

Figure 7
EPA Acid Rain Program SO2 Market Clearing Spot Auction Prices



The EPA auctioned 1995 allowances, the first year of the program, in 1993 and 1994. All the other auctions occur in March of the allowance year.