Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial
2010

Maria Isabel Rodrigues Bastos

Formação do Preço nos Mercados Financeiros de Carbono da Europa

Price Discovery and Price Transmission within CO_2 European Financial Markets

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Economia, realizada sob a orientação científica do Doutor Joaquim Carlos da Costa Pinho, Professor Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro

I dedicate this work to all my teachers and coachers without whose support my whole professional history would have been very different. It would have been much less productive and much more difficult, certainly. Likewise, I want to dedicate this work to all my workers and students, too. In an attempt to teach them well I have acquired a bit more knowledge.

Dedico este trabalho a todos os meus professores, orientadores e *coachers* que me acompanharam ao longo de toda a minha vida estudantil e profissional. Sem eles o meu percurso teria certamente sido bem diferente, talvez mais difícil. Do mesmo modo, também o dedico a todos os meus colaboradores e alunos a quem ao longo dos anos me foi atribuída a responsabilidade de ensinar, desenvolver e orientar. Ao fazê-lo, também cresci um pouco mais.

o júri

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palavras-chave

CO_2, licenças de emissão de CO_2, licenças de emissão de CO_2, preço do carbono, futuros do carbono, cost-of-carry no carbono, formação de preço no carbono, carbon finance, aquecimento global, Gases com Efeito de Estufa (GEE), EU ETS, Protocolo de Kyoto, Comércio de Carbono, Emission Unit Allowances (EUA), Certified Emission Reductions (CER), European Union Emission Trading Scheme (EU ETS).

resumo

O desenvolvimento económico iniciado com a revolução industrial nos finais do século XVIII, deu origem a níveis crescentes de poluição em todo o mundo. O esgotamento dos recursos naturais, preço pago por todas as amenidades criadas, levou os governos mundiais a procurarem um acordo internacional que limitasse o aumento da poluição. A primeira tentativa a, conseguir o consenso internacional foi o Protocolo de Quioto, que entrou em vigor a 16 de Fevereiro de 2005, 90 dias após a ractificação da Rússia. Nele, 54 países concordaram reduzir em 20% as emissões dos Gases com Efeito de Estufa (GEE), até 2020 e com base nas emissões verificadas em 1990. No seguimento da assinatura do Protocolo de Quioto, a União Europeia pôs em marcha o seu próprio plano de controlo das emissões de carbono, designado por "European Union Emission Trading Scheme (EU-ETS)", que, desde então, tem liderado os movimentos mundiais para o controlo do CO_2. Enquadrando-se nas linhas gerais de Quioto, o EU-ETS foi implementado através duma directiva europeia com o objectivo global de fazer incorporar nos custos de produção as externalidades causadas pelas emissões poluentes e promover o investimento em tecnologias limpas, impondo limites máximos ("*caps*") às emissões de cada país e instituindo esquemas específicos para a comercialização de carbono, com vista à mitigação das emissões já emitidas. Alguns anos depois do lançamento do EU-ETS, surgiram os produtos financeiros de carbono.

Até ao momento os mercados de emissões ainda não foram estudados de forma consistente, duma perspectiva financeira, e são ainda necessárias novas investigações académicas sobre o tema específico da dinâmica da formação dos preços dos EUA, dos CER e de todos os restantes activos de carbono, incluindo os seus derivados.

Assim sendo, e com base na informação publicada pela European Energy Exchange (EEX) ao longo de um período de mais de cinco anos, a presente dissertação procura avaliar qual dos mercados – *spot* ou *forward* – lidera o processo de formação do preço do carbono.

Após a análise estatística das características dos dados, analisaremos ao pormenor os preços *spot* e os preços dos futuros de carbono, focando-nos nos conceitos mais importantes dos *commodity markets*: o *convenience yield*, o prémio de risco e a relação entre estas duas variáveis. Ao analisarmos os preços dos futuros de carbono duma perspectiva *ex-post* para verificar se existe evidência empírica para um prémio de risco positivo, concluímos que se verifica uma relação negativa entre os prémios de risco e o *time-to-maturity* de cada activo em análise. Ao investigarmos quais os factores que influenciam os prémios de risco e o *convenience yield*, obtemos resultados que sugerem que ambos são afectados negativamente pela volatilidade do preço *spot*, e que o preço tem um impacto positivo no *convenience yield*; mais, vemos que no geral os *convenience yields* influenciam de forma positiva os prémios de risco.

Sendo variáveis os resultados obtidos em função da Fase do Protocolo Quioto a que dizem respeito os activos analisados e das respectivas maturidades, há evidência de que os direitos de emissão - e o EU-ETS em particular – parecem estar a atingir os resultados procurados no que diz respeito à protecção do ambiente, reduzindo os GEE. Há também indícios crescentes de que as incertezas quanto à viabilidade futura do EU-ETS estão a diminuir.

Como suporte à definição de políticas, destacamos a evidência empírica de que as externalidades provocadas pelos GEE já estão a ser incorporadas nas estruturas de custo dos agentes económicos, nomeadamente nos preços da electricidade. Contudo, a permissão do *short-selling* e do *banking* entre períodos sucessivos do Protocolo de Quioto poderia aumentar a liquidez e melhorar a eficiência do mercado de carbono.

Por último, os factores combustíveis (carvão, gás e petróleo), condições climatéricas e restrições do mercado, revestiram-se de particular interesse ao evidenciar a relação dos contratos de CO_2 com a intensidade de consumo de energia, nomeadamente com os mercados electricidade (*spot* e de futuros).

keywords

CO_2, Carbon-dioxide allowances, carbon pricing, carbon futures, carbon cost-of-carry, carbon price discovery, market efficiency, carbon finance, global warming, Green House Gas (GHG), EU ETS, Kyoto Protocol, Carbon Trading, Emission Unit Allowances (EUA), Certified Emission Reductions (CER), European Union Emission Trading Scheme (EU ETS).

abstract

World economic development, starting with industrial revolution in the late 18th century, has led to increasing pollution levels all over the world. Depletion of natural resources has been the result and the price paid for all the amenities and comfort bring by development. Because of this, world governments decided to try to find a consensual way to control pollution escalation. The first successful international attempt to do that is known as 'The Kyoto Protocol' and entered into force on 16 February 2005, 90 days after its ratification by Russia. There, 54 countries put forward the overall goal of reducing GHG emissions by 20% below 1990 levels, until 2020.

Following Kyoto Protocol signature, European Union has implemented its own carbon control scheme, the so-called European Union Emission Trading Scheme (EU-ETS), which leads the carbon control worldwide movements, since then. With the general aim of incorporating externalities caused by pollution in the production costs and to foster investment in clean technologies, the EU-ETS was launched through an EU directive. Within Kyoto framework, this new EU ETS imposed emission's caps over each European country and established specific carbon trading schemes to mitigate emitted pollution.

Some years after the launching of EU ETS, carbon financial products have also developed all over international Stock Exchanges. So far, emission markets have not yet been consistently studied from a financial point of view and we still have a lack of academic work on the specific subject of pricing dynamics of the EUAs, CERs and other carbon assets, as well as its derivatives.

So, using European Energy Exchange data with a time spam of more than five years, this thesis attempts to evaluate which market – spot or forward – leads the carbon price discovery process. We focus specifically on carbon future prices and on carbon spot prices, analysing them in a most thorough way.

After analyzing the statistical properties of data, we focus on the most important concepts in the commodity markets: the convenience yield, the risk premium and the relationship between these variables, for the Exchange under analysis.

We analyze carbon futures prices from an *ex-post* perspective to find if there is evidence for significant positive risk *premia* and conclude that a negative relationship between risk *premia* and time-to-maturity does exist. When testing for factors influencing risk *premia* and convenience yields, we obtain results implying that spot price volatility impact negatively both of them and that the price itself impact the convenience yield in a positive way; more, generally convenience yields influence risk *premia* in a positive way. Results change depending on the Kyoto Protocol Phase and on the characteristics of the assets used, but seem to confirm that uncertainties about the future of the EU ETS are disappearing. So, we can assume that allowances appear to be producing the desired results, in terms of environmental protection.

For policy, empirical evidence found that there is already a pass-through of externalities caused by GHG costs into the cost structure of economic agents, influencing namely electricity prices. The EU ETS seems, though, to fulfil its goal of reducing GHG emitted. Nevertheless, allowing short-selling and banking between successive Kyoto periods could increase liquidity and improve market efficiency.

Finally, the role of fuels (coal, gas and oil), weather and market constraints, was found to be of particular interest relating CO_2 contracts to energy consumption intensity, namely to electricity spot and futures markets. Moreover, the recently created liberalized electricity market throughout Europe encouraged the development of environmental protection policies since newly carbon financial contracts emerged in this context.

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List of Abbreviations

AAU – Assigned Amount Units of CO_2 emissions permits

CC – Climate Change

CCS - Carbon Capture and Storage

CDM - Clean Development Mechanism

CER - Certified Emission Reductions

CO_2 – Carbon Dioxide

EC - European Commission

ECF – European Carbon Futures

ECX - European Climate Exchange

EEX – European Energy Exchange

ERU - Emission Reduction Unit

ET - Emission Trading

EU ETS - European Union Emission Trading Scheme

EUA – Emission Unit Allowances

GHG – Greenhouse Gases

IET – International Emissions Trading

IPCC – International Panel on Climate Change within the United Nations Framework

JI - Joint Implementation

LULUCF – Land Use, Land Use Change and Forestry projects

NAP - National Allocation Plans

UNFCCC – the United Nations Framework Convention on Climate Change

OTC – Over-the-counter

Chapter 1. Introduction and Structure of the Thesis

The debate about greenhouse gases (GHG) still is at world spot light and the interest it catches (from scientists, governments, enterprises and the general public) is reinforced by all natural catastrophes and climate changes impact on our everyday life, anytime somewhere in the planet. In fact it is increasingly accepted that anthropogenic climate change is enhanced through increased emission of pollutants such as CO_2. Human activities, in particular the development of industry and population growth over the last 200 years, have caused an increase in atmospheric concentration of GHG, mainly carbon dioxide and methane. The augmentation of these gases in the atmosphere - in itself essential to the existence of life - intensifies the natural greenhouse effect that occurs on Earth and leads to the increase in planet average temperatures. This temperature increase causes sea-levels to rise and weather conditions to worsen, giving way to major storms, floods and droughts and causing increasingly severe disruptions on climate and on Earth's life system as we know them. It is now widely accepted that all these environmental problems will have huge economic and social impact.

Because of that, climate change (CC) is no longer an issue discussed by specialists only and has become a focus of general interest among ordinary people and media. As a consequence of all this public attention, societies, led by governments, have been trying to take action to reduce their GHG emissions either voluntarily or through regulatory constraints.

The first international agreement on climate change has been put forward in Kyoto in 1994, entered into force on 16 February 2005, after having been signed by 54 countries and has been formally adopted in 1997. It became known as the Kyoto Protocol with the overall goal of reducing GHG emissions caused by humankind. Specifically it aims to reduce carbon emissions by 20% below 1990 levels, until 2020.

CC is, above all, a terrible threat in most people's minds, but beating climate change is also a historic opportunity to turn humanity onto a path of sustainable growth for everyone around the globe. In fact, the solutions to fight against climate change and stabilize environment will produce further economic development and will vitalize economies, building secure, fairer and more innovative societies. So, not only we must act, but it makes no sense not to act, some authors claim.

In order to fulfill the requirements of the Kyoto Protocol, the European Union has decided to introduce its own emission trading system, the so-called European Union Emission Trading Scheme (EU ETS), which imposes over European countries specific emissions' limits. The EU directive is transposed into national law through the so-called National Allocation Plans (NAPs) where flexible instruments allow national polluting entities for yearly efficient CO_2 abatements. Through NAPs, each year emissions are reduced first where it is possible to do so at the lowest cost.

The purpose of the EU ETS is threefold:

First, to cut carbon emissions, through the definition of a cap fixing the amount each polluting entity can emit over a certain period of time. To respect the cap, either production / consumption have to be reduced or - and that is the more realistic and desired approach - or more efficient technologies must be developed, i.e., industries must switch to "cleaner" technologies.

The **second** aim of the EU ETS is to internalize externalities caused by CO_2 emissions: a higher concentration of carbon in the atmosphere is harmful to everyone, thus people producing CO_2 should pay for it.

Third, European climate policy seeks to foster firms investment in cleaner technologies.

Because of all this legal, social and economic dynamics, CO_2 financial markets have also developed and carbon financial products (based on carbon emission allowances and/or carbon emission reduction credits) have been launched and started being traded with increasing liquidity within international stock exchanges, namely those related to the EU emissions trading scheme. Besides spot contracts, futures and options, carbon financial assets are also available OTC and on exchanges across Europe.

To study the relationship between EU ETS CER and EUA spot and futures prices on European Exchanges and to facilitate progressive building on knowledge, we have chosen to structure our study in five parts: Chapter one presents the introduction and the structure of the Thesis; Chapter two prepares the way for our main objective, presenting the basics of Carbon Market and of Carbon Finance; Chapter three makes a quick literature review related with our theme, allowing us to make the ‘problem formulation’ we want to address; Chapter four presents the data we have used and their statistical properties, and provides the models to be used in the empirical analysis on carbon spot and futures prices in the EEX Exchange, analyzing the evolution of data through time and the relationship that exists between spot and future prices, illustrating the concepts of risk premiums and convenience yields in futures markets; Finally, Chapter five presents and explores the empirical results, presents some policy recommendations and concludes.

Chapter 2. The Basics of Carbon Market and Carbon Finance

2.1. Carbon Market: Policies, Mechanics and Market Segments

The Intergovernmental Panel on Climate Change is an international scientific forum, created in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to help humanity deal with one of the most fundamental challenges of human History: the transition to a low-carbon economy. Its main goal has been to provide world political leaders and thinkers with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. Through a number of reports it has helped developing scientific consensus on the subject.

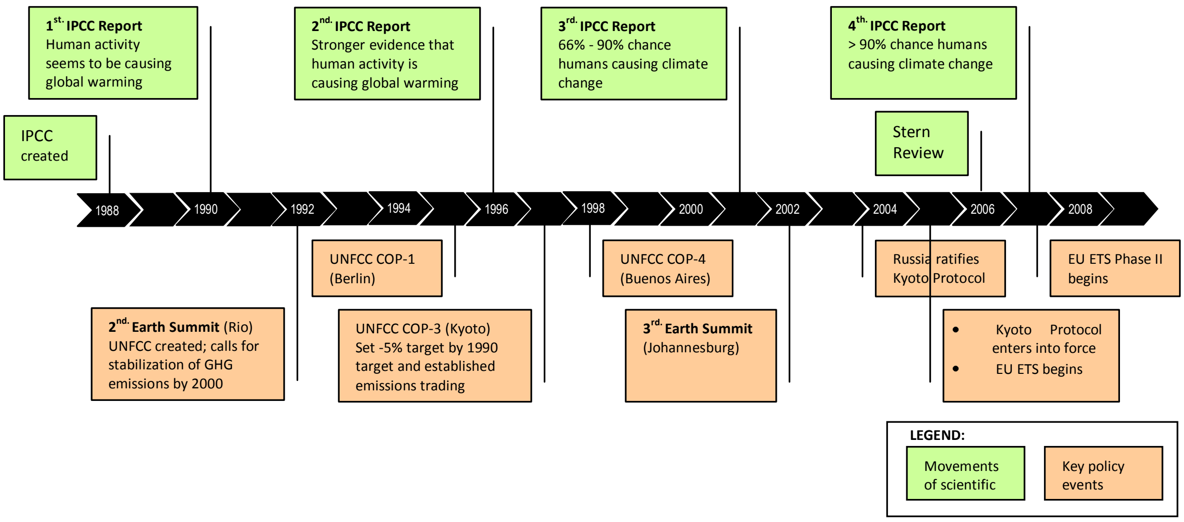


Figure 1: Perspective View of Kyoto Protocol Process

Over a decade ago, in 1992 the United Nations Framework Convention on Climate Change (UNFCCC) has been put forward and created the umbrella framework on climate change which set a strategic direction ("reducing greenhouse gases emissions is good and we all should do it"). This is the largest global consensus framework ever ratified - it is now signed by 194 countries – and, since then, together with the IPCC, the UNFCCC tries to influence world progress on the subject. More recently, a number of nations approved an addition to the treaty: the Kyoto Protocol, which has more powerful (and legally binding) measures.

2.1.1. Carbon Emissions Control Policies – Ways of Action to Solve the Problem

Climate Change issues are not consensual. Across a wide spectrum, some voices argue that carbon emissions and climate change are not linked, while others consider one originates the other and urge immediate concerted global action to reduce the flow of emissions into the atmosphere. Even among those that advocate for action there are not consensus about timing, goals, and means. Despite all the controversy, one thing is certain: any form of intensified regulation will have (and is already having) profound implications on business.

2.1.1.1. The Stabilization Wedge Theory by PACALA and SOCOLOW

In 2003, Professors Socolow and Pacala of Princeton University proposed 15 potential wedges to act over carbon emissions. They have said that to maintain the same global level of carbon emissions between 2004 and 2054 one would merely had to choose 7 out of the 15 wedges they propose and then implement, manage and control them along all the subsequent 50 year period.

They thought of each wedge to be one strategy. The 15 wedges (strategies) they proposed were:

- To drive more efficient vehicles;
- To reduce the number of vehicles on the road;
- To produce more energy efficient buildings;
- To make the coal power plants two times more efficient;
- To switch from coal to gas in base load power production;
- To capture CO_2 at base load power plants and store it;
- To capture CO_2 at hydrogen producing power plants and store it;

- ➡ To capture CO_2 at coal to syn-gas[1] fuel plants;
- ➡ To use nuclear power instead of coal;
- ➡ To use wind power instead of coal;
- ➡ To use photovoltaic power instead of coal;
- ➡ To use wind produced hydrogen in fuel-cell cars instead of gasoline;
- ➡ To use biomass fuels instead of fossil fuels;
- ➡ To reduce deforestation and afforest areas that are currently been denuded of forest;
- ➡ To change agricultural methods from intensive to 'conservation tillage'.

In their opinion, each wedge/strategy has different levels of efficiency and must be carefully combined with other in order to achieve specific policy targets results.

2.1.1.2. Climate Change Investment Strategies

In 2006, British economist Nicholas Stern stated that the benefits of early action on climate change considerably outweigh costs. "*Unless emissions are curbed, climate change will bring high costs for human development, economies and the environment"*, he said. The report he published – the Stern Review - concluded that resource costs required to avoid many of the worst impacts of climate change would be only around 1% of global GDP over a 50 years period (until 2050). Additionally, in the report it was argued that the amount needed to invest would not only be a cost but would also create opportunities, would add to global competitiveness and probably would have other lateral benefits. Finally, the Stern Review argued that investment made in CC would also avoid an expected cost of minus 5% of consumption by mitigating climate change market impacts and risk catastrophe (in his report's baseline climate view Nicholas Stern has given each impact/risk some probability curves).

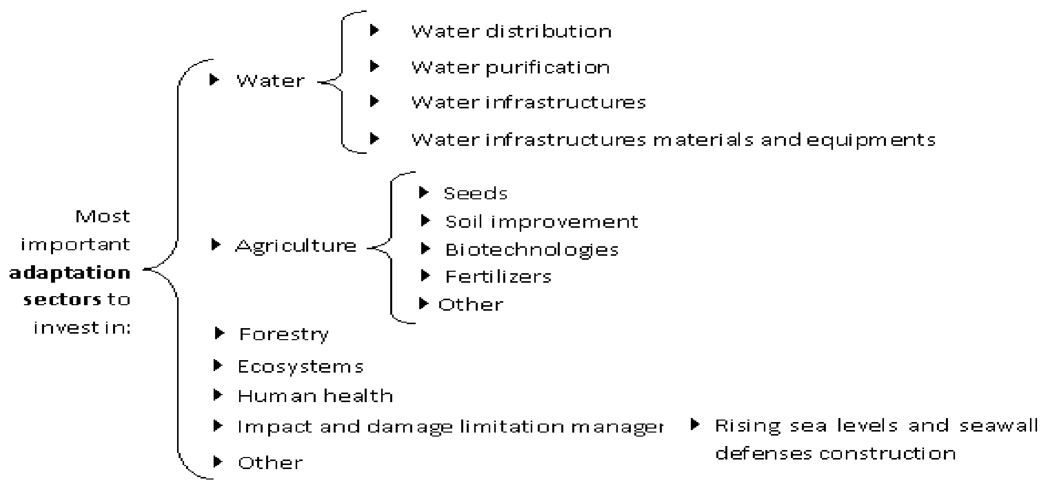
Stern report concluded saying that "*if we invest now, while time frames are long, we are going to have a return on our investment in terms of avoided costs that can be pretty*

[1] Syn-gas is the abbreviation for Synthesis gas. This is a gas mixture that comprises of carbon monoxide, carbon dioxide and hydrogen. The syn-gas is produced due to the gasification of a carbon containing fuel to a gaseous product that has some heating value. Some of the examples of syn-gas are as follows – gasification of coal, waste to energy gasification, steam reforming of natural gas to generate hydrogen. Syn gas has 50% the energy density of natural gas.

significant (factors between 5 and 20 times the required investment, depending upon the future climate scenarios and some other complex factors)".

Even though it is somewhat unusual for investors to include adaptation in their investment portfolio, people still have two ways of action to abate CO_2 and to minimize climate change (CC): mitigation or adaptation.

Adaptation tries to solve problems caused by the carbon already emitted or the one we cannot avoid to emit (that will be emitted for sure, considering present economic and social conditions and outlooks). So, adaptation seeks to deal with global warming that is already taking place or that will inevitably take place in the future. It has been driven mostly by people who believe climate change is really taking place but it is thought to include more and more governments in a near future. Water is one of the most important adaptation sectors for investment within climate change. Others are population growth and infrastructure issues. An exhaustive perspective would be:



Mitigation focuses on how to stop the carbon from being emitted (or on how to reduce carbon emission levels) and tries to change present and future behaviors. Mitigation sectors include the alternative energies and cleantech sector projects, namely: Power, Energy Efficiency, Transportation, Buildings, Industry, Agriculture, Waste and Forestry. Classic Clean Technologies: Solar, Wind, Water, Geothermal, Bioenergies, other clean technologies.

However, it is commonly agreed upon that effective action on Climate Change will require: long-term quantity goals, joint efforts to limit costs, a broadly comparable international price for carbon, cooperation to develop efficient clean technology, effective regulation and fair distribution of effort among all international players. All seasoned with good standards, transparency, political persuasion and, finally, a good public understanding of actions and policies implemented.

2.1.2. The Kyoto Protocol Mechanics

Kyoto Protocol (KP) addresses both carbon adaptation and carbon mitigation and functions based on a 'shortage', a need for carbon assets, artificially created by KP signing parties through emissions limitation, formally entered into the Protocol. It 'imposes' carbon emissions limits over governments for those countries who have ratified it - both the industrialized and the transition ones - who, in turn, restricts emissions of national entities through the so-called "grandfathering" of permits. This entails providing permits to firms for free, on the basis of its historical emissions although keeping in mind the aim of progressive carbon emissions reduction, one year after another. Cap limit is the lever controlled by governments, who control the supply of credits received.

By ratifying Kyoto Protocol, governments accept these limits and impose them on domestic market actors, negotiating allocation plans and allocating each company an amount of credits for every year. Entities that, for whatever reason, emit less in a given year than the emitting limits they have, can take the exceeding amount of credits they didn't use (as a result of emitting less) or those they generate (as a result of investing in CDM[2] or JI[3] projects) and sell them to a company who is going to emit more.

Kyoto Protocol implementation has been organized in three different periods. Phase One of Kyoto Protocol began in 2005 with Russia's ratification and ran until December 2007. Phase II, the Kyoto commitment period, has started about three years ago and it will end in 2012. Discussions to find an agreement for a third period are under way but have already experienced some difficulties. The so-called Post-Kyoto Phase is expected

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[2] Clean Development Mechanism (see § 4 hereafter).

[3] Joint Implementation Projects (see § 4 hereafter).

to run from 2013 to 2020, but its details are still subject to the results of those negotiations (the first attempt to reach a deal has been a public failure, at Copenhagen 2009, followed by the recent Cancun 2010 world meeting on Climate Change).

To help each country meet the specific carbon target it has been given (carbon reductions targets, measurable **emission caps** that governments have to reach against a 1990 'baseline' or starting point), Kyoto Protocol introduced the well known "emission allowances" together with three **flexibility mechanisms**. These 'Flex Mex', as they are called - aimed at GHG emissions reductions and viewed both as critical and innovative - allow governments to interchange and to trade their carbon credits among each other; then, governments allow their own economic actors to do the same. The Flex Mex are considered to be the reason behind all the interest in terms of carbon investment, carbon trading and carbon finance.

Kyoto Protocol incorporates three types of flexible mechanisms, which are: the clean development mechanism (CDM), joint implementation projects (JI), and international emissions trading (IET). CDMs are mechanisms through which investment can be made by historic carbon emitters – developed countries -, to help developing world new infrastructures to become less carbon intense. They constitute a kind of a 'steam valve' that ties together efficiency (in terms of marginal abatement cost), responsibility and equity. Along with CDM we have JI projects, which allow industrialized[4] or transition countries to jointly invest in emission reduction projects in other industrialized and transition countries. For emission reductions resulting from JI and CDM projects, countries are granted Emission Reduction Units (ERU) and Certified Emission Reductions (CER) respectively, which they may use to comply with their emission caps. Unlike CDM, which generates additional reductions, JI projects only allow carbon allowances transfer from one country to another; thus, the total authorized emission level remains the same after the implementation of a JI offset project. IET allows for emissions trading between governments resulting from country's carbon allowances surplus/deficit.

[4] Very often the industrialized countries are referred to as Kyoto Protocol annex B countries.

2.1.2.1. TYPES OF KYOTO COMPLIANCE UNITS

There are several kinds of Kyoto compliance units which have the same value in terms of carbon control: Assigned Amount Units (AAUs), Certified Emissions Reductions (CERs), Emission Reduction Units (ERUs) and Removal Units (RMUs).

- ➡ AAUs are the total budget of emission units assigned to each nation for a given period of time, resulting from the specific Kyoto Protocol reduction target that has been negotiated.
  - ↳ EUA is the EU ETS emissions' unit which has been thought of to be equivalent to a unit of carbon emissions under Kyoto Protocol. That is, an emission permit for a ton of CO_2e[5] in the EU ETS, known as a European Union Allowance (EUA), is fungible with the Kyoto permits that governments use to comply with their Kyoto targets.
- ➡ CERs are additional carbon emission permits that states or polluting entities may obtain through the CDM Kyoto Flexible Mechanisms, designed to help developing countries reduce their dependency on GHG emissions as their economies grow. CERs are created by a firm or an Annex B[6] country's investing in a CO_2e-reduction technology in a developing country project that would not have occurred otherwise. CERs are thus intended to work as carbon offset credits and offer developed countries the opportunity to access cheaper abatement opportunities than might exist domestically, by helping non-Annex I[7] countries mitigating their carbon production. Largely because of their attractiveness as a source of cheap offsets, demand for CERs among European firms has been growing substantially since the EU ETS began. The supply however, has been constrained by the EC because of doubts about if CDM projects are actually contributing to real emissions reductions.

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[5] CO_2e stands for CO_2 equivalent units of any greenhouse gas.

[6] Annex B in the Kyoto Protocol lists those developed countries that have committed themselves to control their greenhouse gas emissions in the period 2008–12, including those in the OECD, Central and Eastern Europe and the Russian Federation. The list of Annex B countries currently (2007) matches that of Annex I, with the exclusion of Turkey (UNFCC)

[7] By default the countries other than those of the Annex I, are referred to as Non-Annex I countries. Annex I to the UNFCCC lists all the countries in the Organization of Economic Cooperation and Development in 1990, plus countries with 'economies in transition', Central and Eastern Europe (excluding Albania and most of the former Yugoslavia). Under Article 4.2 (a and b) of the Convention, Annex I countries commit themselves specifically to the aim of returning individually or jointly to their 1990 levels of GHG emissions by the year 2000. (UNFCC). Non-Annex I countries are developing countries recognized by the Convention.

Therefore, the EC examines all CERs created from CDM projects thoroughly before admitting them into market circulation as fungible carbon credits.

- Finally, ERUs are credits similar in nature to CERs, except they are offset credits that are created by the investment in carbon technology by one Annex B country in another Annex B country through the Kyoto Protocols Joint Implementation (JI) programs. Intended to provide a similar function to that of CERs, JIs have been specifically relevant in the former soviet states of Eastern Europe; nevertheless, its market volume has been extremely small since carbon emission trading schemes began.

Total surrenders for 2008	**2.075.245.163**	**100,00%**
CERs and ERUs	81.717.146	3,90%
2008 free allowances	1.908.402.867	92,00%
2009 allowances or allowances purchased at auction	85.125.150	4,10%

Source: European Commission; IP/09/794; May 2009

FIGURE 2: CARBON ASSETS AMOUNTS SURRENDERED IN YEAR 2008 (EUROPE)

- Specific to LULUCF[8] we still have Removal Units (RMU), which are generated in Annex B parties by LULUCF activities that absorb carbon dioxide. Annex B Parties can use RMUs to help meet their Kyoto Protocol commitments.

2.1.3. World Carbon Markets

There is not one carbon market in the world, but many carbon markets. In a way, we can think about them as carbon “currencies”.

The Kyoto Protocol is the bigger world carbon ‘currency’ market whose total ‘capital stock’ is around 60 billion tons of CO_2. Within Kyoto Protocol each government hold in a government ‘account’ or register its own AAU (European countries have 26,2 billion of these AAU ‘carbon units’, a part of which are distributed through the EU ETS).

Additionally to the big 57 billion Kyoto allowances market, we have the Kyoto Protocol Flexible Mechanisms ‘currencies’ (CER, ERU and RMU) which are “created” by emitting entities investing in CDM, JI or LULUCF projects and add to the AAU market.

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[8] Land Use, Land Use Change and Forestry projects.

The Flex Mex market is estimated to value between 1,5 and 2 million CO_2e tons (coming mainly from CDM and JI projects).

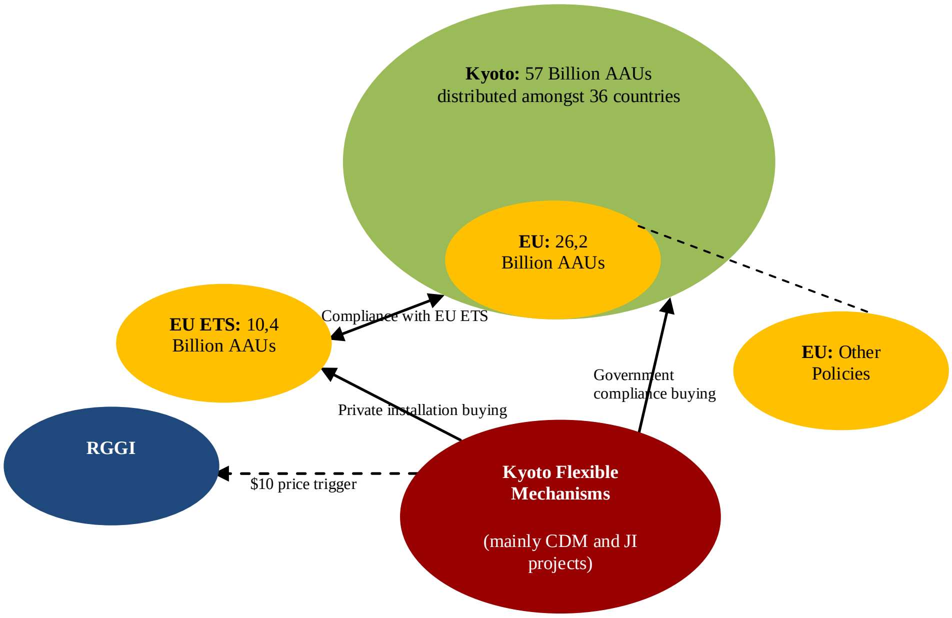

FIGURE 3: WORLD CARBON MARKET SEGMENTS

The most significant CDM and JI greenhouse gas reduction project types (or Project Classes) include industrial gas[9] projects (the biggest class because of its projects being the cheapest to be implemented), renewable energy projects (second largest class; may grow to be the largest as the industrial gas projects start being finished), methane reduction projects (third class; mainly from cement plants, coal mines and waste treatment processes and storage), energy efficiency, fuel switching, transportation and biomass (afforestation/reforestation projects).

The cost of reducing one ton of CO_2 is very different from company to company, from sector to sector and from country to country. Therefore, there are companies that will find it cheaper to invest in reducing their own emissions and others that will prefer to invest in their suppliers' reduction or in developing countries projects (CDM and JI, e.g.). Each one must find their best and most efficient way, starting by 'the low hanging fruit', the cheapest emission reductions.

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[9] Examples of industrial gas projects are the HFC_{-23} and N_2O reduction projects.

In 2007 the Clean Development Mechanisms were expected to have a capital stock of around 2 billion Certified Emission Reduction (CER) credits coming from around 1.600 projects. In that same year (2007) the World Bank estimated the amount of capital committed to CDM projects to be about 12 billion USD (US Dollars) and the capital ready for investment in this kind of projects to be over 20 billion USD.

2.1.4. The EU ETS Market

Under Kyoto Protocol, European Union has committed itself to reduce its GHG emissions by 8% below 1990 year levels, during the period 2008 - 2012.

Seeking to jointly achieve their Kyoto goals in a cost-efficient way, EU member states implemented the European Union Emission Trading System (EU ETS), a Europe-wide cap and trade scheme launched in 2005. Formerly referred to as the EU Emissions Trading Scheme, the EU ETS is based on progressive carbon emissions reduction like Kyoto Protocol and is the largest single market in the world emission allowances trading. Considered the first of its kind, it accounted for approximately 67 billion Euros in 2008.

The Directive 2003/87/EC, enforced on 25 October 2003, did not include all sources of emissions on the EU ETS. Initial covered sectors were: installations in the energy and industrial sectors (specifically combustion energy activities and biomass plants with a rated thermal capacity greater than or equal to 20 MWh), mineral oil refineries and coke ovens, ferrous metal production, cement and lime, bricks and ceramics, glass, pulp and paper. At first, transport, aviation, land use change, forestry, and wastes were not covered by the scheme. After having enlarged its initial coverage, the EU ETS currently includes more than 12,000 installations in the 27 EU Member States, accounting for around 55 % of the EU's total CO_2 emissions and about 30% of its overall GHG emissions. The majority of these emissions covered – approximately 60% – belong to the EU's 200 electricity generators which form the biggest single sector in the carbon permits market.

Beyond the EU ETS market we still find in Europe the 'Other Policies' market, called the 'non-regulated market', which comes mainly from transport and heating and represents 45% of Europe's total GHG emissions.

2.1.4.1. The Functioning of the EU ETS

European Commission (EC) is the institution responsible for setting the cap on the total net emissions allowed within the EU ETS. After deciding the total number of European Union Allowances (EUA)[10] to deliver for each Phase, EC allocates to EU member states each own annual quotas, making it available at the start of each year (in February). Afterwards, usually by the end of March of each compliance year, the member state government submits to the approval of the EC its own National Allocation Plan (NAP).

To enforce the emissions' cap, after analyzing their actual emission volumes over the previous year, at the end of compliance year (on April 30th) the EU requires entities covered by the scheme to hold and convey one emission permit for each ton of CO_2e[11] emitted. So, after receiving its permits allocations, each emitting entity must evaluate its estimated emissions for the year ahead; if they estimate to exceed their allocated EUAs, companies have two possibilities: they may either abate some of their emissions or buy on the market the EUAs[12] they lack. The intended effect is that companies with cheap abatement opportunities will abate more CO_2 and sell the exceeding EUAs in the market to companies for which abatement is more costly.

Compliance is enforced by a rigorous financial penalty per missing permit and a requirement to cover any deficit resulting from a compliance failure, through the surrendering of additional permits in excess of compliance needs in the following year. Thus, the penalty is not a cap's price but a strict disincentive to non-compliance: if companies fail to comply, they have to pay the penalty and must also deliver the

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[10] One EUA allows for the emission of one ton of CO_2 in each calendar year.

[11] "CO_2e" carbon dioxide equivalent unit is the common carbon standardized measurement; is the unit in which greenhouse gas emissions are measured under the Kyoto Protocol. It includes all 6 gas types identified by Kyoto as having high global warming potential: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (MH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

[12] Keep in mind that companies may also use CERs and ERUs generated from CDM and JI projects for compliance instead of EUAs.

missing EUAs in the following year. For the period 2005-2007 the penalty has been 40 Euros but it has been raised to 100 Euros/ton[13], from 2008 onwards.

European Commission monitors the trading and surrendering of carbon permits through a European wide system of company accounts. Once firms have obtained their annual allocation they are free to trade it on the market, through any of the Carbon Exchanges that have emerged with the EU ETS: European Climate Exchange (ECX London), European Energy Exchange (EEX, Leipzig), Blue Next (Paris), NordPool (Oslo), etc.. According to PointCarbon, besides these four European exchanges, there are two other world leading exchanges in term of volumes traded: the Green Exchange (Nymex, NewYork) and the Energy Exchange Austria (EEA, Wien).

Other than emissions of carbon dioxide, at first, from 2008 onwards the EU ETS also includes emissions of nitrous oxide (N_2O), resulting from the production of nitric acid in the Netherlands and in Norway.

2.1.4.1. EU ETS Banking and Borrowing Limitations

EUAs can be traded freely between states and, with some restrictions, pollutant entities can "bank[14]" or "borrow" allowances and credits from one compliance year to another. Using the permits saved in previous periods to comply with next period needs (or selling them on the market) is called "banking".

However, banking is allowed only between compliance periods <u>belonging to the same Phase</u> of the ETS, and it is strictly prohibited between Phases. This major restriction is commonly known as the trading period break: EUAs that were issued in a previous trading period (2005 – 2007 or 2008-2012) were valid only during that same trading period [15] and could not be used for the subsequent trading period, the Kyoto commitment period (2008 - 2012) or the post-Kyoto period. Figure 4 below shows the

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[13] Refer to International Network for Sustainable Energy and to www.ourclimate.eu

[14] The act of storing a EUA for later usage is commonly called banking. The act of emitting more than the allocated cap and using permits from the following period to cover excess emissions is called borrowing.

[15] France and Poland initially allowed for limited banking between 2007 and 2008, but later decided to ban inter-period transfer as did all other members.

effect of the prohibition banking between Phase I and Phase II for different futures prices.

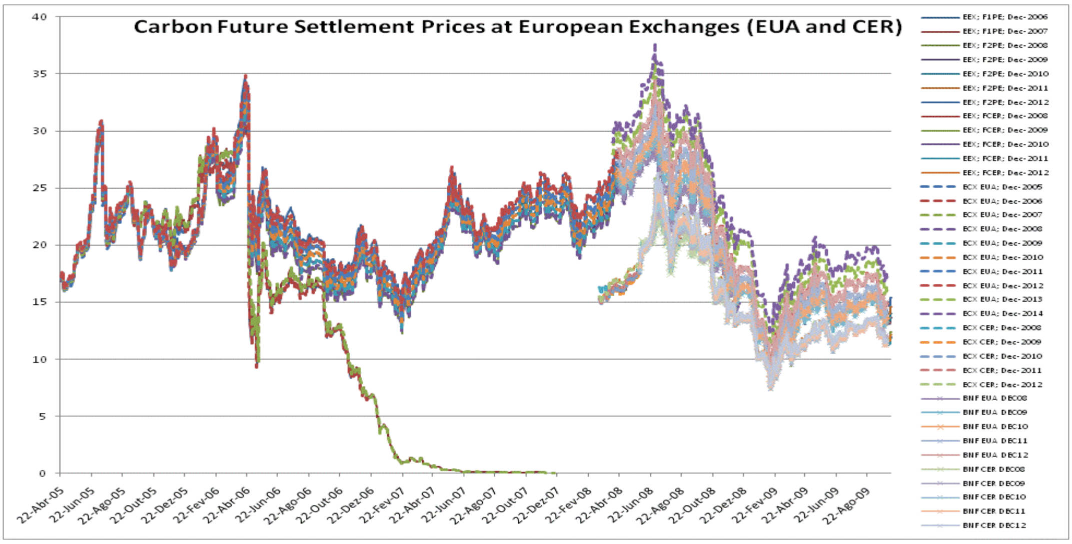

FIGURE 4: HISTORIC PRICE EVOLUTION OF CARBON ASSETS (EEX, ECX, BN AND PN EXCHANGES)

The series show EEX, ECX and BlueNext carbon futures contracts quotations from April 2005 to October 2009 with different maturities. The sharp drop on the price we observe at the beginning of 2007 is the result of non-bankability of permits from Phase I into Phase II, which meant that the underlying spot price was not a valid reference for the ensuing period. This also meant that any possible arbitrage between spot and 2008 futures contract prior to the issuance of Phase II permits was not possible.

The opposite approach of "banking" is called "borrowing[16]" and is also possible. Since companies obtain their EUAs for the current year at the end of February and the compliance date is only on April 30th, they may use them to comply with the preceding year's requirements. For example, firms are allocated their yearly allowances in March each year. However, to help firms avoid being caught short of permits at compliance date, the European Commission requires surrendering of compliance permits for the year just ended only on April of the following year. Thus, it is always possible for firms to take a portion of their next year's allocation and use it for the previous year's compliance, should they need to. In this way borrowing from future years within a

[16] Borrowing a EUA is to use at the present compliance year a carbon permission unit delivered for compliance in a future year.

Phase can occur. Similarly to the banking restrictions, permits may be borrowed from future years <u>within</u> Phases, but <u>not between</u> Phases.

2.1.4.2. EU ETS Phase III

Since regulation issues are critical to carbon price development, we will summarize in this section the most important regulatory cornerstones for the third period of EU ETS (and Kyoto Protocol). The diagram below displays its decision making process, until 2013.

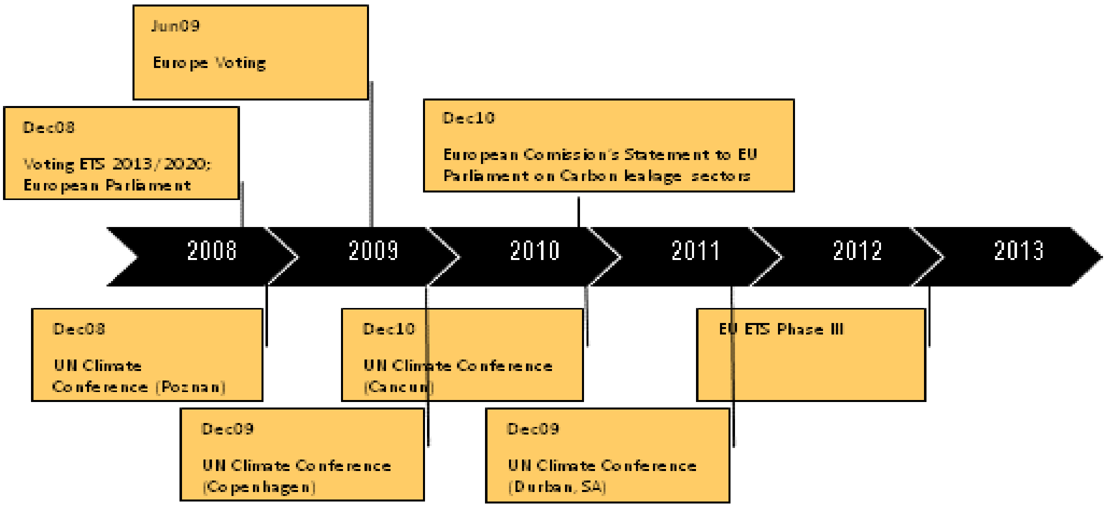

Figure 5: Time schedule for Kyoto Third Period

With the third period agreement in perspective, in January 2008 the European Commission has put forward its climate and energy proposal. Following agreement among Member states and the European Parliament, a revised EU ETS Directive for Phase III was put forward on 17 December 2008, as part of the wider EU 2020 Climate & Energy Package. The so-called 20-20-20 policy is to be reached by 2020 and consists in a three wedge policy:

- 20% reduction in emissions for the European countries by the year 2020;
- 20% renewable energy target-share by the year 2020;
- 20% net energy efficiency gains by the year 2020 (through increased efficiency, energy use reduction through other measures).

Further, in order to demonstrate its leadership, to challenge and to encourage broad participations in the post-Kyoto low carbon world, Europe has announced that, if the world actively engages in this challenging quest, it would raise its own GHG reduction target to 30% by year 2020.

Building on learning from the first and second periods and with the objective of improving the EU ETS design in such a way that it will be more efficient, more harmonized and fairer, the revised CO_2 Emissions Trading Directive becomes more environmentally ambitious, foreseeing some important changes for the third trading period, starting in 2013. Its goal is to keep the EU on track to cut 60-80 percent emissions by year 2050, so that it raises emissions reduction targets and delivers more predictable market conditions and more certainty for industry.

Key elements of the Revised EU ETS Directive are:

- Compliance periods length will be enlarged from 5 to 8 years.
- A centralized, EU-wide cap on emissions (compared with the current system of National Allocation Plans set by individual Member States). The cap will follow a declining trajectory from 2013 onwards, being annually reduced by 1.74% of the average annual level of the Phase II cap. It will deliver an overall reduction of 21% below 2005 verified emissions by 2020.
- A significant increase in auctioning levels, to ensure that carbon cost is better integrated into business decisions. During the first two periods, most certificates were allocated for free. However, some industries, such as electricity generators, are able to pass on to customers the opportunity costs of CO_2, generating extra profits. So, a decision is taken that at least 60% of allowances will be auctioned by 2020, compared to around 3% in Phase II. Moreover, there will be 100% auctioning to the power sector, across most of the EU.
- 300 million allowances from the New Entrant Reserve will be made available until the end of 2015 to co-fund up to 12 commercial scale demonstrations of environmentally safe Carbon Capture and Storage and renewable energy technologies, in order to provide an incentive for their rapid development. This is thought to put the EU at the forefront of the development of CCS technology.

Regarding banking possibilities for the third period, at first the common view at the beginning of 2008, was that only certificates from CDM/JI-projects delivered pre-2013 could be included in phase III, within certain limits. However, the rights to use CERs have been extended by the revised EU Directive and a limited quantity is allowed to be used in such a way that the overall liability with these credits does not exceed 50% of the EU-wide regarding the 2008-2020 period reductions. Further, based on the argument that stricter emission reductions can be achieved only within an international agreement, the generation of new CERs in the third period will be allowed only if an international agreement on a Kyoto follower carbon protocol is reached.

2.1.5. Voluntary Markets

Besides Kyoto Protocol related markets, we still have the so-called Voluntary Carbon Markets (appearing everywhere, in Australia, China, Russia, etc.). Voluntary markets include any non-regulated carbon market having firm or fixed emissions targets, including any GHG emitting activity of an unregulated firm or one which does not have to comply with one of the previously described carbon markets.

WCI	RGGI	ASIA-PACIFIC MARKET
50% of the EU ETS market; **Is the largest carbon trading market in North America;** **Until 2012 will cover only electricity generation and consumption;** **Until 2015 will add transportation and heating fuel.**	Is the USA regional cap-and-trade program of 10 northwestern states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont); Fist auction was on Sept.25, 2008; Not restricted to RGGI companies; Any interested entity can buy; If total demand is inferior to supply of allowances ⇒ allowances price will be \$1,86/ton (this is called the reserve price); On August 26, 2008 the Chicago Climate Exchange (CCX) launched: ▪ RGGI allowance futures contract ▪ RGGI options contract.	New South Wales (Australia) targeting power sector; Australian government green paper (cap-and-trade schemes); New Zealand ETS covering forestry sector (January 2008); other sectors to be phased in by 2013.

FIGURE 6: WORLD CARBON VOLUNTARY MARKETS

One of these Voluntary Carbon Markets is the Regional Greenhouse Gas Initiative, formed by an association of 10 US States cooperating to reduce their GHG emissions. It is the first organized market created in the U.S. and has begun its own ETS in 2008, having a CO_2 futures market already underway. At present there is no established flow of Kyoto credits into the RGGI system but there can be if the price of the RGGI carbon units goes above 10 USD.

In year 2006 these markets were estimated to be around a factor of 100 less than what was traded in the regulated markets. Nevertheless, they have the advantage of preparing the way for carbon emission reductions, helping to spur innovation and presenting specific emission caps / trading regulated allowances more appropriate to deliver the scale of change required within a limited time frame.

Around the world we can find the following most significant voluntary carbon markets:

- The North American Western Climate Initiative (WCI), in the United States and Canada;
- The North American Regional Greenhouse Gas Initiative (RGGI), in the USA;
- The Asia-Pacific Carbon Market.

Voluntary markets are fast growing markets. Committed to reduce GHG emissions 6% below the baseline period of 1998-2001, by 2010, Chicago Climate Exchange Carbon Financial Instruments alone accounted for a trading volume of 72 million USD in 2007 (with similar volume in the first 3 months of 2008). In 2007 it has been expanded to list:

- futures on CER contracts;
- futures on AAU/EUA contracts;
- CER options;
- futures and options on RGGI (in 2008);

Voluntary markets also include project-derived carbon credits for voluntary end users (not generated under a regulatory scheme), which comprise verified emissions reductions (VERs), non-verified emission reductions (ERs) and prospective emission reductions (PERs).

2.2. FUNDAMENTALS OF CARBON FINANCE

Increased levels of uncertainty and risk resulting from Kyoto Protocol Emissions Trading Systems implemented around the world have caused higher costs to companies. To help them deal with these new issues, a set of proper financial tools has developed and a whole new financial area of research has appeared. With new financial assets to be managed and new financial instruments to be learned Carbon Finance was born.

2.2.1. Carbon Finance – a definition

Carbon finance can be defined in many different ways and there are many different definitions we can refer to. A few examples follow.

The **World Bank** Carbon Finance Unit offers us a somewhat traditional, transaction-based definition for carbon finance:

Carbon finance is basically a payment to a project entity (any legal entity, public or private, NGO, etc.) for the emission reductions [units/certificates] from that project, once the project is operational and typically at a yearly basis, like a commercial transaction. … **carbon finance** provides a means of leveraging new private and public investment into projects in developing countries and economies in transition that reduce greenhouse gas emissions, thereby mitigating climate change while contributing to sustainable development.

Sonia Labatt and Rodney R. White, in their book on carbon finance[17], put forward the following definition of carbon finance:

Carbon finance explores the financial implications of living in a carbon constrained world – a world in which emissions of carbon dioxide and other greenhouse gases carry a price. Thus, **carbon finance**: 1) Represents one specific dimension of environmental finance. 2) Explores the financial risks and opportunities associated with a carbon constrained society. 3) Anticipates the availability and use of market-based instruments that are capable of transferring environmental risk and achieving environmental objectives.

The Yale University publication “Carbon Finance: Environmental Market Solutions to Climate Change” proposes us a collection of definitions and usages. A few examples:

In its Preface, Stewart Hudson approaches this topic directly:

[17] Carbon Finance: The Financial Implications of Climate Change, Wiley Finance, ISBN: 978-0-471-79467-7, April 2007.

… **carbon finance** has several different features. The first involves developing a market that trades in two new commodities – carbon allowances and their close cousins, carbon offsets. A second feature of carbon finance relates to investment. … carbon finance has a research element, one that will lead to a better understanding of how private firms have positioned themselves for success in a clean energy economy, or more troubling, how they have failed to do so. Assessments of carbon risk and reward, and the readiness of corporate firms to profit from the transition to a low carbon future, will […] affect the trading and investment prospects inherent in what we mean by carbon finance.

In Chapter 13 of Yale's book, Andrew Aulisi employs the term **carbon finance** to specifically mean *carbon pricing, or transactions associated with* CO_2 *credits*. He remarks, for instance, that carbon pricing or carbon finance is really just one facet of a much more complex issue.

Finally, if we report to **Wikipedia**[18], we can find a broader definition:

Carbon finance is a new branch of Environmental Finance. Carbon finance explores the financial implications of living in a carbon-constrained world, a world in which emissions of carbon dioxide and other greenhouse gases (GHGs) carry a price. Financial risks and opportunities impact corporate balance sheets, and market-based instruments are capable of transferring environmental risk and achieving environmental objectives. Issues regarding climate change and GHG emissions must be addressed as part of strategic management decision-making.

The general term [Carbon finance] is applied to investments in GHG emission reduction projects and (to) the creation (origination) of financial instruments that are traded on the carbon market.

Whether carbon finance is in fact a narrow or a broad term, a simple revenue stream or a complex instrument, a transactional or a general approach to solve environmental problems and climate change, or some combination of all of these, most of these and other definitions try, above all, to illustrate that finance, in general, can be an important tool to include in the climate change solution set that the world needs to put forward.

2.2.2. Commodity Likeness

Usually, within Economics literature, the term "commodity" refers to a physical good, such as food, oil, corn or gold, which are bought and sold in markets, often through derivatives contracts. A commodity is thus a product which is traded on a commodity exchange.

Carbon allowances are not physical products. They are immaterial assets needed only because of governments' actions and because of legislation, when caps were imposed

[18] http://en.wikipedia.org/wiki/Carbon_finance

on emissions and each polluting entity is asked to convey a permit per each ton of GHG produced. If industries pollute less than the amount of allowances they have got, they can trade the surplus through spot, forward, future or options contracts. Allowances' price is determined by difference between allowed and real emissions, meaning by market equilibrium between offer and demand. So, when an industry has more allowances than actual emissions it will cash them out on the market, if it is short on allowances it will buy more on the market.

Hence, carbon allowances are assets representing the right to pollute the environment, a right formally guaranteed by governments and given to different industries depending on their own polluting historic profile. Carbon allowances are like a commodity. And its price can be understood as the cost that must be paid to benefit from the possibility to surpass the permissions' amount that has been given. Thus, it is the marginal cost of polluting the environment or the marginal gain of reducing the GHG emissions and an independent (financial) investor can perceive the money he invests on the carbon market as a physical tool that can be used to help reducing carbon emissions at the same time it generates financial returns to him.

2.2.3. The Convenience Yield

Commonly, in Finance literature, the convenience yield is a measure of the added value or premium associated with holding an asset, instead of detaining its term contract (i.e. forward, future or option). Because of relative scarcity of the product, of strong demand or of hazardous market movements, sometimes, holding the underlying asset may become more profitable than carrying the contract or derivative instrument.

By choosing to hold the physical good instead of its term contract, the agent has the option regarding consumption and no risk of commodity shortage. However, often the decision to postpone consumption implies storage expenses. The net cost per unit of time between the benefits of postponing the consumption and the costs of storing the product is termed the convenience yield. A good example is the actual purchasing of physical barrels of oil instead of its future contracts. In the hypothesis of a sudden oil offer reduction due to OPEC's production downgrade decision, the difference between initial oil purchasing price (plus its storing costs) and the price after OPEC's decision would be the convenience yield.

It is though easy to understand that GHG allowances are, in fact, a classic commodity like oil, gas or gold. The only difference is that for CO_2 allowances there are no storing costs. So we must find similarities in its economic fundamentals.

2.2.4. Carbon Assets Trading

Within Kyoto Protocol framework to get the amount of allowances and/or credits needed to offset their emissions and respect their defined carbon targets, emitting entities may choose between:

- ➡ implementing internal emissions abatement schemes, or
- ➡ launching external strategies (namely by participating in emissions trading or in JI and CDM projects).

To choose which carbon control strategy they must choose, polluting companies must start by taking into consideration carbon allowances' price and their own internal emissions abatement costs level. Because of internal abatement costs becoming higher and higher, emissions trading schemes are getting increasingly popular policy instruments through which both national and local governments around the globe seek to move their economies to a model of growth that doesn't cause unsustainable quantities of CO_2 and other GHGs emitted into the atmosphere.

A research by Point Carbon (Point Carbon, 2008) among a sample of ETS market operators, indicates that 33% of them were GHG emitting companies regulated by a ETS, 32% were CER generators, 15% were Financial & Banking Institutions, 3% were from Governmental Organizations, 3% were companies from outside the ETS and 14% had other non specified objectives. So, not all the operators pursue their compliance objective through trading. Furthermore, according to the World Bank the most active carbon market participants are large power companies, banks and investment funds. (Gagliardi & Sehest; 2008).

Carbon trading market covers transactions of GHG emission allowances and of project-based emission reductions credits. We can summarize the types of carbon assets available for trading these days as presented in Figure 7 below.

Carbon Assets Classes	Carbon Assets Typologies[19]	Description
Allowances	Assigned Amount Unit (AAU)	Total carbon emission quantity each state/entity is allowed to emit within Kyoto Protocol
Allowances	European Union Allowance (EUA)	Unit issued to installation under the EU ETS
Credits (both primary and secondary)	Emission Reduction Unit (ERU)	Unit of emissions reductions created through JI[20] projects Units that are issued to Annex I parties.
Credits (both primary and secondary)	Certified Emission Reduction (CER)	Unit of emissions reductions created through CDM[21] projects
Credits	Removal Unit (RMU)	RMUs are generated in Annex B Parties by LULUCF[22] activities that absorb carbon dioxide. Annex B Parties can use RMUs to help meet their Kyoto Protocol commitments.

FIGURE 7: CARBON ASSETS TYPOLOGIES

According to its financial relevance we can find three types of carbon assets:

- Primary CERs and primary ERUs (purchased on a forwarded basis and prior to certification; carry project delivery risk);
- Secondary CERs and secondary ERUs (traded in the futures and in the forwarded markets; volume is guaranteed).
- Carbon Emission Allowances (emission caps accepted by governments under Kyoto Protocol).

The trading of emission allowances focus on formal, specific carbon products, created under the Kyoto Protocol (Assigned Amount Units and European Units Allowances, for

[19] The underlying value for every typology of these carbon assets is one ton of CO_2-equivalent emissions.

[20] Joint Implementation projects (see title 2.1.2.)

[21] Clean Development Mechanism (see title 2.1.2.)

[22] Land Use, Land Use Change and Forestry Projects. Under Article 3.3 of the Kyoto Protocol, Parties decided that greenhouse gas removals and emissions through certain activities — namely, afforestation and reforestation since 1990 — are accounted for in meeting Kyoto Protocol's emission targets. Conversely, emissions from deforestation activities will be subtracted from the amount of emissions that an Annex I party may emit over its commitment period. (see www.unfccc.int)

example) which are allocated by a regulator, usually under a cap-and-trade regime. Project-based credits transactions focus on the purchase of emission reduction credits (CERs and ERUs) obtained from the participation and/or financing of GHG emissions reducing projects. Contrary to allowances trading, a project-based transaction can occur even outside a regulatory framework, where an agreement between a buyer and a seller is sufficient.

To comply with Kyoto Protocol, governments in most of the EU countries and Japan have CER/ERU purchase programs. According to some authors, the total governmental demand for the first Kyoto phase has been around 707 million tons units (both CER and ERU).

Carbon assets can be traded as spot financial instruments but since 2005, when carbon trading started, an important derivatives market has developed throughout Europe, alongside the spot market. The following carbon financial products are available at regulated Exchanges: spot settlements, forward contracts, futures contracts, and option contracts.

Carbon Market Assets	Value (million USD) in Q1 2009	% Change from Q1 2008
EU ETS	23.781	35%
AAU	885	N/A
Others	250	N/A
Total Allowances	24.917	41%
Primary CER	636	-59%
Secondary CER	2.536	106%
JI	15	-99%
Others	133	-40%
Total project based assets	3.321	-21%
Total Market	28.238	29%

FIGURE 8: ETS MARKET SIZE AND CHANGE OF VOLUMES

In Europe, the most traded carbon finance instruments are the AAU, which accounted for 84,2% of all EU ETS transactions, in the first Quarter of 2009. Primary CERs[23] and secondary CERs can also be traded and can be converted into EUAs, accounting for 2,3% and 9% respectively.

[23] Primary CER are related to projects that have not yet received approval.

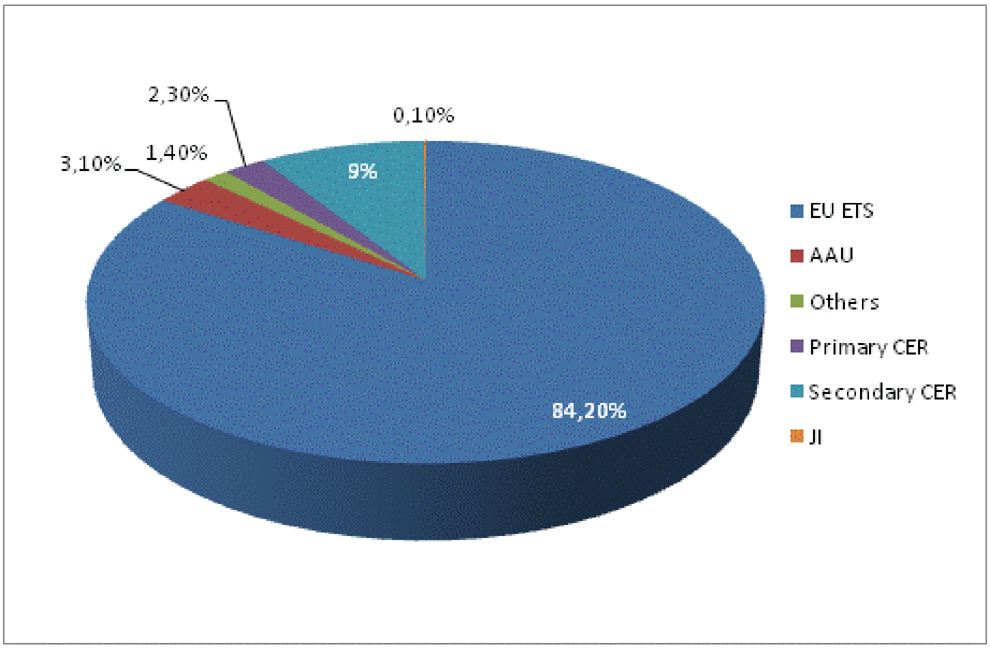

FIGURE 9: ETS MARKET SHARE BY INSTRUMENT

Figure 8 and 9 show the weights, volumes and annual change rate of the CO_2 spot transactions in Q1 2009.

2.2.4.1. CO_2 TRADING IN EUROPE

Even though there is room for considerable growth and consolidation yet, carbon market is now a fully operational commodity market characterized by a low degree of both liquidity and transparency.

In fact, the Exchange Handbook (EH) refers to the EU ETS as "the world's largest [carbon] compliance market, … both in terms of volume and volatility" representing some two-thirds of carbon market activity. The fact that both EU demand and EU ETS structural flaws are quickly reflected in exchange traded prices confirms its dominance. The EH goes further arguing that the collapse of EUA prices on the Exchanges listing them, between year 2006 and year 2007, has been initiated by information that European Commission had issued too many emissions permits in Phase I of the EU ETS. Also, the announcement by the European Commission of its intention to curtail the use of CERs in Phase Three (beginning in 2012) had an almost immediate depressive effect both on prices and on exchange activity. We agree with EH analysts when they say that these are indications of healthy market functioning but, at the same time, a manifestation of poor market regulation.

The European GHG emission allowances market has been created by a regulatory system, universally accepted by market actors. It presents the following characteristics:

- Asymmetric information access among market players. Due to fact that some big companies submitted to Kyoto protocol and some funds involved in quota/credit trading are at same time investors and clients, they get more information about current market status than their peers;
- The EUA system is a dealer market. The European Carbon Exchanges provide liquidity to investors by trading shares for themselves and publicizing prices even if no trade exists. For a significant number of trading days during 2008 and 2009, the EUA exchanged volumes of contracts were very small or even zero and the prices were set through the auction trading system. During this period CO_2 prices showed evidence of high variability and big discontinuities in offer/demand equilibrium.
- EUAs being perceived more as a financial liability than as having intrinsic value or as being able of generating real economic added value;
- High impact of regulatory announcements (f.i. may 2006);
- The liberty of negotiating where ever one wants to. The legal framework of the EU ETS does not regulate how and where the trading of carbon assets takes place and installations engaged in carbon control schemes may negotiate OTC contracts and trade assets directly with each other, or use the organized markets to buy and sell their assets via a broker, a bank or other market intermediary.

The EU ETS dominates the world global carbon market with spot, futures, and option trades in market valuing €37 billion (US$50 billion) in 2007, with future contracts accounting for the major part of this value.

A - Carbon Finance Contract Types

Carbon contracts can be defined as transactions whereby one party pays another party in exchange for a given quantity of GHG emission credits (or allowances), to be used by the buyer to meet its climate mitigation objectives. Being highly sensitive to regulation, design parameters and rules, ETS are heavily dependent on government policy settings.

Spot Contracts offer immediate delivery, between 24 and 48 hours after transaction have taken place. Typically, as in the European Energy Exchange, the minimum size of the contract is 1000 tons of CO_2e, even though other exchanges allow for lower minimum amounts. Price tick size is 0.01€/t.

Within a ***carbon futures*** contract, at the time of the settlement the buyer and seller agree on the delivery and/or payment of a certain quantity of allowances at a certain point of time in the future and at the price agreed upon. This contract gives the holder the right and the obligation to buy or sell a certain amount of CO_2 allowances, at a pre-settled date in the future and at a predefined price. Carbon future contracts are written over EUAs or CERs and are fully standardized. Its expiry dates are the last trading day of December, from 2009 to 2012 for EUAs Futures and from 2009 to 2014 for CERs Futures. Usually the delivery is physical. Both parties of a futures contract must exercise the contract (buy or sell) on the settlement date. ECX is by far the most liquid market in the carbon Futures segment, accounting for almost 98% of all the market.

In the case of the European Carbon Futures the buyer and seller agree at the time of the conclusion of the transaction that EU emission allowances of a certain quantity will be delivered and/ or paid at the price agreed on at a certain point of time in the future.

Forward contracts are also available, where the maturity and the underlying amount are not standardized but negotiated between counterparties. Amounts and tick specifications are similar to spot contracts.

Options are contracts whereby one party (the holder or buyer) has the right, but not the obligation, to exercise the contract on a future date (the exercise date or expiry date). The other party (the writer or seller) has the obligation to respect the contract. Since the option gives the buyer a right and the seller an obligation, the buyer pays the option premium regardless of exercising it or not exercising it. The ECX exchange offers European-style options with underlying EUA and CER Futures. Its expiry date is three trading days before the expiration of the underling Future contract. According to Brett Genus and Aidan Freebairn from Evolution Markets, the year2009 was the first full year of European carbon options trading. They refer that EUA options volumes on the European Climate Exchange (ECX) experienced 71 per cent growth on a year-on-year basis, with 415.5 million tones traded, and that CER options which trade began on ECX only in May 2008, showed 34% growth with 91.1 million traded in 2009 against 67.8 million in 2008.

With markets becoming more mature, more sophisticated products are expected to be introduced in the market. Specifically it will be possible to trade Spreads on EUAs and CERs, by buying or selling the implied price difference between EUA and CER (both for spot and futures contracts), and Strips, by buying or selling simultaneously Futures contracts from all available maturities (www.bluenext.fr). In this thesis we will only focus, though, on carbon future and spot assets, not on options, or on any other carbon derivatives.

2.2.5. EU ETS Price Mechanics

Being an externality, carbon costs could be forced to be incorporated directly, through the definition of GHG taxes, or indirectly, through definition of emission caps leading to the development of a CO_2 emissions market. Either way, policy makers should be able to minimize environmental impacts and costs and markets should respond to new information.

Europe has chosen regulation instead of taxing and created the EU ETS carbon market. Because of carbon caps imposed on them by legislation countries, companies and other emitting entities gave rise to the carbon market when they sought to meet their GHG commitments through the buying and selling of emission allowances and emission reduction credits. So, for policy to be effective in influencing investment decisions in cleaner technologies factors like carbon price signals, system credibility, market predictability and flexibility are of crucial importance. So far, the results are promising. In fact, a 2005 survey[24] indicates that half of all companies in Europe's energy-intensive

[24] Review of EU Emissions Trading Scheme, conducted by McKinsey on behalf of the EU Commission, was published in November 2005. Its findings reflect responses from 167 companies and 163 other institutions.

industry regarded already the EU ETS as one of the primary factors affecting their long-term investment decisions and profitability outlook.

In spite of being an artificial market created by regulators, the dynamics of carbon prices have been increasingly driven by market fundamentals, as in other commodities markets. Currently, economic activity, oil, natural gas and coal prices, changes in political frameworks as well as uncertainty and expectations regarding the achievement of Kyoto targets are - among others - the main components influencing the market price of carbon.

Hereafter we recall the basics of some economics rationales, presenting them in the perspective of the CO_2 market: the marginal cost of abatement, the supply and demand price mechanics and the emissions shortfall factor (as well as other carbon impacting factors, like institutional aspects, economic growth, energy consumption and weather conditions).

2.2.5.1. The Marginal Cost of Abatement

The economics reasoning behind any product profitability states that, in a competitive market, its price must be equal to its marginal cost. Similarly, in theory, carbon price should be equal to its marginal abatement cost. In fact, a polluter company will abate emissions if the carbon marginal abatement cost (CMAC) is smaller than current EUA price and will buy emission permits if the CMAC is above EUA spot quotation. Thus, each one must know each own CO_2 abatement cost curve or, at least, a typical, average one.

Within a dynamic equilibrium model, Rubin (1996) and Baker and al. (2009) argue that there is a typical abatement cost curve, that the CMAC is equal for every company within the same trading scheme and, finally, that the discounted CMAC is invariable over time, for a given quantity of emissions (see Figure 10 below).

Usually, on the left-hand side of the dashed line in Figure 10 we find the cheapest emissions, those to be reduced through optimization of output process; between the two dashed lines, namely in the steeper part of the curve, we must use technical instruments[25] to reduce GHG; finally, in the third part of the curve, it is too costly to improve carbon efficiency further through technical improvements and it is more sensible to buy allowances.

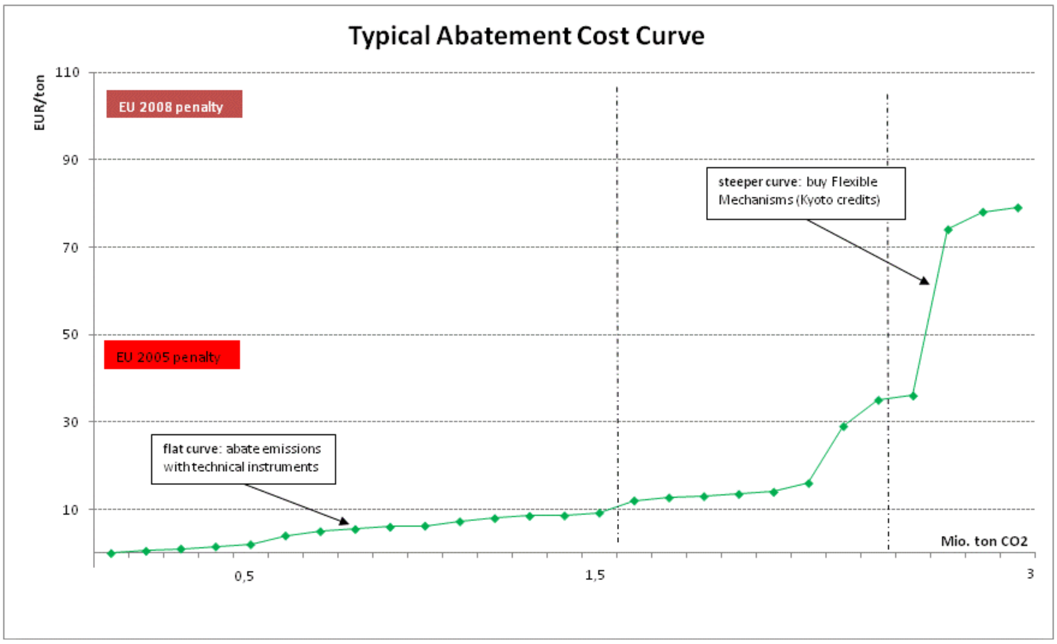

Figure 10: The cost of different abatement instruments - the abatement cost curve
Source: Partially adapted from Tillmann (2009), Figure 3.2.

However, some authors claim, the process of finding its own marginal costs is polluted with too much difficulties and there are some problems we have to consider when taking decisions upon abatement costs. Similar to carbon allowances demand, marginal costs are dependent of economic conditions, weather, fuel prices, aids, political framework and many other factors which companies cannot control all the time.

So, starting from there, the characteristic marginal abatement curve is determined by each own cost structures and technical opportunities leading to emissions abatement, along with the possibility of using Kyoto flexible mechanisms (Emissions Trading, Joint Implementation and Clean Development Mechanism). The most important

[25] See second § hereafter.

technical instruments one can use include fuel switch, energy efficiency improvement, heat and power co-generation, renewable or technological change (TC)[26].

2.2.5.2. CO_2 ALLOWANCES SUPPLY AND DEMAND MECHANISMS

Like other commodity markets, the EUA price is mainly driven by the equilibrium between supply and demand and influenced by other factors related to market structure and institutional policies.

However, EUA is a non-standard commodity which exhibits some specific features. For instance, polluting production entities do not need to physically hold the actual permits to perform their objectives. They just have to match the allowances they have been given (or they have acquired) with the verified emissions they have produced, reporting them on their yearly compliance report to the European Commission.

A. Market Supply of EUAs

Carbon allowances supply is politically fixed, first by European Commission and then by each Member State government through National Allocation Plans (NAPs).

During the first Kyoto period market offer (the carbon allowances supply side) was quite limited, since no carbon credits other than Phase I EU allowances could be used for compliance: neither the use of Kyoto credits nor Phase II EUAs – through borrowing – were allowed. Also, in Phase I polluting entities have been given all the allowances they need, based on their GHG emitting historic profile. Thus, the number

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[26] Addressed in several research papers, TC is considered to be a very interesting way to change the structure of the abatement cost curve and to reduce CO_2 emissions. It is understood as “the increase in output resulting from the creative use of the same level of inputs, through the process of invention, innovation, and diffusion" (free adaptation from Tillmann (2009); page 13.

Trying to understand how TC affects the structure of the Abatement Cost Curve, in his paper “Valuation and Hedging of Carbon-Derivatives” Mathias Tillmann warns that “in spite of all the assumptions that we can take about the reducing impact of TC all over the CMAC curve, there can be increasing CMAC with TC at high levels of abatement”.

Elaborating a little more on that, Tillmann reminds us Baker’s research (2008) which states that at very high levels of abatement costs the new, more efficient, technology will be substituted away (because of its extremely high costs). So he concludes, we must try to understand which type of marginal costs we are dealing with, especially when marginal benefits to be obtained from abatement are uncertain. It may be critical to ensure that new technologies make it possible to abate emissions, even at higher levels of abatement (for instance, using carbon capture and storage (CCS) technologies) and to know the CMAC associated with each type of technology in order to select the best abatement alternative, with a clear view of its real impact on cost . For in-depth analysis on the impact of Technological Change on abatement costs and on CMAC, refer to Mathias Tillman and Baker work papers (2008).

Because of its importance for policy makers, who have to determine the cap value for the years ahead, TC has been object of many other research and different approaches have been proposed in order to represent it.

of allowances available on the market was strictly equal to the number of allowances initially allocated by regulators to installations and to new entrants[27] and matched the amount just needed by polluting entities. There was no need for trading them.

In Kyoto Phase II, the flexible mechanisms and the emission shortfall factor were introduced into the system, allowing for the "production" of CER. It also emerged some companies who didn't need all the allowances they have got. Since there were some other who needed more than they have got, companies start trading between each other. After some time, institutional investors came into play and allowances trading became increasingly sophisticated.

It is expected that, from 2013 onwards, a distinction will be made between industries facing competition outside the EU[28] and other companies, like electricity producers, which have the ability to pass-on the increased costs of carbon certificates. Progressively, auctioning will become the basic principle and will be the rule rather than the exception. No allowances will be allocated free of charge for electricity production (where, across most of the EU, will be 100% auctioning to the power sector), with very limited and temporary options to derogate from this rule. Sectors and sub-sectors found to be exposed to a significant risk of carbon leakage will receive allowances for free, based on ambitious benchmarks, but for non exposed industries it will be phased out. These rules imply that a much larger (estimated at more than half the total number of allowances in 2013) and increasing share of allowances will be auctioned.

B. Market Demand of EUAs

Carbon allowances demand is a function of expected CO_2 emissions, defined caps and "market sentiment". In the long run, the demand for carbon allowances can also be affected by economic growth and marginal abatement costs.

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[27] During Phase I none of other equilibrium factors that could affect market price, such as banking and borrowing provisions or the inflow of project credits and other flexibility mechanisms, were allowed.

[28] in order to eliminate the competitive disadvantage European players are said to have because most of their competitors outside the EU not being subject to mandatory CO_2 control schemes

Like other commodities, one of the factors influencing EUA demand that is most difficult to capture is “market sentiment”. This expression refers to factors such as uncertainty about future energy prices and policy decisions, which are especially important for investors’ expectations and the building of their own risk and defense strategies.

The level of expected emissions depends on a large number of factors, both short run and long run, like energy prices (which are influenced by weather conditions), consumption levels, industrial production, economic growth and technology used.

Long-term marginal abatement costs are determined by investment decisions in low carbon-intensive technologies and in energy saving measures. Since investment costs are high and the future of the ETSs still present some uncertainties, on the overall firms still choose to face mainly short term abatement costs, when deciding on their allowance demand level.

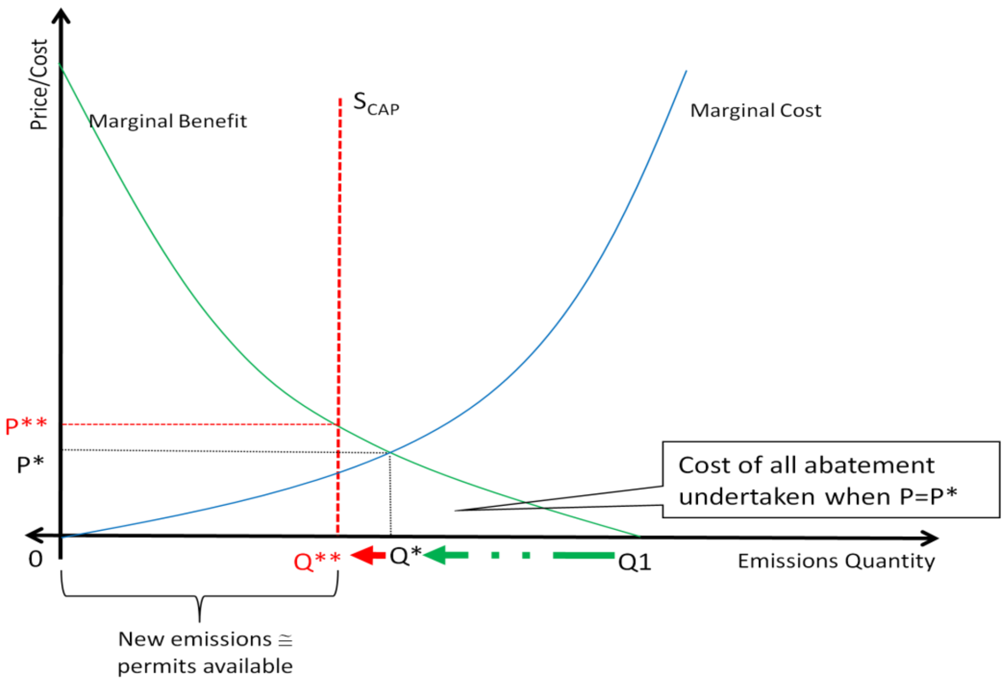

FIGURE 11: EMISSIONS TRADING MOST EFFICIENT POINT
Source: Partially adapted from Sartor (2008), Figures 1 and 2.

Under the standard assumption of rising marginal costs and in order to respect the carbon emissions cap it has been given a profit maximizing firm will decide to abate all those emissions for which the marginal abatement cost falls below the market price of carbon permits (through technological change or using any of the referred technical instruments). Considering the economic rationality of people and firms' decisions, it is expected that only those emissions that are cheaper to abate than the corresponding permit's price will be abated. On the other hand, firms will buy allowances on the market for all those emissions that would be more expensive to abate than the price to be paid to continue to emit them.

This result is presented graphically in Figure 11 above where only the cheapest abatement alternatives have been carried out in moving from Q1 to Q* and where CO_2 allowances have to be bought to move further from Q* to Q**, to respect regulator's pollution limits.

By doing so, the social optimal level of emissions (the point where Marginal Social Cost is equal to Marginal Social Benefit) and the cap limit is attained with the least possible cost.

2.2.5.3. CO_2 Marginal Damage Function, CO_2 Marginal Benefit Function and CO_2 Price

Because carbon emissions are a market externality, in the absence of regulation they are costless from the perspective of polluters. However, pollution imposes damages on society and, like any other negative market externality, causes an increasing damage to society as the quantity polluted increases. As a result, we can draw a marginal damage upward function showing that the higher the pollution the higher the cost to society, per each new pollution unit produced (see Figure 12). At the same time, because it takes companies' resources to reduce their emissions, it is more costly to abate all emissions than only a small portion of them and marginal costs of abatement rise with the total amount of abatement to be done, we can also represent the marginal abatement cost function (CMAC) on an equivalent upward sloping function.

On the other hand we know that:

- the lower the price of carbon allowances/permits, the higher the quantity polluters are willing to buy (using them instead of reducing emissions);
- the lower the emissions the higher the benefit for society (that is the benefit society can get from pollution is a downward sloping demand function).

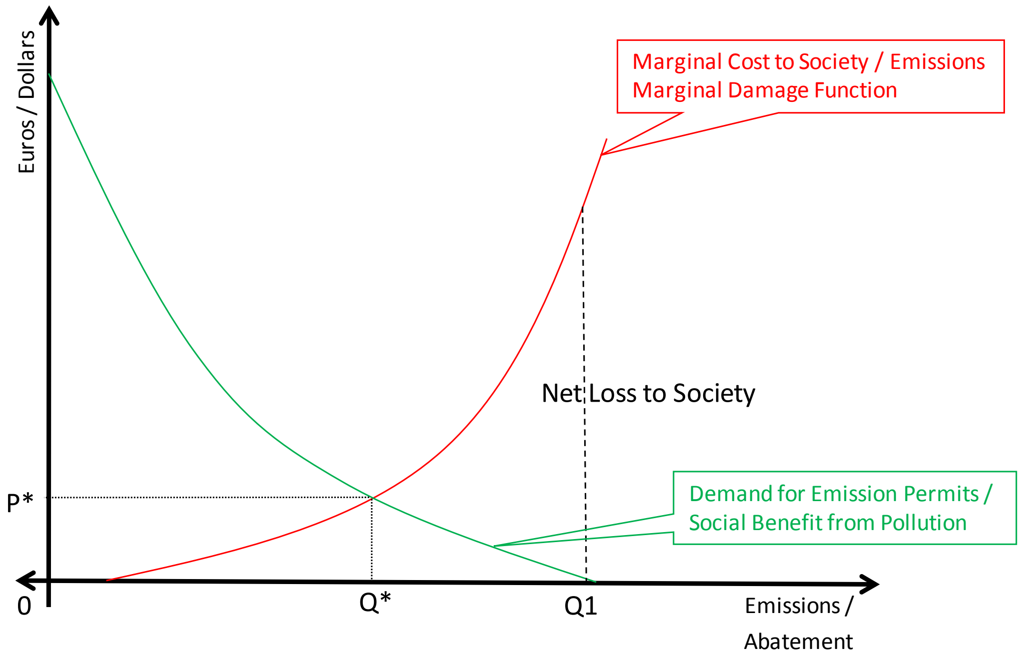

Figure 12: The welfare loss to society from the absence of control on emissions of a pollutant
Source: Partially adapted from Sartor (2008), Figures 1 and 2.

So, a normal downward sloping curve describing the demand for emission permits and the marginal benefit society get from pollution can also be drawn as being the same curve.

Considering this assumptions, at first and if we disregard the damages pollution imposes on society, the total pollution the economy would produce would be the entire amount under the demand curve and the quantity emitted would be Q1, that is, all the emissions the economy need to make <u>with no restriction</u>. Nevertheless, at this pollution level the marginal cost to society from emitting, measured by the marginal damage function, would be greater than the marginal benefit, as measured by the demand curve for allowances. We find the net welfare loss for society resulting from this externality by computing the excess of cost over benefit, for each unit emitted over the point Q*, where the marginal benefit of polluting is equal to its marginal cost. Therefore, there would be a net **welfare loss** to society from emitting Q1 and it would have an incentive to emit less, either by producing (polluting) less or by abating/mitigating the pollution it makes. In this case, those who want to emit more either will invest on CDM projects to generate CER or go to the market and buy to those who emit less and still have permits to sell. The resulting equilibrium carbon price will be [P*;Q*] in Figure 12.

2.2.5.4. THE RATIONALES BEHIND CARBON EMISSIONS CAP

Emissions trading systems propose a policy tool to help society limit pollution to 'efficient' levels, incorporating all polluting costs and starting by stopping those polluters for whom it is cheaper to abate. The process begins with an environmental regulator deciding on a socially optimal level of pollution allowable for that market: Q** in Figure 13 below. To enforce that social optimum, the regulator issues permits up to the quantity of Q** (S_{CAP}, offer level of polluting allowances) and then legally requires each polluter to hold a permit for each unit of pollution they wish to emit.

Now, provided that the market regulator can effectively enforce the new law, firms, in the aggregate, will be allowed to emit the socially optimal level of emissions Q** only.

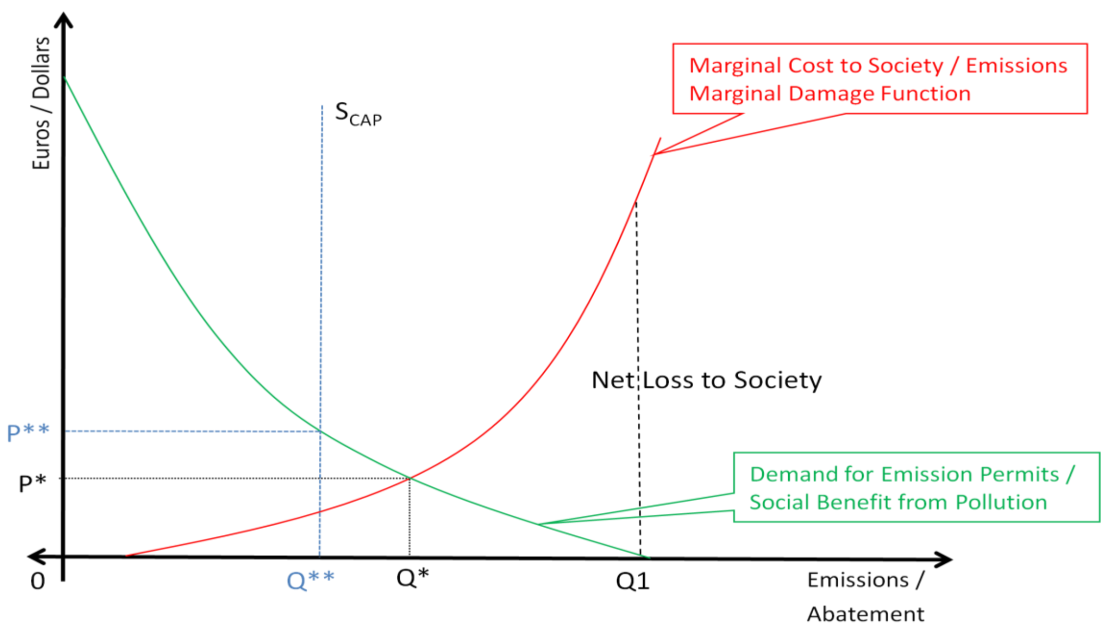

FIGURE 13: THE EMISSIONS SHORTFALL FACTOR
Source: Partially adapted from Sartor (2008), Figures 1 and 2.

Furthermore, by making pollution permits scarce through the setting of a cap on the total level of emissions, the regulator forces its value to increase from P* to P** (this cap limit is represented by the supply curve labeled "S_{cap}" in Figure 13). As a consequence of the cap imposed on emissions (S_{cap}) the supply of emissions is forced to shift to a lower aggregate quantity – from quantity Q* to the new compulsory quantity Q**. Consequently, from basic supply and demand theory, allowances will have a new equilibrium value in the market (marked "P**; Q**" in Figure 13).

If carbon allowances have a positive market value and are trading freely on the market, profit maximizing companies which make pollution face an economic choice: for each extra unit of pollution made beyond their allocated cap by their activity, they have to choose either: 1) to pay the cost of abating the additional unit of emissions (e.g. through investment in a new production technology or simply choosing not to produce the extra unit); or 2) to sacrifice the cost of buying an allowance, conceding them the right to emit the additional unit of pollution and carry on their normal activity.

On the other hand, if that profit maximizing firm got from the regulator more emissions permits than it needs, it can sell the excess it got to firms needing to pollute more.

The difference between verified emissions and allocated allowances within a given compliance period is termed *the emissions shortfall factor* and it depends on the emissions abatements required by governments through the cap, which can be estimated upon released data. It is one important factor, critical to carbon price determination.

2.2.5.5. The Impact of Other Factors

➜ **The Impact of Institutional Factors**

It is easy to understand that, within EU ETS, institutional decisions about the strictness of the cap are decisive to initial carbon price formation within a Kyoto Trading Period. Besides, any decision or announcement from regulators (Member States governments or the EC itself) can easily induce changes in market players' behaviour.

During K.P. Phase I, official communications by the European Commission were essential to reach a better information flow on installations' net short/long positions[29] and the disclosure of compliance results keeps being seen as the cornerstone of changes in market participants' expectation and strategies. In April 2006, for instance, when Member States and the European Commission disclosed the 2005 verified emissions for all EU ETS installations, the positive gap between initial allocation to industrials and

[29] An installation is defined as short (long) when it records a deficit (surplus) of allowances allocated with reference to its actual emissions level.

business-as-usual emission forecasts caused a sharp fall in carbon prices of all maturities (more than 50% in four days)[30].

Political choices can also impact the functioning of the market: in October 2006, announcements by the European Commission to validate more strictly NAPs during Phase II reinforced the general feeling that the market could be short during 2008-2012. From this date on, Phase II prices increased and stabilized over 20€/ton of Carbon Dioxide[31]. In this sense, Alberola (2008) identifies two structural endogenous breaks in the time-series of spot prices during 2005-2007: the first compliance period break goes from April 24, 2006 to June 12, 2006; and, due to the EU Commission stricter Phase II validation, the second break occurred from October 26, 2006 onwards[31].

- **The Impact of Energy Prices**

CO_2 emissions are directly linked to the use of fossil fuels (such as oil, gas and coal), at least in Europe. In turn, demand for fossil fuels depends only on their absolute and relative prices.

During Phase I, short term abatement decisions, and thus the demand for allowances, were mainly driven by unexpected fluctuations in energy demand, energy prices and weather conditions. Power and heat operators are major actors on the EU ETS[32] and, so, unexpected fluctuations on energy demand for power and heat generation and the marginal costs of fuel switching, from high carbon intensive energy sources to low carbon-intensive sources, still be the most important determinants of carbon allowances demand and carbon abatement measures implementation, in the short run.

Many studies conducted on the subject [Mansanet-Bataller (2007), Delarue and D'haeseleer (2007), Alberola (2008), Bunn and Fezzi (2008), Ellerman and Feilhauer (2008)] concluded that, in fact, energy prices are the most important short term drivers

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[30] See Figure 2, Figure 15, Figure 16 and Figure 17.

[31] By mid 2006 Phase I spot prices started its way downwards towards zero until the end of Phase I due to banking restrictions implemented between 2007 and 2008 [Alberola and Chevallier (2009)]. See Figure 4 in page 16, title 2.1.4.1.

[32] The main sector whose share was the largest in terms of emissions covered by the EU ETS in Phase I was the power sector, which accounted for over 50% of emissions capped by the scheme. Their emissions abatement costs were (and still are) assumed to be the lowest compared to others sectors, notably through fuel switching from coal to gas.

of the demand for EUAs, due to the ability of power generators to switch between their fuel inputs. As shown by Alberola, energy prices forecast errors have basically driven EUA price changes during 2005-2007, but their influence depended also on institutional events. Most part of analysis made, show that brent, natural gas, coal, as well as switching prices all impact significantly carbon spot prices, their influence varying in function of the Kyoto sub-periods under consideration and of potential structural breaks to be detected in the time series.

➜ The Impact of Weather Conditions

In addition, Alberola (2008) pointed out also that CO_2 prices are also affected by unexpected weather variations like temperature levels, rainfall and wind speed. Cold winters increase the need for heating by electricity or fuels, whereas warm summers lead to higher electricity demand for cooling and lower rate of operation of nuclear power plants due to reduced cooling capacity of rivers. Rainfall, wind speeds and sun shine hours affect the share of power generated by carbon-free heat generation from hydropower, wind and solar energy. As a whole, weather conditions influence both the demand and the offer of energy and they are widely acknowledged to play an important role in explaining CO_2 prices.

As an example, during the winter 2006, colder temperatures than the decennial average have had the expected positive impact on EUA price changes; on the other hand, temperatures hotter than average during the Winter 2007, have affected negatively carbon price changes.

➜ The Impact of Economic Activity

Many experts consider that economic activity is the most obvious driver of CO_2 price changes. It is the least understood, though. Economic growth leads to higher industrial production in general, to an increase in energy demand and to higher pollution emissions. This leads to higher CO_2 allowances demand. The first empirical analysis devoted to this topic may be the one conduct by Alberola in 2009. Based on a thorough analysis of EU economic activity evolution between 2005 and 2007, Alberola attempted to extricate economic activity potential impacts on carbon price changes. His econometric analysis shows that three out of nine industrial sectors had a significant effect on EUA price changes from July 1, 2005 to April 30, 2007. These sectors were combustion, paper and iron which totaled 78% of allowances allocated. He have also referred that both the variation of production and the net carbon short/long position clearly impacted CO_2 price changes, as expected. He has concluded that the role played by yearly compliance positions and industrial production peaks on the new carbon market is significant and, based on the 2009 analysis he extended to German industrial sectors (during 2005-2007), he confirmed the role played by the power sector in EUA price changes.

Chapter 3. Price Discovery and Price Transmission within European CO_2 Financial Markets - Problem Formulation, Methodology and Literature Review

3.1. Comments on the Interest of the Topic

Climate change, global warming and all the effects of human-caused GHGs are major challenges faced by international community, with its negative outcomes being increasingly evident, from record temperatures to rising sea levels. In economic terms the Stern review has warned that, in the absence of policy action, climate change would reduce world GDP by between 5% and 20%; on the other hand, Stern Review estimated as well the cost of acting to reduce GHG emissions to be around 1% of world GDP, only. So, it would compensate to act.

Based on a "cap and trade" system Kyoto Protocol (UNFCCC 1998) has been the first international joint-attempt to slow down and stabilize the pace of climate change. There, most countries joint together and set targets to reduce GHG and to force a downward trend on carbon emissions. The trading mechanism implemented by Kyoto allows most GHG abatement to occur in those sectors of the world economy in which it is cheapest to do so, making it possible to achieve the cap with the lowest possible economic impact and in a most efficient manner. So far, and following the Kyoto Protocol signature, several international markets for carbon permits have emerged around the world with the EU ETS at the forefront, both in terms of market size, market maturity, and regulatory framework. In fact, the European Union Emissions Trading System is already a success story, being considered worldwide one of the major steps towards reducing the environmental pressure humanity has put on Earth equilibrium.

However, the introduction of the ETSs by Kyoto Protocol has also created some new challenges to polluters, especially to polluting companies. They started being forced to monitor and control their own carbon emissions, afterwards they were asked to manage new systems, to develop knowledge on carbon assets, including its derivatives, and to incorporate costs of carbon allowances into their cost structures. So far, companies have succeeded to deal with all these new challenges, but there is too much to be learned and too much need for more technical research and guidance. And, as Nicolas Stern has put it, the issue of having a broadly comparable global price for carbon is one of the most important ones. For market participants, academics, policy makers and traders/hedgers understanding carbon pricing processes and carbon price behavior, as well as the links between carbon allowances spot price and carbon allowances futures price within the EU ETS is of vital importance.

Besides, trading in CO_2 is rather different from trading in more traditional commodities. **First**, in carbon market polluters (namely energy producers) hold EUA or CER primarily to reduce the cost of adjusting their production structure over time or to avoid shortages, while in pure financial markets securities are used mainly for protection, speculation and hedging. **Second**, through the cap regulators impose on them, EUA/CER sellers are forced to reduce their emissions and, most of all, are expected to save a part of the allowances they get; if they do this they can cash them out on the market and sell them to someone who emits more than his allocated amount. **Third**, contrary to the value of a stock which depends on profit expectations of the firms, EUA/CER price is determined mostly by balance between supply and demand of permits (Madaleno and Pinho, 2010). **Fourth**, contrary to ordinary stocks which liquidity may be influenced by the amount of shares to be released, the annual amount of carbon allowances given to each polluting entity or to each country is set up in an administrative way for all trading periods in the EU-Directive. **Fifth**, carbon allowances have full validity only during a trading period, meaning that the value of an allowance expires after each commitment period. Nevertheless, for the next period break (between 2012 and 2013), it is expected that unused allowances will keep being converted into allowances valid for the ensuing period (banking will be allowed), but each time-break period decision may be left up to each individual European member state. This means that all excess licenses may become worthless.

Illustrating this very fact, at the end of 2007, EU ETS spot price approached zero. As Pinho and Madaleno (2010) point out, Parsons, Ellerman and Feihauer believed this zero value to result from the allocation mechanisms features of carbon allowances, namely the banking and borrowing prohibition between Kyoto periods.

Because of carbon spot value having crashing down to zero and having been taken out of markets during almost two years, questions about what should be the right price for carbon externalities arouse. As well as questions about carbon price discovery. As Milunovich and Joyeux (2007) put it, “the existing literature on carbon markets provides theoretical arguments for and against [carbon control] schemes. […] the effectiveness of any existing carbon trading scheme will rely on the ability of the market mechanism to produce prices which accurately reflect the true marginal costs of GHG abatement. In this context, the important issue of market efficiency and price discovery in carbon derivative markets also arises.” The existence of a long-run link between carbon spot price and its derivative price (futures price in our case) is essential and may help in estimating future spot price or in taking management decisions about investment in carbon emissions reduction. Milunovich and Joyeux (2007) add, “otherwise, spot and futures prices could diverge by assuming independent stochastic paths and the futures position that was meant to mitigate price risk would instead result in additional risk exposure”. They conclude saying that an independent (inefficient) futures market “has a potential to undermine the efficiency of any carbon trading scheme and we [need] to uncover which market reflects new information first and leads the price discovery process.”

In fact, like any other commodity market carbon allowances and its derivatives – both futures and options – carry risk to which all operators are exposed, namely investors and traders. Specifically, price risk arises when futures price fluctuates, forcing agents to hedge their positions through the taking of long or short positions both in the forward and in the spot markets. The existence of forward risk *premia* in carbon prices makes it evident that there are some carbon market agents that act because of risk considerations whereas other are energy market agents who act in an attempt to take environmental risks into their cost structures and into energy’s prices.

That’s why, companies participating in Emission Trading Schemes – both on a compulsory and on a voluntary basis -, have to master all aspects related to the new financial instruments created by this new regulatory framework. Because carbon market embodies energetic, economics and finance related issues, at the same time, it is very challenging and renders carbon price discovery and carbon price transmission between

Exchanges especially complex issues and important questions to be addressed. Even though there are already good work on the subject, so far, emission markets have not yet been consistently studied from a financial point of view. So, we think there still is room for more academic work, namely on the specific subject of pricing dynamics of the EUAs, CERs and other carbon products, as well as its derivatives. That's why we choose to address the theme of carbon price discovery in this master thesis.

Referring to price discovery Milunovich and Joyeux (2007) argue that Empirical analyses of price discovery in general uses Granger type causality tests between spot and futures prices or volatility spillover tests. Thus if the futures price [volatility] is found to lead the spot price [volatility] then the futures market is said to dominate the spot market and vice versa. Other studies develop the hypothesis of spot and futures prices being co-integrated and the subsequent decomposition of the price vector into a permanent and a transitory component (Stock and Watson 1988) assuming that the permanent component is an unobserved efficient market price. Information contributions to efficient price discovery are then measured using, for example, Hasbrouck (1995) and Gonzalo and Granger (1995) decompositions. Even though empirical evidence is not sufficiently clear, there seem to be more accounts of the futures market dominating the spot market than the other way around, these authors conclude.

Uhrig-Homburg and Wagner (April, 2009) also consider that there are indications "… that the futures market leads the price discovery process [which] is consistent with results known from many financial and commodity markets. One reason may be the higher liquidity in the futures market. As opposed to spot contracts, transactions with EUA futures do not have to be accounted for in the emissions registers before maturity [and] companies without their own EUA allocations can only achieve short positions in the futures and not in the spot market. Companies seeking reliable price signals in the EU ETS should therefore always start by looking at the futures market", they conclude.

As the issue of carbon price discovery is complex and can be addresses with different perspectives and methodologies, this is not a comprehensive study. We will only try to contribute with some more light into the subject.

The remainder of this thesis is organized as follows: Section 3.2. presents a brief literature survey and analyzes the relationship between spot and future prices; Section 3.3. formulates the problem to be studied and presents the methodology of our analysis; Section 4.1. describes the data and its stylized statistical properties; Section 4.2. provides the models to be used in our empirical analysis and computes them (concentrating on the relationship between carbon spot prices and carbon futures prices in the EEX through time and illustrating the concepts of risk *premia* and convenience yields in CO_2 futures market); Section 4.3. provides our empirical findings. We conclude in Chapter 5.

3.2. Previous Studies and Literature Review

With the maturing of CO_2 market, relevant academic works taking a financial perspective of carbon trading have been published, more and more in recent years. Nevertheless these academic financial analyses remain quiet sparse and concentrate mainly on EU ETS Phase I - and sometimes on its early stages -, so that an extensive and consistent analysis on the subject is still needed.

In fact, until now the economics of the EU ETS has been the focus of most of the academic work done, trying to evaluate whether the market is effectively leading towards a reduction of world emissions, or if it provides the necessary flexibility and cost abatement tools for reaching Kyoto Protocol targets. [Rubin (1996), Egenhofer (2007), Kruger (2007), Veith (2008), McKinsey (2009) and Baker (2009)].

Benz and Klar (2008) analyses the liquidity of the EU ETS futures market. Paolella and Taschini (2006) advocate for an econometric approach to the analysis of unconditional tail behavior and the heteroskedastic dynamics in the CO_2 and SO_2 allowances returns for the US markets. They also propose a GARCH structure to model the heteroskedastic (changing volatility) dynamics of carbon returns. Uhrig-Homburg and Wagner (2006) explore the performance and optimal design of derivatives on carbon emission allowances and Seifert, Uhrig-Homburg and Wagner (2008) built a stochastic equilibrium model for the EU ETS and analyze the resulting CO_2 spot price dynamics. Using spot and futures prices from German EEX, Daskalakis, Psychoyios and

Markellos (2009) find evidence that market players tend to adopt standard no-arbitrage pricing techniques. Benz and Trück (2009) put forward the use of Markov switching model, as well as ARCH and GARCH models for stochastic variables because of the presence of different stages in price development, price volatility and density forecasts allowing for heteroskedasticity. Daskalakis and Markellos (2009) suggest that inter-phases carbon futures can best be modeled with stochastic convenience yield models. Chevallier, Ielpo and Mercier (2009) give statistical evidence that the cost-of-carry relationship does not hold with 2008 and 2009 carbon allowances contracts prices (spot and futures); nevertheless, Uhrig-Homburg and Wagner (2007) use cointegration methodology and found evidence of linkage between spot and futures prices using the cost-of-carry approach; using the VECM, they also find that futures markets lead carbon CER price discovery process. Contraditing the findings of Benth, Cartea and Kiesel (2008) for electricity markets, Chevallier (2010) explore the value of risk *premia* in carbon allowances spot and futures prices from Bluenext and ECX and find positive time-varying risk *premia* (higher for post-2012 contracts than for Phase II contracts). Also contradicting previous researches from Bessembinder and Lemmon (2002) for the electricity market, Chevalier find a positive relationship between risk *premia* and the variance of carbon spot prices.

Regarding market efficiency, Daskalakis and Markellos (2008) found inconsistent evidence about the weak form of market efficiency; they justify their findings with the immaturity of the EU ETS and with the restrictions imposed on short-selling and on banking. Similar findings from Milunovic and Joyeux (2007) conclude that market is efficient in the long run. In terms of price discovery, they find that the spot and futures markets seemed to share information efficiently and to contribute to price discovery jointly. Parallel to the information diffusion pattern found in returns, they describe some evidence of bi-directional volatility transfers between the spot and various futures contracts.

Some other previous studies have focused on price discovery and on the major factors which might drive the EUA prices. They conclude that EUA prices appear to be drived mainly by energy prices (e.g. Bunn & Fezzi 2008; Benz & Klar, 2008), oil prices (Bataller, 2006), and unanticipated weather conditions (Alberola, 2008). Furthermore, given that power sector is the main operator in the emission schemes, there is evidence of existing a strong linkage between electricity prices and carbon assets prices (Daskalakis & Markellos, 2009). In fact, generally big spikes (both high and low) seem to be linked to oil markets, energy sector and economic cycles.

Literature on the study of the convenience yield in carbon allowances is much rare. However, also for the EEX market, Borak and al. (2006) examined the nature of convenience yield for carbon allowances futures, finding that the market has changed from initial *backwardation* to *contango*, with major convenience yields explained mainly by price values and volatility of spot prices. Nevertheless, they have analyzed only data of carbon spot and futures available from October 2005 to September 2006, which refers just to the first year of the Kyoto Protocol experimental period.

Gagliardi (2009) considers that carbon spot and futures prices follows the same process and are almost perfectly correlated. He goes on arguing that "in general, forward and futures prices differ due to marking-to-market and implied options. Since the futures on EUA do not include valuable options, such as those regarding the quality of the underlying to be delivered, only the valuation differences due to marking-to-market effects resulting from correlations between the EUA spot prices and the risk-free interest rates remain." However, in another analysis Uhrig-Homburg and Wagner (2007) argue that this correlation is not evident and chose to ignore the difference. They conclude that the relationship between spot and futures prices within a trading period "should thus be explained entirely by the cost-of-carry approach".

Relevant to our present study, about price discovery is the work made by Cason & Gangadharan (2006), Rubin (1996), Godal & Klaasen (2006) and Schleich and al. (2006), all focusing on the implications for financial markets of the EUA banking prohibition between EU ETS Phases.

We have already realized that the existing literature on carbon markets provides theoretical arguments for and against CO_2 trading schemes – e.g. Cooper (1996), Klepper (2003), McKibbin (1999) and McKibbin and Wilcoxen (2006) - but Samuelson have already told us: "… the effectiveness of any existing carbon trading scheme will depend upon the ability of the market mechanisms to produce prices which can reflect the true marginal costs of GHG abatement". Surely the Planet, the Kyoto Protocol and all of us will gain if we listen to our long known teacher of Economics.

So, we agree with him and, at the same time, we share the point of view of Milunovich and Joyeux (2007) when they point the issue of market efficiency and price discovery in carbon derivative markets as one of the most important to be addressed. After their analysis Milunovich and Joyeux conclude that, overall, it seems that the EU ETS futures market fulfils its roles of providing a means for effective risk management and at the same time they contribute to the price discovery process in the spot market. However, they also conclude that "it appears that, comparing to mature markets, this [carbon] relatively new market exhibits a number of peculiarities (e.g. the lack of market efficiency) which participants must take into account when trading in carbon futures."

Empirical research made by Uhrig-Homburg and Wagner (2007) show that, for futures maturing within the Kyoto Protocol trial period, after initial divergence spot prices equal discounted futures prices. They also defend that futures contracts lead the price discovery process of CO_2 emission allowances. Therefore, because of its price discovery facilitating role and because of offering means of hedging from CO_2-related risks, EUA futures are of crucial importance for all participants in the carbon emissions market. However, all their analysis were performed regarding early stages of Phase I and, due to market design and bankability limitations between periods, they alert that their conclusions may not be applicable for Phase II; so, maybe market agents are not able to learn much about fair third period futures prices, neither from the first period prices nor from the current prices of carbon futures.

As a reference, we have also reviewed some works related to risk premium on electricity and on other energy markets. Fama and French (1988) say that it may occur violations of the Samuelson effect when inventory is high and forward price volatilities increase with contract maturity. Pindyck (2001) made some research on oil and on crude oil futures markets finding evidence of *backwardation* in these markets, higher during times with big volatility data. Botterud and al. (2002) found equivalent results regarding the Nordic market of electricity. Longstaff and Wang (2004) found evidence of implicit negative excess yields and positive risk *premia* in futures for PJM (Pennsylvania, New Jersey, Maryland) electricity markets. Wei and Zhu (2006) analyzed convenience yields and risk premium for natural gas market. Daskalakis and Markellos (2009) concentrate on the impact of CO_2 EU ETS allowances on electricity risk premium and conclude that there exists a positive relationship between emission allowance spot returns and electricity risk *premia* within the EU ETS. Redl et al. (2009) also conclude in favor of the existence of a positive forward *premia* in EEX and Nord Pool electricity prices from 2003 to 2008.

As opposed to some previous researchers and to public's attention – which has been more directed towards the economics and efficiency of the trading systems – we will focus on the financial perspective of carbon market, concentrating mainly on the characteristics of the EU ETS Phase II and basing our analysis on the carbon products traded in the EEX regulated exchange. Furthermore, contrary to previous studies which have generally focused on the EU ETS Phase I (2005-2007), this study extends the period of analysis to a broader time-period using data from October 2005 to October 2009 and examines EEX carbon allowances price from a risk management perspective. Since it covers a complex issue that can be addressed from very different perspectives and methodologies, the present Master Thesis does not aim to be a comprehensive study. It attempts to analyze market efficiency and price discovery within carbon allowance markets with a double focus: "Price Transmission and Price Discovery within CO_2 Financial Markets" and the study of "The relationship between spot and futures markets in the EU ETS".

Our motivation arises from the fact that carbon emission trading schemes are a relatively new subject, mainly in its financial angle, and its markets are expected to grow fast. Volumes are increasing at a fast pace and many investors and operators are increasingly attracted by the opportunities created in this new and challenging market. We believe this speed will accelerate with the economy crisis overcome.

3.3. Problem Formulation and Methodology of the Study

Regulatory, economics and some finance work on carbon market have already been addressed in some previous studies, so that we have included a short summary of the existing literature in the previous section. Even though it is necessary to understand the main characteristics of the market, it is not in the scope of this thesis to address EU ETS economical issues. We take here a purely financial perspective.

So, like Gagliardi and Sehested (May 2009) we too do not aim to analyze the consequences of CO_2 allowances allocation process - even if it impacts the price itself -, nor will we examine the economic rationales and the repercussion on market efficiency resulting from the prohibition of banking/borrowing. However, we are aware of the importance of pinpointing some restrictions of carbon market that may impact the pricing of carbon financial instruments. For example, it is important to consider that both derivatives and its underlying assets should be continuously traded throughout the life of the derivative contract, in order to have risk neutral pricing. This does not happen within CO_2 market since banking and/or borrowing is prohibited between Kyoto market phases. In fact, inter-phases futures can be traded continuously, but the underlying spot product (the carbon allowances, AAU and EUA) from different phases cannot. These restrictions on banking and borrowing means that emission allowances become worthless at the end of each phase and that an inter-phase derivative is essentially written on an asset that is not available during the whole life of its contract. According to Gagliardi and Sehested (May 2009), this restriction put a serious doubt on the applicability of the theoretical framework of the cost-of-carry pricing model for futures and the Black-Scholles framework for options (the latter is not relevant for us here, since we will focus our analysis only on futures and spot contracts). So, relative to inter-phase assets they consider it may therefore be necessary to adopt alternative models[33].

Finally, in order to evaluate carbon price discovery process it is imperative to understand how pricing significant information is integrated into the market. Thus, like Milunovich and Joyeux (2007) and like Gagliardi and Sehested (May 2009), we seek:

- to find out which market reflects new information first and leads the price discovery process;
- to evaluate the EU ETS carbon asset's performance in sending to users price signals that reflect relevant information about the future cost of carbon emissions.

[33] For example, equilibrium models (Daskalakis, 2008) or multi-factors models (Schwartz-Smith model, for instance, refer to Carvalho paper (2010) on References Chapter of this thesis).

- Which market – spot or future – leads the carbon price discovery process.

Will new information show up in spot markets or in futures markets first? In other words, which market is the center of price discovery[34] on carbon exchanges? Volume data from different exchanges and agencies shows that EUA futures trading is much more liquid than spot trading, even for the least liquid futures contract under scrutiny. This is frequent in many other commodity markets and, within carbon market, could have some specific explanations like the absence of a spot carbon asset being traded all long the inter-phase period. So, a first guess would be in favor of the futures contract leading price discovery process.

All this and other issues have been studied in the context of other commodities and financial assets but regarding carbon permits it still lacks some more in-depth empirical work. Again, here we pretend to add with our own contribution to the discussion, focusing on understanding the relationship between EEX carbon spot price and EEX carbon futures spot price, namely through deep analysis of its risk premium and of its convenience yield.

The financial products used in our analysis are EUA and CER spots and futures prices with different maturities (Dec2006, Dec2007, Dec2008, Dec2009, Dec2010, Dec2011 and Dec2012) listed in the European Energy Exchange (EEX)[35], from 2005 to Oct2009. The historical prices have been obtained directly from the EEX website.

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[34] Spot and futures prices are usually tested in mature markets with very high data frequency. For example, Theissen (2005) uses data with a frequency of 15 seconds. For the immature EU ETS, only daily data are available. However, in sparsely traded markets, differences in price discovery between spot and futures contracts may also be observed on a daily data basis, as shown, for example, by Kavussanos/Nomikos (2003) for the freight futures market.

[35] The EEX is located in Leipzig. Other important European carbon exchanges are the Bluenext based in Paris, the ECX based in London and the NordPool with its head offices in Oslo. Competition for market share of the global carbon market induced several announcements about alliances between exchanges and the launch of new exchanges. Powernext® Carbon, the leading spot EUA market, was sold to NYSE Euronext in December 2007 and NYSE Euronext launched the new environmental exchange BlueNext.

Chapter 4. Price Discovery and Price Transmission within European CO_2 Financial Markets - Evidence from Market Data

In this analysis we use spot and futures prices of carbon allowances that trade under the EU ETS. The European Union allowances (EUA) are allocated to carbon emitting installations by regulator and the Certified Emissions Reductions (CER) are obtained by polluting entities through investment in CDM projects. Both are traded on the OTC markets and on the organized exchanges. The trading occurs between firms that over-emit and firms that under-emit relative to their allocations and among other market participants such as speculators, arbitrageurs and hedgers. The total number of permits issued is consistent with the path undertaken by the EU towards its overall Kyoto commitment objective (reduction of greenhouse gas emissions 8% below its 1990 level by year 2012 and reduction of 20% by year 2020). The EUA are legally binding and targeted installations are required to surrender, in the month of April of the following year, permits equivalents to the amount of emissions produced each year. In the case where an insufficient number of permits are surrendered, the organization is given a penalty[36] and still has to surrender the deficit permits. Therefore the penalty charged does not represent an upper limit of the price of carbon emissions; it really is a severe discouragement to exceed the imposed limit.

Until now the EU ETS has evolved through two phases. Phase I (2005–2007) was planned to be a pilot phase to prepare the EU for compliance with the Kyoto Protocol, included only about 40% of European CO_2 total emissions and targeted mainly the electricity sector. With the beginning of the second phase (2008–2012), the EU ETS has broadened its coverage and incorporated other industries and other types of greenhouse gases (e.g. methane, nitrous oxide, etc). The EU ETS is expected to achieve full compliance with the Kyoto Protocol in Phase II. Although some European member countries have suggested that unused Phase I permits should be valid GHG offsetting instruments in Phase II, most of them have decided that the two Phases were

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[36] 100 Euros; refer to the end of point 2.1.4. of this thesis

inconsistent and Phase I permits should not be used in Phase II. After 2012 the EU-ETS will enter what is already referred to as the Post-Kyoto Period.

As argued by Daskallakis and Markellos (2008) the fact that the EU ETS is a very young, immature market means that significant differences in terms of stakeholders, liquidity, information and pricing may exist between spot and futures markets and among market operators. Furthermore, the pricing mechanism and the relationship between spot and futures allowance prices may vary considerably depending on the futures contract that is written and on if it expires in the same phase or between different phases of the EU ETS, respectively. Given these idiosyncrasies of carbon markets, the present study analyses spot market data along with futures market data from contracts maturing both inter-phase and intra-phase.

4.1. DESCRIPTIVE STATISTICS (DATA DESCRIPTION) OF THE DATA USED

Contrary to Daskalakis/Psychoyios/Markellos (2009), who focus only on spot and futures markets for contracts written within the trial period, and to Uhrig-Homburg (2009), who also limit their analysis to the first period contracts, we will analyze a larger data span, covering both the trial period and the Kyoto commitment period. Therefore, we will focus in a time-period ranging from 2005 to 2009 and will include both Phase I and Phase II carbon assets. Data used is daily prices coming from the EEX official website. For carbon spot price we have divided our sample into two sub-periods in order to organize our analysis into a Phase I period (October 2005 to November 2007) and a Phase II period (March 2008 to October 2009).

Like any other futures contract, at the date of the transaction the buyer and the seller of European Carbon Futures (ECF) traded in the European Energy Exchange (EEX)[i] agree on the payment/delivery of a certain amount of EUA/CER, at a certain price and at a certain point of time in the future. Each contract's party has the right or the obligation to buy or sell a certain amount of CO_2 allowances, at a pre-settled date in the future and at a predefined price. Thus the delivery and/or purchase of EUA/CER form the object of ECFs contracts and its price is specified in Euros per EUA or Euros per CER. Settlement prices for the respective futures contract are established after the end of trading, on each exchange trading day. The penultimate exchange trading day of November is the last day of trading for each future contract. Carbon derivative products used in our analysis are EUA and CER spots and futures prices with maturities Dec2006, Dec2007, Dec2008, Dec2009, Dec2010, Dec2011 and Dec2012.

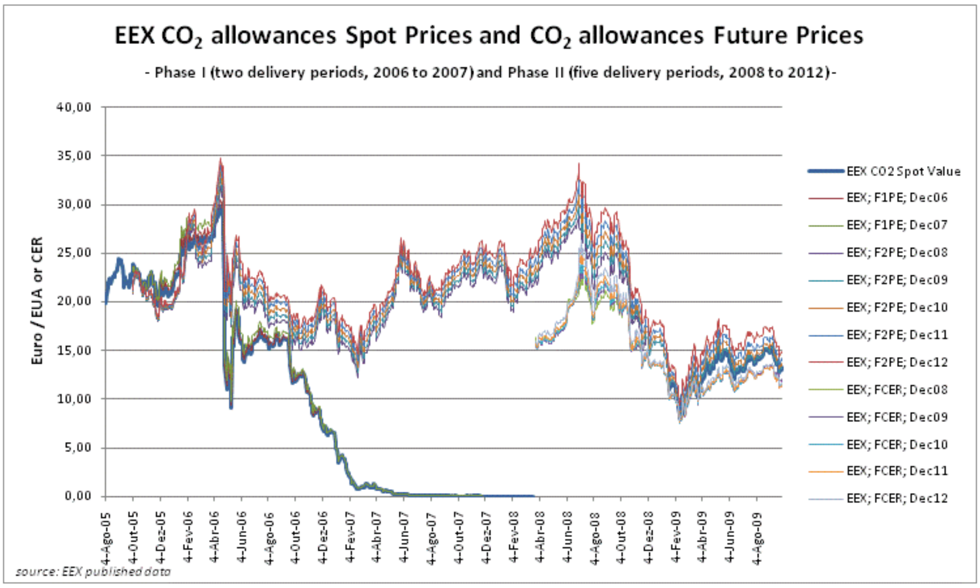

FIGURE 14: HISTORIC CO_2 SPOT PRICES AND CO_2 FUTURES PRICES (EUA AND CER)

Figure 14 above depicts the evolution of spot prices and futures contracts, both for EUA contracts and for CER contracts, for all maturing dates considered (from 2006 to 2012). Data time span is from 04 August 2005 to 01 October 2009.

As we can see, both spot and futures carbon markets are characterized by a particularly high historical volatility, with some major spikes appearing here and there, showing periods of different volatility all along the years we have got. Alberola, Chevalier and Chèze (2008) have identified two structural breaks for the 2005-2007 period and we think it could be interesting to test for structural breaks also within Phase II futures contracts. We will let it for future research.

If we disregard the beginning of the Fist Period falling towards zero value, from September 2006 to March 2008 (Spot value and Futures Dec2006 and Dec2007), we can observe that EUA futures prices ranged from a minimum of 9,43€ (EUA Futures Dec2006; 12/05/2006) and 8,10€ (EUA Futures Dec2009; 12/02/2009) to a maximum value of 34,72€ (18/04/2006) and 33,30€ (30/06/2008). The record low came with the market turmoil that took place in February 2009, as an effect of international sub-prime crisis and of decreasing energy prices. After this recent break-down, carbon prices increased again and remained relatively stable around 15€/EUA, until the end of our sample data. On the other side, carbon maximum values are considered to be a consequence of high oil prices which pressures electricity production through the use of fossil fuels and, thus, pressures demand for carbon assets. If we refer to CER futures we see that prices have had minimums of 7,55€ and maximums of 26,30€, with an average ranging from 14,86€ to 18,35€. So, we agree with Gagliardi and Sehested (May 2009) when they conclude that, generally, big spikes in both directions seems to be linked to oil markets, to economic expectations and to the energy sector.

Before going any further and apply the econometrical analysis to our data it is necessary to perform a quick statistical analysis on the series to identify the main features of price dynamics and the characteristics of price distribution. In general terms, data main statistics are: average prices for the period ranging from 11,24€ to 21,71€ (depending on the asset being analyzed) with negative mean returns ranging from -0,025 to -1,124.

	EEX CO2 Spot Value	EEX; F1PE; Dec06	EEX; F1PE; Dec07	EEX; F2PE; Dec08	EEX; F2PE; Dec09	EEX; F2PE; Dec10	EEX; F2PE; Dec11	EEX; F2PE; Dec12
Obs.	547	295	547	176	390	390	390	390
Mean	-1,125	-0,357	-1,124	-0,042	-0,038	-0,031	-0,025	-0,018
Variance	8,200	5,167	6,690	3,842	3,170	3,088	3,039	2,940
Skewness	0,050	-0,404	-0,856	-0,752	-0,437	-0,486	-0,598	-0,574
Kurtosis	10,426	30,829	11,798	15,220	16,451	16,465	17,283	16,380

FIGURE 15: DESCRIPTIVE STATISTICS OF SPOT PRICES AND FUTURES PRICES (LOGARITHMIC RETURNS)

Data explanation: "EEX CO_2 Spot Value" is the EEX spot price, "EEX; F1PE; Dec06" and "EEX; F1PE; Dec07" is the EEX carbon future contracts for period I with maturity in 2006 and 2007, respectively, "EEX; F2PE; Dec08", "EEX; F2PE; Dec09" "EEX; F2PE; Dec10", "EEX; F2PE; Dec11" and "EEX; F2PE; Dec12" is the EEX carbon future contracts for period II with maturities from 2008 to 2012. "Obs." refers for the number of observations. The rest of the variables are the standard ones.

In this table we present the descriptive statistics for logarithmic returns, meaning that we have computed $f_t = \log F_t - \log F_{t-1}$ and $s_t = \log S_t – S_{t-1}$, where low case letters are returns and F and S stand for future and spot prices, respectively.

All price series present non-zero skewness and excess kurtosis. Also, summary statistics of the data show that we have non-normal distributed returns negatively skewed and leptokurtic. The negative skewness suggests that the distribution has a long left tail, hence generating large negative values. The value for kurtosis is very high (higher than three) which indicates that tails decay less quickly compared to a normal distribution, implying that the distribution has fat tails. Since we work with logarithmic returns, price stationarity would not be a problem, as the variables are stationary at their log first difference[37].

As we have referred to earlier in this thesis, in the literature carbon emission allowances prices are usually presented as having high historical volatility[38]. In fact historic carbon spot prices show some volatility, with a standard deviation value of 2,86%; futures price present standard deviation values ranging from 1,74% to 2,59%, depending on which future contract maturity we are talking about.

Both in Figure 15 above, in Figure 16 and in Figure 17 below we can see that volatility for Period I futures - FutDec06 and FutDec07 - is higher than that of Period II. This is consistent with the fact of market being very young, recent and immature, with Period I functioning as an experimental stage for carbon market. Carbon futures contracts from 2008 to 2012 show a much lower volatility between them, may be due to market building on learning from Phase I.

Going a little bit further, if we break up data series and plot them according to Kyoto Protocol Period (plotting each Phase's trading prices separately), we can get some more detail on information. In Figure 16 below we can see that carbon prices – both spot and futures - tend to move together. As we have pointed out, during year 2006 prices showed great volatility and, after having attained its highest level (around 30 Euros per permit), they started its way down towards zero.

At the beginning of year 2006 we can see the effects of growing energy consumption, caused by an extreme cold in Europe. Together with increasing oil prices (relative to

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[37] Results will be provided upon request.

[38] Refer to Paolella and Taschini (2008) or to Daskalakis, Psychoyios and Markellos (2009) for a detailed description of the statistical properties of EUA prices series.

coal), this led to an increased use of electricity production power plants and to higher demand for CO_2 allowances, pulling prices up and up in the months ahead.

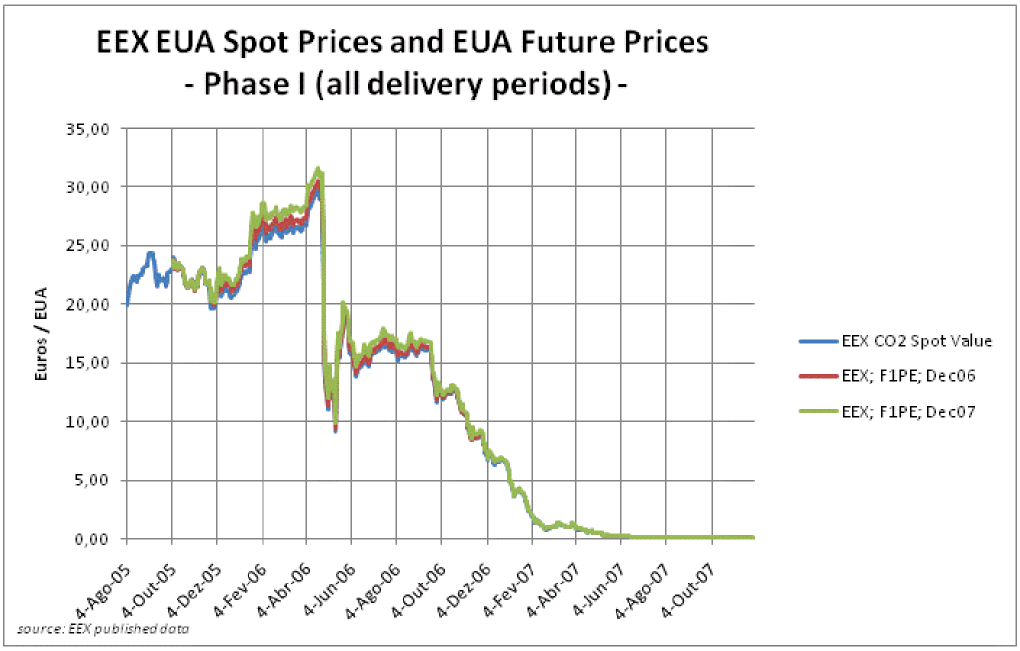

FIGURE 16: PHASE I EEX CARBON PRICES (SPOT AND FUTURES)

Nevertheless, as argued by Daskalakis and Markellos (2008), immediately after that we can observe a major market correction which took place during April/May 2006 and turned out to be the first negative spike of the data series. In fact, carbon price dropped abruptly from approximately 30 to 10 Euros washing away over half of the EU ETS market value. It is believed that this market correction has been fostered by the publication of some reports regarding 2005 actual emissions level for every installation falling under the EU ETS directive. These reports indicated that EU member states had over-allocated EUAs to their emission intensive firms and that consequently the market was not as short as was thought to be. For Gagliardi and Sehested (May 2009), the publication of 2006 emissions and allowances data did showed that most sectors and member states had excess allowances comparing to their needs.

We have already referred that banking and borrowing was prohibited between the first two EU ETS Kyoto periods (from 2007 to 2008) and any unused allowances by the end of year 2007 could not be used for compliance in 2008. Moreover, as Gagliardi reminds us the expected spot price for the year 2008 was influenced by factors that did not have any impact on first period's spot prices, such as the European Union final decision regarding EUA allocations for the second trading period. As a possible consequence of that, first period futures EUA lose value until they reach zero Euros (what we can observe clearly in Figure 16 above).

In effect, looking at Figure14, at Figure 16 and at Figure 17 we can see a real break down of CO_2 spot price along with Phase I futures price. Even if Phase II futures price have also felt a great impact, carbon spot price (the bold blue line) and Phase I futures start falling apart from Phase II futures prices since Spring 2006 and, from mid September, they experienced a real price crash (refer to Figure 14). Carbon spot price reaches zero value and, since Q1 2008, it is stopped from being traded during almost one year, until 16 January 2009.

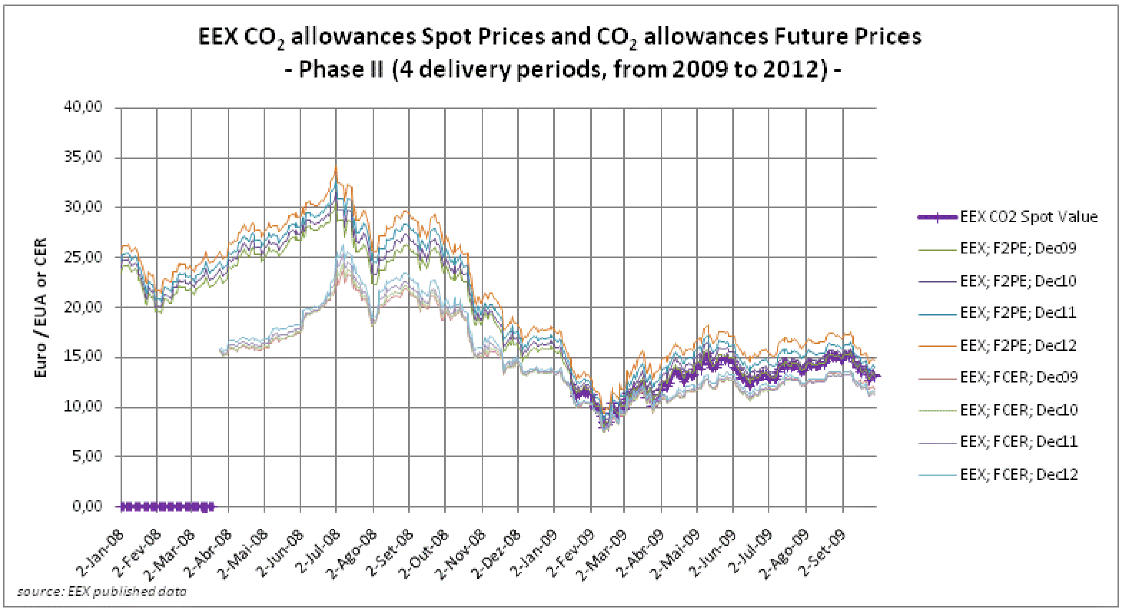

FIGURE 17: PHASE II EEX CARBON PRICES (SPOT AND FUTURES)

Because of that, between year 2006 and the beginning of year 2009 we can see that none of the futures contracts exhibit a stable long-run relationship with spot price. As Milunovich and Joyeux argue (2007) this was due to the unavailability of a relevant carbon spot price for the Phase II of the EU Emissions Trading Scheme. Adding to this, we also consider that information instability and regulation uncertainties resulting from Kyoto Phase change has greatly contributed to carbon spot pricing break-down and to futures breaking apart from spot. Hence, during this inter-Period break, futures prices were not co-integrated with carbon spot price. Many academics consider that, during this period, futures contracts have functioned as a vehicle of price discovery for the future Phase II spot price.

Both in the figure 14 and in Figure 17 we can also observe the beginning of trading of futures on Certified Emission Reductions (CER)[39]. After some years of trading only EUA futures at EEX, futures on CER were launched, starting being traded on 26 March 2008. At first, its trading price was much lower than this of EUA futures, but slowly it went up until it approaches EUA futures prices. Nevertheless CER futures trading prices tend to be lower than those of EUA futures prices and than those of carbon spot price (we can observe the price difference with spot price after spot trading prices reappear, in January 2009).

4.2. THE RISK *PREMIA* AND THE CONVENIENCE YIELDS IN CARBON EMISSION ALLOWANCES

As Uhrig-Homburg and Wagner remind us (2009), in general the relationship between spot and futures prices depends on the fundamental market characteristics and there exists a wide variety of markets. At the one end of the spectrum we find commodities such as gold, which can easily be stored and function like investment assets. In cases like this the futures price is determined by no-arbitrage circumstances. If we presuppose a constant interest rate r and no storage costs or dividends, the only costs of holding the underlying will be the predetermined interests. In this case, futures price is given by the standard cost-of-carry econometric model.

Nevertheless, in many commodity markets, Uhrig-Homburg and Wagner (2009) keep arguing, a significant part of the demand is determined by real needs. As a result, holding the physical security will impose costs but can result also in extra benefits for the holder. These benefits, which add to the income of the spot commodity's holder as opposed to the holder of a futures contract, are defined as a convenience yield. Such profits may result from the opportunity to avoid shortages in the spot commodity when required for incorporating into the production process. Classical examples are those of fuels like gas, coal, and oil.

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[39] Remember from previous Chapters that CERs are the certified emission reductions generated by polluters through their participations in CDM projects. See Chapter 2.

In addition, at the other end of the market spectrum, Uhrig-Homburg and Wagner (2009) tell us, we find pure consumption goods, such as power or wheat, which are either almost non-storable or are storable only at unaffordable costs. In this case, the link between spot prices and futures prices no long exists.

As we have explained before, EUAs are traded without restrictions within the same trading period; the only major storage costs are the predetermined interests. So, in the absence of stochastic interest rates, the only probable reason for up-dated carbon futures prices to be different from carbon spot prices is the existence of a latent convenience yield on the spot EUA, Uhrig-Homburg and Wagner (2009) conclude. Nevertheless, since companies can easily borrow EUAs from next year's allocation it is not anticipated a major convenience yield for futures maturing after the subsequent compliance date but still be within the same trading period.

Finance theory tells us that, in general, forward and futures prices differ due to marking-to-market and implied choices. Since futures on EUAs do not include valuable choices, such as those vis-à-vis the quality of the underlying asset to be delivered, Uhrig-Homburg and Wagner (2009) consider that it only remains the valuation differential due to marking-to-market effects coming from differences between the EUA spot prices and the risk-free interest rates; they carry and argue that the relationship between spot and futures prices within a trading period should therefore be fully explained by the cost-of-carry model. Since first period spot certificate could not be transferred to the second trading period they viewed the transition period between 2007 and 2008 to a different situation, considering a future 2008, for example, to be comparable to the situation described previously for power and wheat. With the cash-of-carry arbitrage not being possible and the first period spot certificate not suitable for the second trading period, spot price for the year 2008 was expected to be influenced by factors not having any impact on first period's spot prices (such as EC final decision regarding EUA allocations for Phase II). As such, Uhrig-Homburg and Wagner (2009) expect the cost-of-carry or constant convenience yield model not to hold in such a situation.

Financial literature early models – namely the cost-of-carry model - generally state that in equilibrium discounted forward prices must equal current spot prices. So, implied yields from spot and futures prices should equal riskless interest rates within the same trading period. Even if we accept that there may be temporary disequilibrium due to the immaturity of the market, in the long-term, discounted futures prices and spot prices should be co-integrated. Like Pinho and Madaleno (2010) refer, this no-arbitrage reasoning is based on a buy-and-hold strategy which functions well in typical financial and commodity markets, but doesn't function in non-tradable commodities markets, like electricity and carbon.

Gagliardi and Sehested (2009) remind us that the Futures market is usually described as having four possible conditions. The market may exhibit *backwardation*, when futures price $F_{t,T}$ (price in time t, with maturity or delivery in T with T > t) is less or equal the current spot price S_T . It is described as normal *backwardation* if $F_{t,T}$ is less or equal to the expected value for spot price in T, that is $E(S_T)$. On the other hand, *contango* usually refers to a situation where futures price is higher than the spot price, and normal *contango* similarly denotes the market condition in which $F_{t,T} \geq E(S_T)$.

In fact, for every moment t in time, carbon allowances futures price $F_{t,T}$ with delivery in T can be greater than current spot price at time t, S_t and greater than the expected spot price at delivery time T, $E_t(S_T)$. In this case the market is said to be in *contango* (more, in normal *contango*). When futures price $F_{t,T}$ is less or equal than current spot price S_t and less than expected value of spot price at delivery time T, $E_t(S_T)$, futures market is said to exhibit *backwardation* (and normal *backwardation*). Normal *backwardation* is equivalent to a positive risk premium, since the risk is transferred to the long position[40] in futures contract. Figure 18 below summarizes these four possible states of the futures market.

Futures Market Possible States	
Backwardation Normal Backwardation	$F_{t,T} \leq S_T$ $F_{t,T} \leq E(S_T)$
Contango Normal Contango	$F_{t,T} \geq S_T$ $F_{t,T} \geq E(S_T)$

FIGURE 18: FUTURES MARKETS ALTERNATIVE SITUATIONS

[40] The buyer of a futures contract is said to have a long position, while the seller assume a short position.

There is no clear consensus about the reasons which drive the market towards one of the above conditions, nor on the actual situation of the market. In the opinion of Gagliardi and Sehested (2009) market appears to be in *contango* when operators believe the demand will rise and when the market is not in over-allocation as it has been in Phase I of the EU ETS. Otherwise it will be in *backwardation*.

Previous research[41] results point out that price volatility influences negatively both the convenience yield and risk *premia*, while spot price influences positively the convenience yield value. More, there are signs that there exist a relationship between risk premium and the convenience yield, but there persists some uncertainty about its sign and, also, the level of its statistical significance. Results change depending on the Kyoto Phase under analysis and on the futures contract maturities. Nevertheless, we can conclude that carbon market has been in *contango* most of the time.

According to the theory of storage, in addition to interest foregone through the commodity, storage costs for holding the commodity and a convenience yield on inventory has to be considered. This reasoning is integrated in the following expression:

$$F_{t,T} = S_t e^{(r+sc-\varphi)(T-t)} \qquad (1)$$

where $F_{t,T}$ is the futures price at time t for a contract with delivery in time T;
S_t is the asset spot price at time t;
r is a constant interest rate[42];
sc stands for storage costs, and
φ is the convenience yield and represents the benefit obtained by holding the physical asset, using or applying it.

So, the convenience yield is the incremental value of spot prices over futures prices after accounting for carrying costs. According to this theory, arbitrageurs would be able to make risk-free profits if futures price deviates from this relationship.

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[41] Some authors that have studied CO_2 price dynamics are: Madaleno/Pinho (2010), Uhrig-Homburg/Wagner (2009), Daskalakis/ Psychoyios/Markellos (2009), Benz/Trück (2008), Paolella/Taschini (2008), Seifert/Uhrig-Homburg/Wagner (2008), Fehr/Hinz (2006), Borak et al. (2006), among others.

[42] In the estimations we performed we have assumed a constant interest rate of 4%. Sensitivity analysis performed with this interest rate revealed that the main conclusions remained the same.

An easily understandable way to think of the cost-of-carry model is to think of it as comparing the futures and spot prices of a product by adjusting the spot price for the advantages to holding it rather than the long futures position (that is, the right to buy the spot product at time T) and the disadvantages of holding it versus the long futures contract. The cost-of-carry model is also referred to as the no-arbitrage pricing model because it implies that, under a set of conditions that are approximated by modern financial markets, market participants can make risk free profits if they buy the underpriced good and sell the overpriced good.

Despite some market distortions in the real world – such a trader borrowing constraints, and transaction costs – there is considerable literature which suggests the cost-of-carry model frequently holds in mature and liquid financial and storable commodities markets within the limits of transaction costs. Nevertheless we know that, within carbon markets, storage costs are null.

So, we agree with Milunovich and Joyeux when they say that in an efficient market the futures price should equal the spot price, adjusted for the opportunity cost of holding a spot position, that is, the interest foregone, less a dividend/convenience yield. The cost-of-carry model is derived from a no-arbitrage condition that operates on a risk-free portfolio. We also share the point of view of Pindyck (2001) when he says that differences between current spot prices and futures prices can be explained by storing costs, ware-housing costs and a convenience yield. Considering that in carbon markets storage costs are null[43], if we presume no-arbitrage possibilities between spot and futures markets, we can obtain a formula for the convenience yield. S, we can imagine that we hold a unit of carbon emissions rights at time t, which current spot price is S_t. As Borak and al. (2006) put it, if we assume the existence of a convenience yield, holding the emission rights until maturity will pay the following revenues:

$$S_T - S_t + \varphi_{(T-1)} \qquad (2)$$

[43] Carbon allowances are immaterial and carbon storage costs only exist on company's balance sheets.

where $\varphi_{(T-1)}$ is the convenience yield gained from holding the asset from time t to time T. If at the same time we right a futures short contract for delivery in T, its return will be equal to $F_{t,T}$-S_T.

So, given the no-arbitrage argument we must have:

$$S_T - S_t + \varphi_{(T-1)} + F_{t,T} - S_T = (e^{r(T-t)} - 1)S_t$$

$$\Leftrightarrow \quad \varphi_{(T-1)} = S_t e^{r(T-t)} - F_{t,T} \qquad (3)$$

which is the equation for the convenience yield. Given that positions are covered, the transaction involves no risk and the total return ends-up being non-stochastic (Wei and Zhu; 2006). So, the returns should be equal to those of a risk-free investment, whose return is r_f, with price S_t.

Like in all other markets, expectations and risk choices of carbon market operators will decide CO_2 futures prices. This approach states that futures price is composed of two components, the expected future spot price and the risk premium. Thus, the very existence of risk *premia* means that futures prices are not unbiased predictors of future spot prices. In this case, if we did used simple futures prices it would end up in erroneous estimates of future spot prices and in ineffective decisions of carbon market participants.

Similar to all other financial markets, we can take risk premium as the reward of market participants for accepting to bear risk, meaning, for choosing to hold risky investments instead of choosing to invest in risk-free assets. Since carbon allowances demand fluctuates through time depending on economic conditions, energy markets demand and on weather conditions, we also expect risk *premia* to vary in magnitude over time, in response to the evolution of those markets and of the global economy. Samuelson (1965) found a typical decreasing term structure in futures price volatility as maturity increased (the term structure of a commodity forward price volatility), which became known as the Samuelson effect or time-to-maturity effect.

Let $E_t(S_T)$ be the spot price we expect today (time t) an asset will have at time T, and $F_{t,T}$ the price we have to pay today for a carbon allowances future contract with maturity at time T. The risk premium (RP) is given by:

$$RP_t = F_{t,T}-E_t(S_T) \tag{4}$$

Weron (2008) tells us that many authors consider the forward premium (FP) to be the risk premium (RP), but putting RP=-FP. Chevallier (2010) also uses the forward premium, referring to it directly as the risk premium. We agree with the latter and will use the forward risk premium each time we want to refer to the risk premium. So, we calculate carbon allowances risk premium at time t as the difference between traded futures price and the ex-post delivery spot price (Chevallier; 2010), where the spot price at time T (the ex-post delivery futures price $F_{T,T}$) is used as a proxy of the expected futures price at time t with delivery in T, that is $E_t(F_{T,T})$:

$$RP_t = F_{t,T}-S_T \tag{5}$$

We also compute this risk premium in carbon allowances prices for all contracts in EEX with delivery between 2006 and 2012. We expect this risk premium to vary in magnitude over time due to the fact that carbon allowances demand also varies through time depending on weather and other energy markets. The way risk premium method does function as a good estimator for carbon futures prices suggest that futures prices cannot be used as unbiased estimators of expected future spot price. On the contrary, they reflect the demand and supply for hedging purposes (Karakatsani and Bunn, 2005).

Earlier studies on electricity market forward risk premium concluded that risk *premia* in electricity markets are a negative function of time-to-maturity (Benth, Cartea and Kiesel, 2008; Diko, Lawford and Limpens, 2006). In order to test if this relationship between time-to-maturity and forward risk premium holds also at carbon market, we estimate the following model:

$$RP_t = \alpha+\beta T_t+\delta T^2_t+\varepsilon_t \tag{6}$$

where:

α is the constant term ;

T_t = T-t stands for the remaining time-to-maturity of the underlying contract, and ε_t is an i.i.d. Gaussian white noise error variable with mean 0 and variance σ^2.

Time-to-maturity is computed as the difference between the trading day t and the first day of the delivery period for the underlying contract (in calendar days). The constant term α stands for the overall relative hedging pressure, while β and δ coefficients represent the relationship between risk premia and time-to-maturity.

To assess the commodity price models used, we have inspected separately the empirical determination of the convenience yield and risk premium.

We have already seen that the convenience yield is the gain achieved for holding the commodity instead of holding its derivative contract. Its value depends on a number of factors (Pindyck, 2001), such as: current price level, price volatility and storage level (for deeper explanations refer to Wei and Zhu; 2006). As previously mentioned, in carbon allowances there is no physical storage cost for holding an emission right (Borak and al., 2006). Our empirical convenience yield can then be formalized as follows:

$$\varphi_t = \beta_0+\beta_1 S_t+\beta_2\sigma^2_t+\varepsilon_t \qquad (7)$$

where:
φ_t is the marginal convenience yield as specified in (3);
S_t is the log spot price of carbon emission allowances;
σ^2_t is the price volatility modeled as a GARCH (1,1)[44].

If theories are correct, we should expect both β_1 and β_2 to be positive.

To validate the theory of commodity prices we also regress the extracted risk premium component on the convenience yield and price volatility. The risk premium is then modeled as:

$$RP_t = \beta_0+\beta_1\sigma^2_{s,t} +\beta_2\varphi_t+\varepsilon_t \qquad (8)$$

[44] We will specify the volatility forecasting measures below, but for the convenience yield regression we have just used the GARCH(1,1) specification given that results obtained were very similar using other common volatility forecasting measures.

We choose to perform the regression in this way since Considine and Larson (2001) suggested that risk premium is positively related to price volatility, and Schwartz (1997) suggested that risk premium should be positively related to the convenience yield. Also, we assume a simple variance structure for the spot for the tractability of the estimation, which simultaneously captures the time-varying aspect and, finally, we obtain the time varying conditional variance from the GARCH (1,1) model.

In the following section we will present and discuss the empirical results obtained.

4.3. Empirical Results

After applying the econometric models presented above, in the following section we will give detailed analysis results for carbon allowances risk *premia* and convenience yields. Prediction

Initially we anticipated that carbon futures prices would predict expected CO_2 future spot prices. Hereafter we present the results obtained with carbon allowances risk premium measure we have used [described in equation (5) above].

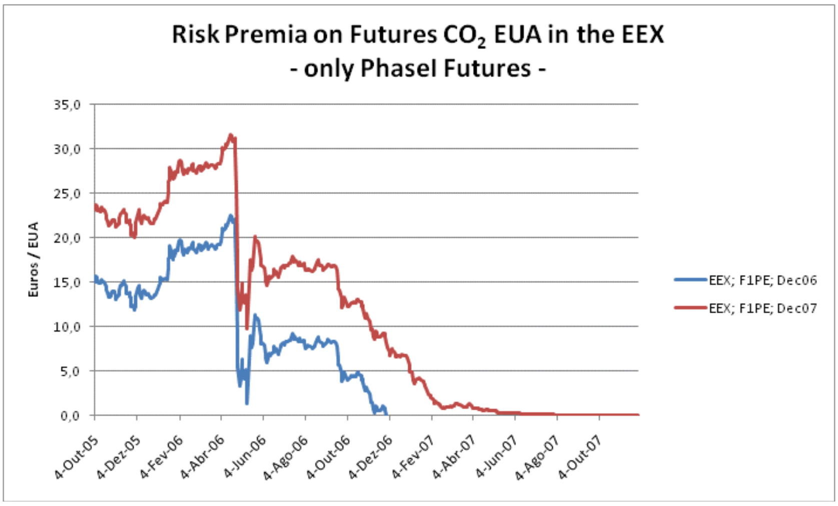

Figure 19: Risk *Premia* on EEX Phase I Carbon Assets

In Figure 19 above we present risk premium evolution for carbon spot prices and for carbon futures with maturity December 2006 to December 2007 (Kyoto Protocol Phase I data). In Figure 20 below we display the evolution of risk premium for carbon spot prices and for carbon futures with maturity December 2008 to December 2012 (Kyoto Protocol Phase II data).

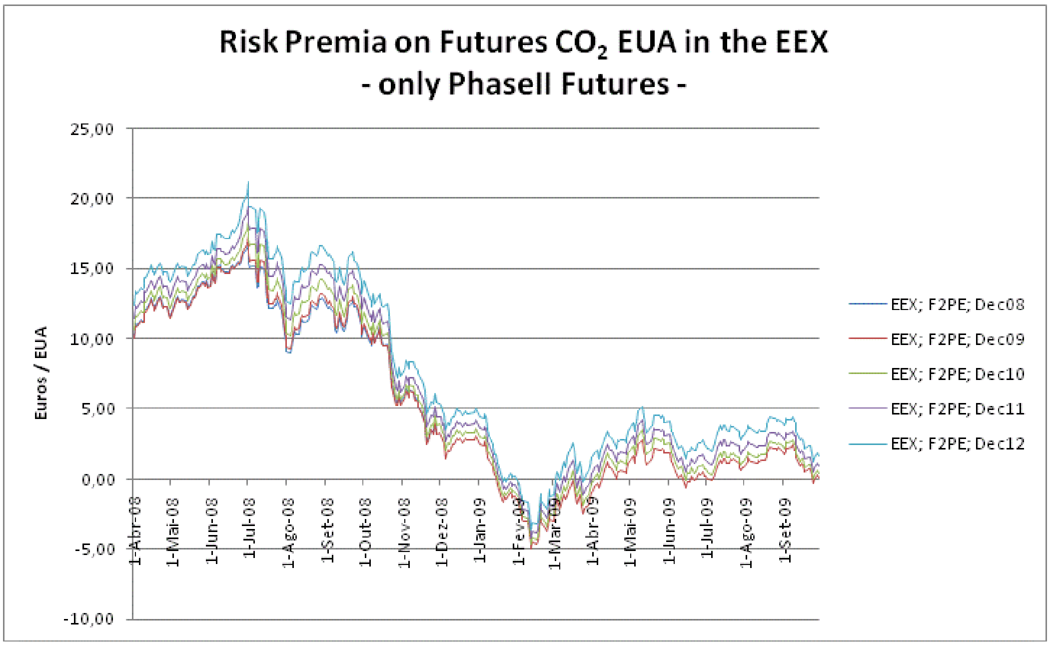

FIGURE 20: RISK *PREMIA* ON EEX PHASE II CARBON ASSETS (EUA)

We also present risk *premia* of CER (which started being traded at EEX only at the end of March 2008) in Figure 21 below.

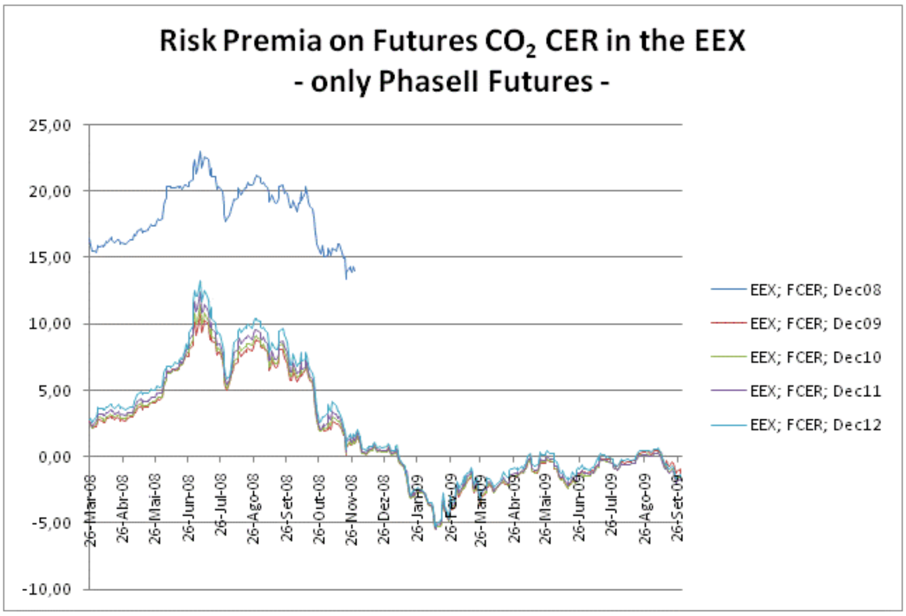

FIGURE 21: RISK *PREMIA* ON EEX PHASE II CARBON ASSETS (CER)

All these three figures allow us to recognize the time varying nature of risk premium in EEX carbon allowances. Moreover, regardless of its size and maturity period, risk *premia* seem to vary together, even though it presents different magnitudes among futures of different maturities (especially with respect to CER risk *premia*).

We can see that Phase I contracts presented much higher risk *premia* and much higher risk *premia* variations than those of Phase II, especially during the first quarter of year 2006. Phase II contracts show higher variations of risk *premia* between the end of quarter two and the beginning of quarter three of year 2008. The lowest values of Phase I carbon contracts happened at the beginning of quarter two 2006 and from quarter one 2007 onwards, because of exogenous factors to which we have already referred to earlier. In Phase II carbon allowances futures contracts, the minimum values were reached at beginning of first quarter 2009, maybe because of international economic crisis, economic activity slow down and consequent lowering in pollution emissions. This has probably contributed to the start of carbon risk *premia* decreasing. During 2009 risk *premia* remained relatively stable but low (below 5€/EUA).

We also think that differences between Phase I risk premia and Phase II risk premia may be an indication of decreasing uncertainties around post-Kyoto negotiations, increasing efficiency of the EU ETS, which allow for easier and faster incorporation of information into prices, and increasing rationality of investors, who have learned through time all along Phase I. In spite of all these maturing market signs, we still have a long way to go in terms of energy efficiency and emissions control in electricity production and all other economic sectors. In fact, Germany (and EEX) seems to be giving the first steps towards reducing GHG emissions burden and cleaner technologies are starting to be preferred to other more pollutant alternatives.

The positive sign of risk *premia* shows that expected future spot prices turned out to be lower than forward prices. This means that market for CO_2 at EEX those days has been in normal *contango*[45] (except for FCER, during 2009), which disagrees with Daskalakis and Markellos results of 2009 but is in direct support of Chevallier's conclusions (2010) for the French market. Furthermore, risk premium found for carbon allowances prices vary in magnitude across delivery periods of both Phase I and Phase II futures even though the relative magnitude of risk *premia* keeps being similar all along the period analyzed, maintaining its relative position. Regarding CER futures, we can see that

[45] The sign of the risk premium (positive for most of the sample period) indicates that expected spot prices are lower than the forward price, which implies that the day-ahead market for CO_2 in EEX is in normal contango. Notice that we have mentioned previously that we are considering RP = -FP. Refer to section 4.2. for the definition of normal contango.

FCER Dec08 had a much greater risk premium compared to all other CER futures, maybe because of its cross-Periods characteristic.

In Figure 22 below we present descriptive statistics for risk *premia* calculated through equation (5). We can see that the average risk premium is positive for all futures contracts analyzed.

Risk Premium	EEX; F1PE; Dec06	EEX; F1PE; Dec07	EEX; F2PE; Dec08	EEX; F2PE; Dec09	EEX; F2PE; Dec10	EEX; F2PE; Dec11	EEX; F2PE; Dec12
Obs.	293	545	174	389	389	389	389
Mean	11,294	11,253	3,679	7,099	7,593	8,100	8,623
Variance	5,855	10,389	3,432	3,421	3,407	3,402	3,400
Skewness	0,023	0,300	0,588	0,660	0,716	0,777	0,841
Kurtosis	1,906	1,621	3,648	3,827	3,960	4,082	4,172

FIGURE 22: DESCRIPTIVE STATISTICS FOR RISK *PREMIA* OF FUTURES MATURING DEC2006/DEC2012

As we can observe, mean Phase I futures contracts risk premium and variance are clearly higher than those of Phase II. As such, we may conclude that risk *premia* may tend to reduce as the market matures. Besides, differences in spot and futures prices can also be associated with weather conditions, economic activity risks, and other fuel markets relationships, as we have mentioned before. In summary, risk premium is a substantial component of carbon futures prices and in a significant way from the economics perspective. Uncertainties over the future of EU ETS appear to be disappearing and maybe allowances are producing the targeted results on the whole economy, namely regarding the incorporation of externalities costs due to pollution. In fact, we must note that a competitive market should reflect the costs associated with EU ETS carbon allowances and it seems that German market has started doing that.

In order to investigate the relationship between risk premium and time-to-maturity equation (6) has been computed and results plotted in Figure 23 (there, for each future contracts under analysis, we have plotted risk *premia* and time-to-maturity, in days).

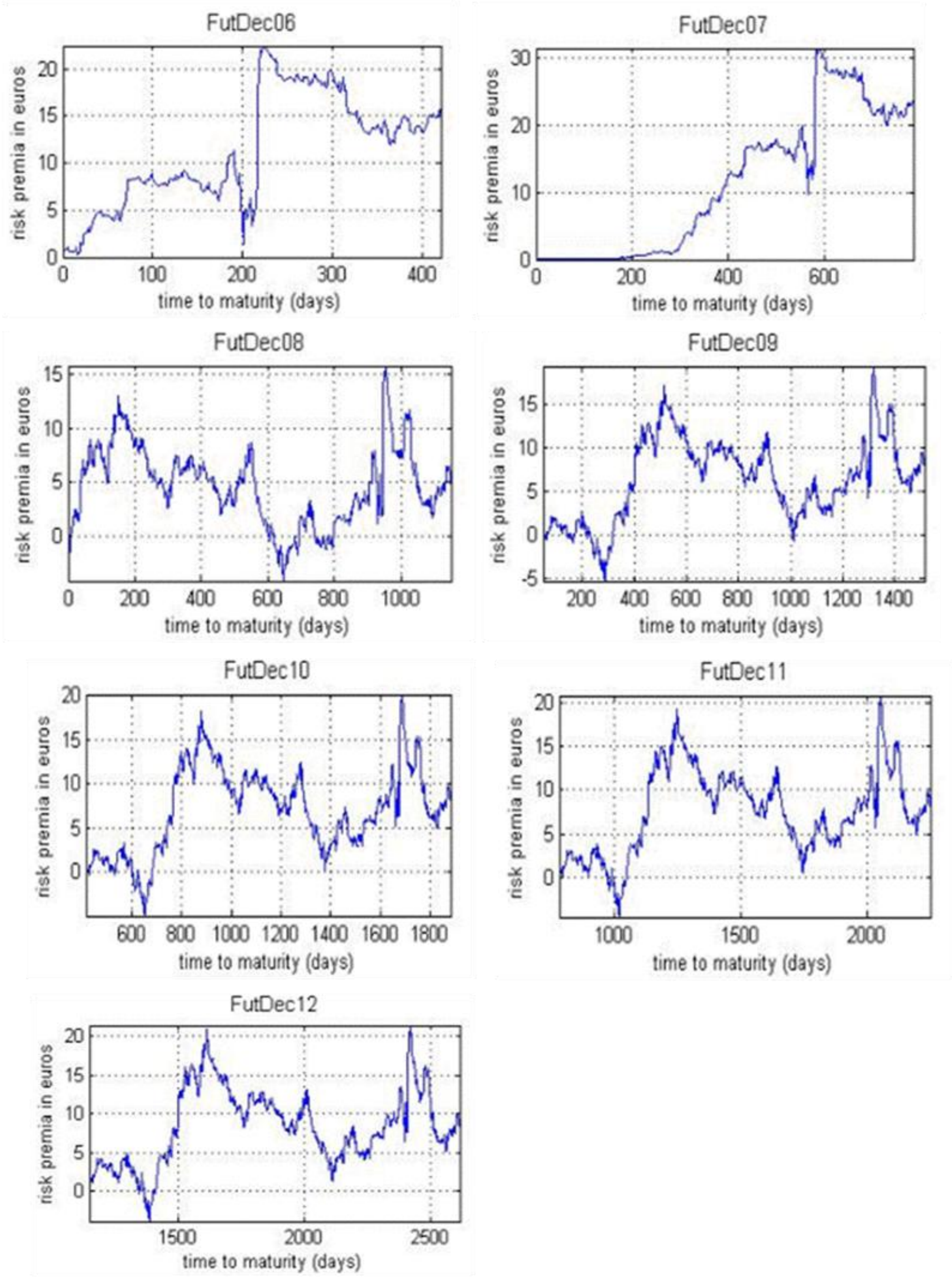

FIGURE 23: RISK PREMIUM BY TIME-TO-MATURITY FOR EACH OF THE FIVE SAMPLE CONTRACTS

In direct contradiction with earlier results attained for electricity markets but favoring those of Chevallier (2010), the negative relationship between risk premium and time-to-maturity (risk premium increases with decreasing time-to-maturity) is not verified in the EEX market. In effect, Phase I futures contracts show higher risk *premia* in spite of their lower time-to-maturity. In spite of this, there is evidence of significant time-varying risk premium in carbon allowances prices but the relationship for futures contracts in Phase II (2008-2012) does not seem to have changed as time-to-maturity increases.

Now, we go to the next stage and calculate the convenience yield regression computing equation (7) using for the volatility the specification of a GARCH(1,1)[46] model for the conditional variance. At the same time, we evaluate how the variance of spot prices and yields improve the forecast performance of futures premium by regressing equation (8). At the top panel of Figure 24 below we plot the convenience yields in futures prices maturing in November 2006 and November 2007, and at the bottom panel we plot futures prices maturing in November 2008, 2009, 2010, 2011 and 2012.

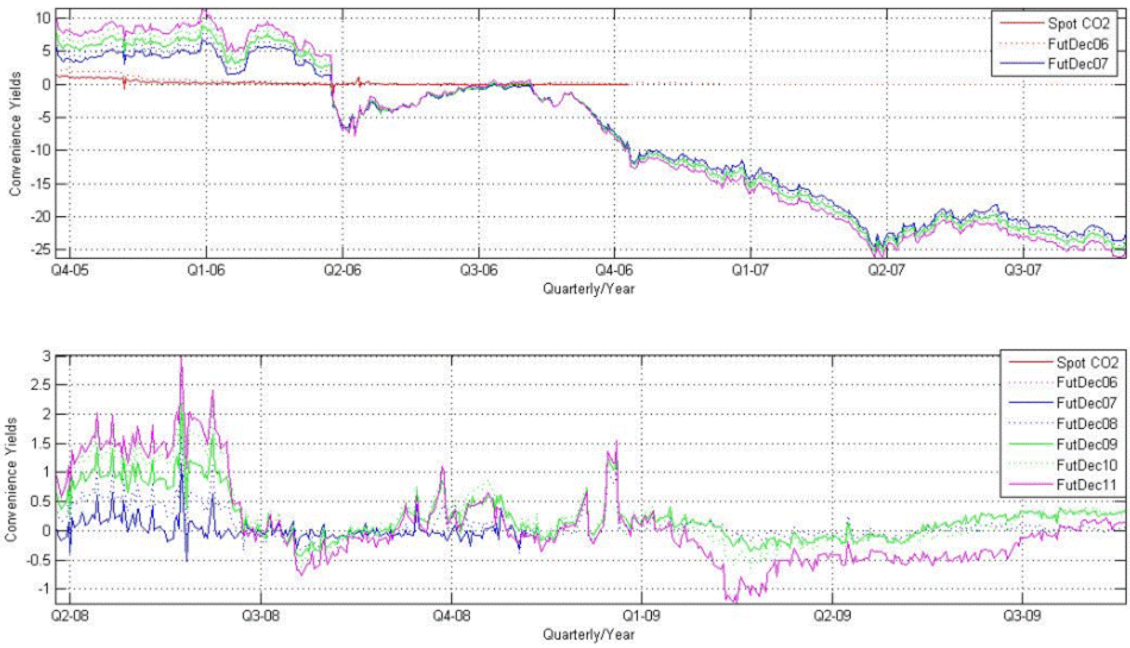

FIGURE 24: CONVENIENCE YIELDS IN FUTURES PRICES WITH DELIVERY IN PHASE I (TOP PANEL) AND WITH DELIVERY IN PHASE II (BOTTOM PANEL)

At a first glance we can say that the series for the convenience yields estimates differ significantly from Pilot Period (2005-2007) to Kyoto Period (2008-20012). Between quarter four 2005 and quarter two 2006 (top panel) the yield is positive with values $0<\varphi<10$ and we can observe high volatilities. At the beginning of 2006, when news

[46] Defined by the recursive relationship $\sigma^2_{t|t-1} = \omega + \alpha\varepsilon^2_{t-1} + \beta\sigma^2_{t-1|t-2}$. This model could be extended to a higher order GARCH(p, q) model simply by including additional lagged squared innovations and/or conditional variances on the right-hand-side of the equation. Nevertheless the GARCH(1,1) fitted just well to our purposes and is supported by the findings of, for example, Figlewski (1997) of GARCH(1,1) superiority confined to stock market and its volatility forecasting.

about allowances over-allocation for the pilot period were released, it occurred a significant shock on carbon allowances price that also affected convenience yields, which decreased until -20<φ<-25 values from Q2 2007 to Q4 2007.

Shock on convenience yields for Phase II contracts showed a different pattern, with much lower convenience yields compared to those of Phase I. Maybe due to the larger data span we have for empirical analysis performed, we find results that contradict those of Borak and al. (2006). The effect of price shock on futures prices was more dramatic in Phase II contracts than during Pilot Phase (2005-2007). In spite of the strong similarities for convenience yields in the time series of both Phases, we find different long-term reactions to the price shock. The persistence of negative convenience yields in Phase II futures may result from market participant's expectations regarding lower allocations for the commitment period (Borak and al., 2006). Between quarters 2 and 3 of year 2008 we may say that the longer the maturity date, the higher the convenience yields. On the whole, results obtained in our analysis are opposite to those of Borak and al. (2006). However, for the description of the relationship between the convenience yields and spot prices we take these authors' work as a reference.

In Figure 25 hereafter we present the data leading to the plot of Figure 24. In this table we present the coefficients and standard errors for the estimated regression (7) using GARCH (1,1) as computed for the volatility of spot price returns. Each column refers to a different future maturing date (first line of the matrix).

	FutDec06	FutDec07	FutDec08	FutDec09	FutDec10	FutDec11	FutDec12
	Model: $\psi_t = \beta_0 + \beta_1 S_t + \beta_2 \sigma_S^2 + \varepsilon$						
Period:	Phase I		Phase II				
β_0	-0.345^{***}	-0.019	0.332^{***}	0.204^{***}	0.459^{***}	0.54^{***}	0.254^{**}
	(0.109)	(0.074)	(0.098)	(0.042)	(0.042)	(0.0828)	(0.105)
β_1	0.0254^{***}	0.026^{***}	-0.0055	0.0064^{***}	0.006^{***}	0.0215^{***}	0.0363^{***}
	(0.0046)	(0.002)	(0.003)	(0.0015)	(0.0015)	(0.0030)	(0.0038)
β_2	0.074	-0.044	-0.597^{***}	-0.624^{***}	-0.624	-1.76^{***}	-2.12^{***}
	(0.08)	(0.072)	(0.139)	(0.109)	(0.109)	(0.216)	(0.273)
R^2	0.11	0.263	0.098	0.106	0.106	0.214	0.260
N	293	545	174	389	389	389	389

, * indicate significance at level 5% and 1%, respectively. N stands for the number of observations available.

FIGURE 25: REGRESSION ESTIMATES FOR THE FUTURES EUAS CONVENIENCE YIELDS OF MATURITY DEC2006 THROUGH DEC2012 FOR THE ENTIRE SAMPLE PERIOD.

Except FutDec08, both price and volatility seem to significantly influence the convenience yield, with its signs being as anticipated by price theories. Even though price volatility does not have a statistically significant impact on convenience yield for Phase I futures contracts and the signs of the estimated coefficients for December 2007 through December 2012 contracts oppose the existent theory, it favors the results of Borak and al (2006). As a result, the spot price is positively correlated to the convenience yield, which becomes higher the longer the date maturity is. On the whole, due to spot prices remaining at low levels, the market still exhibits negative convenience yields regardless of the shock. Thus, results show that convenience yields can be explained by spot price levels and volatility, while the stochastic volatility have a negative impact on yields.

Keeping in mind that the yield is the dividend that we receive from holding the asset (an allowance unit, in the case of carbon market), the negative sign relating both indicates that investors may see no privilege in holding the asset with respect to futures periods (even if not statistically significant for FutDec07 and FutDec10). However, this result deserves a deeper analysis.

Finally, in an attempt to confirm the theory of commodity prices we compute equation (8) and calculate the risk premium on the volatility of spot carbon allowances and on the convenience yield. Figure 26 show the results we have obtained.

	FutDec06	FutDec07	FutDec08	FutDec09	FutDec10	FutDec11	FutDec12
Model: $\pi_t = \beta_0 + \beta_1\sigma_S^2 + \beta_2\psi_t + \varepsilon_t$							
Period:	Phase I		Phase II				
β_0	14.2***	20.5***	14.6***	10.6***	10.0***	9.98***	12.1***
	(0.474)	(0.606)	(0.471)	(0.821)	(0.872)	(0.847)	(0.779)
β_1	−9.45***	−16.5***	−24.0***	−18.9***	−17.1***	−15.3***	−15.9***
	(0.944)	(0.748)	(1.47)	(2.31)	(2.36)	(2.31)	(2.24)
β_2	3.29***	4.34***	−1.3	4.85***	4.59	4.56***	4.05***
	(0.714)	(0.58)	(0.818)	(1.03)	(0.687)	(0.487)	(0.361)
R^2	0.319	0.597	0.62	0.233	0.27	0.336	0.388
N	293	545	174	389	389	389	389

*** indicate significance at level 1%. N stands for the number of observations available and π is the risk premium defined before as RP_t.

FIGURE 26: DETERMINATION OF THE RISK PREMIUM FOR EEX EUA OF MATURITY DEC06/DEC12.

Once more we confirm that carbon spot prices volatility has a significant negative sign and this time it influences negatively the risk premium. The convenience yield seems to have a statistically significant, strong, positive correlation with Phase I risk premium, namely on Phase II Kyoto period futures maturing on December 2009, 2011 and 2012.

Hence, in terms of volatility influence on risk premium our results are opposite of preceding theories postulates. Regarding convenience yields, at best, we can describe the outcome of this explanatory variable as mixed.

For FutDec07 and FutDec08, this simple empirical model explains a significant portion of estimated risk premium variation. The adjusted R^2 is 0,59 and 0,62 respectively. For all others, it is able to explain no more than a small portion, where $0,23 < R^2 < 0,38$. The result obtained is consistent with the risk premium regressions for other financial and commodity markets (see Wei and Zhu, 2006).

Chapter 5. Conclusions and Policy Recommendations

The purpose of this thesis has been to examine the correlation between spot and futures markets for CO_2 emission allowances in the EU ETS, trying to contribute for a better knowledge of the carbon price discovery process. Specifically, on the basis of the German electricity and carbon market, the EEX, we have examined the issues of price discovery, market efficiency and the empirical relationship between carbon allowances (both EUA and CER) futures price and carbon spot price in the European Union carbon market.

Keeping this purpose in mind we have started by describing the EU ETS market functioning, with a particular focus on its organization, its participants, the economics of its fundamentals and the basic principles of carbon finance. After highlightening the main characteristics of the market which might affect carbon pricing methodology, we have carried out some empirical analysis on both spot and futures EEX time series. We have defined and measured carbon futures risk premium and its convenience yield, we have inspected their properties and, finally, modeled the relationship between futures and spot prices in the EU ETS using classic theories. To conclude, we have examined the computation of risk premium and convenience yields on the basis of specifications put forward by several commodity pricing models. Since increasing historic data is available, it has been possible for us to extend the period of analysis, comparing to other previous studies. So, all the research was made for the first two Phases of Kyoto Protocol (the pilot period, from 2005 to 2007, and the Kyoto commitment period, from 2008 to 2012).

The statistical and econometrical analysis have showed that the historical distribution of our data diverge significantly from standard normal distribution and empirical results suggest a changing correlation pattern between carbon futures and carbon spot prices, depending on the type of futures contract or on the Phase we are looking at. Our findings may be summarized as follows:

First, we have got evidence of *contango* in the EEX futures carbon market.

Second, we found considerable differences in results obtained for different maturity contracts and for different Kyoto Protocol trading periods.

Third, the traditional negative relationship between risk premium and time-to-maturity is not verified in the EEX market.

Fourth, spot prices have a significant positive influence on convenience yields; on the contrary, price volatility seems to have a negative impact on them. More, the convenience yield increases with time-to-delivery (the longer the latter, the higher the first).

Fifth, there is a statistically negative relationship between price volatility and risk premium.

Finally, the positive impact of the convenience yield onto the risk premium gives mix results, depending on the Period and on futures contract used for performing the computation.

Like Daskalakis and Markellos (2008), our results show that allowing for short-selling and banking between successive Kyoto periods could boost liquidity and develop market efficiency. As such, this should be taken into account in policy building. Future research may undertake more in-depth analysis about forecast errors, which may help for a better understanding of differences between estimated futures price and real (ex-post) spot prices. Furthermore, price volatility, future spot prices and convenience yields don't appear to be the most important explanations for convenience yields values and for risk *premia* magnitudes; this led us to attempt to identify fundamental drivers for risk *premia*. Fuels (coal, gas and oil), weather and market constraints, were found to be of particular interest relating CO_2 contracts to energy consumption intensity, namely to electricity spot and futures markets.

Moreover, increasing impact of CO_2 allowances contracts on the electricity industry's costs show that energy market has indeed become a critical factor for carbon market development. In fact, the recently liberalized electricity market throughout Europe led to the development of environmental protection policies as newly carbon financial contracts emerged in its context.

Agreeing with Milunovich and Joyeux (2007) we consider that, overall, it seems that the EU ETS futures market fulfils its roles of contributing to carbon price discovery process in the spot market. Even more, it starts being a mean of effective incorporation of the GHG externalities into the production cost structures and into products/services final price. However, this relatively new market still exhibits a number of idiosyncrasies (e.g. it still lacks some market efficiency) relative to mature markets which must be taken into account both by market operators and policy makers. Empirical results provide evidence that uncertainties over the future of carbon markets seem to be decreasing, that it has started to produce the targeted results and, finally, that the EU ETSs carbon emissions futures market is beginning to provide meaningful forward price signals to market participants (influencing spot electricity prices and the costs of other polluting activities). This means that market participants are already factoring carbon prices into their long term business decisions, with a pass-through of additional costs caused by pollution externalities into production costs [at present, there is an ongoing research that is already investigating these specific aspects].

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Appendix

Table I: The determination of the risk premium for EEX EUA maturing from Dec2006 to Dec2012 – daily square returns

	Fut Dec 06	Fut Dec 07	Fut Dec 08	Fut Dec 09	Fut Dec 10	Fut Dec 11	Fut Dec 12
	model used: $RP_t = \beta_0+\beta_1\sigma^2_{s,t}+\beta_2\varphi_t+\varepsilon_t$						
	Phase I		Phase II				
β_0	10,7***	9,72***	7,66***	5,07***	4,84***	5,36***	7,45***
	(0,357)	(0,444)	(0,268)	(0,347)	(0,374)	(0,354)	(0,314)
β_1	-0,004**	-0,009***	-0,062**	-0,0848***	-0,077***	-0,068***	-0,071***
	(0,001)	(0,002)	(0,021)	(0,0192)	(0,019)	(0,0185)	(0,0182)
β_2	4,21***	9,01***	2,08***	6,57***	5,82***	5,37***	4,63***
	(0,814)	(0,726)	(1,23)	(1,05)	(0,686)	(0,482)	(0,364)
R^2	0,099	0,265	0,0693	0,143	0,204	0,285	0,334
N	293	545	174	389	389	389	389

Obs. - FutDec06, FutDec07, Fut Dec08, FutDec09, FutDec10, FutDec11 and FutDec12 refer to EEX; F1PE; Dec06 and Dec07 Futures Contracts, as well as to EEX; F2PE; Dec08, 09, 10, 11 and 12 futures contracts, respectively. *** indicates 1% significance level and ** indicates 5% significance level. N indicates the number of available observations. The model used is the one of Equation (8) measuring daily returns volatility through $h_{1,t} = \sigma^2_{s,t} = s^2_t$.

Adapted from Pinho and Madaleno (2010)

Table II: The determination of the risk premium for EEX EUA maturing from Dec2006 to Dec2012 – risk metrics

	Fut Dec 06	Fut Dec 07	Fut Dec 08	Fut Dec 09	Fut Dec 10	Fut Dec 11	Fut Dec 12
	model used: $RP_t = \beta_0+\beta_1\sigma^2_{s,t}+\beta_2\varphi_t+\varepsilon_t$						
	Phase I		Phase II				
β_0	11,5***	14,5***	13,7***	8,95***	8,84***	8,88***	10,4***
	(0,389)	(0,526)	(0,37)	(0,457)	(0,543)	(0,544)	(0,485)
β_1	-0,029***	-0,0745***	-1,14***	-0,519***	-0,479***	-0,423***	-0,402***
	(0,006)	(0,005)	(0,061)	(0,042)	(0,046)	(0,471)	(0,0469)
β_2	3,68***	5,86***	-1,41	4,06***	3,21***	3,51***	3,26***
	(0,797)	(0,67)	(0,75)	(0,941)	(0,677)	(0,5)	(0,382)
R^2	0,154	0,449	0,678	0,355	0,351	0,388	0,419
N	293	545	174	389	389	389	389

Obs. - FutDec06, FutDec07, Fut Dec08, FutDec09, FutDec10, FutDec11 and FutDec12 refer to EEX; F1PE; Dec06 and Dec07 Futures Contracts, as well as to EEX; F2PE; Dec08, 09, 10, 11 and 12 futures contracts, respectively. *** indicates 1% significance level. N indicates the number of available observations. The model used is the one of Equation (8) measuring daily volatilities for a wide range of diferent financial rates of return through [$h_{3,t} = \lambda h_{3t-1} + (1-\lambda)s^2_{t-1}$; λ=0,95].

Adapted from Pinho and Madaleno (2010)

Table III: The determination of the risk premium for EEX EUA maturing from Dec2006 to Dec2012 – rolling window

	Fut Dec 06	Fut Dec 07	Fut Dec 08	Fut Dec 09	Fut Dec 10	Fut Dec 11	Fut Dec 12
	model used: $RP_t = \beta_0+\beta_1\sigma^2_{s,t}+\beta_2\varphi_t+\varepsilon_t$						
	Phase I		Phase II				
β_0	11,9***	16,2***	16,8***	9,78***	9,91***	9,67***	10,9***
	(0,42)	(0,566)	(0,513)	(0,49)	(0,617)	(0,618)	(0,55)
β_1	-0,0414**	-0,108***	-1,84**	-0,603***	-0,571***	-0,495***	-0,459***
	(0,00794)	(0,00664)	(0,0954)	(0,046)	(0,0534)	(0,0548)	(0,0548)
β_2	3,25***	4,67***	-2,07*	3,07**	2,14**	2,94***	2,9***
	(0,807)	(0,671)	(0,744)	(0,943)	(0,717)	(0,532)	(0,408)
R^2	0,162	0,485	0,691	0,379	0,36	0,389	0,415
N	293	545	174	389	389	389	389

Obs. - FutDec06, FutDec07, Fut Dec08, FutDec09, FutDec10, FutDec11 and FutDec12 refer to EEX; F1PE; Dec06 and Dec07 Futures Contracts, as well as to EEX; F2PE; Dec08, 09, 10, 11 and 12 futures contracts, respectively. *** indicates 1% significance level and ** indicates 5% significance level. N indicates the number of available observations. The model used is the one of Equation (8) measuring daily returns volatility through

$\boldsymbol{h_{2t} = \frac{1}{60}\sum_{j=1}^{60} s_{t-j}^2}$

Adapted from Pinho and Madaleno (2010)

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[i] Considered one of the largest power markets I Europe, the European Energy Exchange is located in Leipzig and was established in 2002. It provided the framework for trading both electricity contracts and carbon allowances contracts.

Spot trading started in 2000 and, at present, hourly and various other electricity block contracts are traded: base (average price for the 24 hours of the day) and peak (average price for the work day, from 9a.m. to 8 p.m.) load contracts. EUA spot trading began in the early days of 2005 and, in August 2005, EEX started providing clearing services for EUA OTC trading. EUA Spot contracts have a contract volume of 1 EUA and are traded in EUR per EUA. The settlement price is established after the end of trading on every exchange trading day.

Derivatives market in EEX started in 2001 with futures contracts on electricity indices. Three years later begun the trading of options on these futures and in 2005 futures on physical electricity and on European Carbon Futures (ECFs) were launched. ECFs are characterized as First or Second period, depending on when the EUA actual delivery takes place: those which the delivery was planned to happen during the three year period 2005-2007 belong to First period category, those with delivery planned to happen during the five year period 2008-2012 belong to Second period category. Belonging to the First period, there were traded ECFs maturing on December 2006 and on December 2007. From the Second period, ECFs maturing in December 2008, December 2009, December 2010, December 2011 and December 2012 were traded (the last two still are, at present).