JEL Classification: C72, H23, Q25, Q28
Keywords: CO_2 emission allowances, Emissions Trading Scheme, EU ETS, CO_2 price, carbon market

The Economic and Financial Determinants of Carbon Prices

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Abstract
The aim of this paper is to analyze the economic and financial determinants of carbon dioxide (CO_2) prices from the short and long-term perspective, in particular within the EU-wide CO_2 emissions trading system (EU ETS). After reviewing present carbon markets, this paper investigates the several drivers of carbon prices from both n financial and an economic perspective. It then examines the main impacts of these drivers in the short and long term. Finally, by comparing the results of several academic and financial studies, this paper identifies the average carbon price and its standard deviation for different future time horizons.

1. Introduction

Carbon emissions from energy production and industrial processes are deeply entrenched in the economy. Thus, in order to mitigate the risk of catastrophic climate change, they need to be reduced to a fraction of today's level. In this context, the challenge for climate policy is to deliver these emissions reductions effectively and at low cost. Carbon prices play an essential role in this process by creating incentives for all players in the economy to reduce carbon emissions. Carbon pricing can contribute to emissions reductions in two ways: (i) by shifting production towards low-carbon and more energy-efficient technologies; and (ii) by substituting high-carbon input factors, products, and services with less carbon-intensive alternatives.

Governments can introduce a price for carbon either by using a cap-and-trade scheme or by imposing a tax on carbon emissions or other forms of regulation. In cap-and-trade schemes, governments set a cap on the total volume of emissions of a given pollutant and allocate the corresponding volume of allowances. Such allowances can then be freely traded. In particular, firms that would face high costs to reduce their emissions will buy allowances from firms with lower costs, thus reducing the total costs of emissions reductions. Hence, within a cap-and-trade scheme, carbon prices are set by market forces, whereas in the case of a carbon tax, the national government decides the price of carbon at the national level.

This paper analyzes the functioning of carbon markets and focuses in particular on the determinants of carbon prices in a cap-and-trade scheme. Section 2 describes the origins of carbon markets and related policy decisions. Section 3 identifies the determinants of carbon prices, whereas section 4 uses existing climate economy models to provide an assessment of future short-term and long-term carbon prices. A concluding section summarizes our results.

2. Carbon Markets

Carbon markets originated from the Kyoto Protocol, which introduced three market-based mechanisms: the Emissions Trading Scheme (ETS),[1] the Clean Development Mechanism (CDM)[2] and Joint Implementation (JI).[3] These mechanisms yield certified emission reductions (CERs) and emission reduction units (ERUs), allowing both allowances and credits to be traded in the market.

In order to understand carbon markets, it is important to recognize the differences between these types of carbon commodities and the systems that create them. For instance, allowances are created by cap-and-trade systems, while carbon credits are created by baseline-and-credit systems such as JI and CDM. Baseline-and--credit systems do not entail a finite supply of allowances, rather they allow for credits generated by each new project implemented; such credits can then be used by buyers to comply with a regulatory emission target, to offset an emitting activity, or as voluntary measures.

Carbon markets can be both regulated and voluntary; the latter can be defined as markets aimed at generating GHG emissions reductions not required by the Kyoto Protocol's derived regulation.

Currently, the most liquid markets are the European Union Emissions Trading Scheme (EU ETS) and the global Kyoto compliance market. The European Union adopted a CO_2 market as the centerpiece of its own strategy for regulating emissions, thus creating the largest emissions market in the world so far. Hence, the European CO_2 price is the global benchmark price.

There is a multitude of other different cap-and-trade schemes being developed across Australia, New Zealand, some US states, and Canada. For instance, the Australian Carbon Pollution Reduction Scheme is scheduled to start operation in 2011;[4] Japan is trialing a voluntary ETS after years of negotiation between government and powerful utilities and industry groups. The US is also making rapid progress; firstly, President Obama has clearly stated his support for a federal cap-and-trade scheme. In addition, the Regional Greenhouse Gas Initiative (RGGI) is up and running, while California and the Western Climate Initiative are working on state-level or regional plans. There is also a voluntary market rapidly taking shape and increasing in volume.

Hence, even if the Kyoto Protocol failed to introduce a global emission trading system, separate market fragments with different price ranges have evolved in different countries. This implies that there is no single price for carbon across the world. The international carbon market is a system with different commodities, or types of carbon credits, that are linked to varying degrees. The emerging mosaic of carbon markets may look chaotic, but what we are observing is the emergence of a system of interlinked, policy-led, financial markets, similar to today's currency markets.

[1] Emissions Trading – intended as a government-to-government market where sovereign states can buy or sell credits they are issued with as part of their cap under the Kyoto Protocol, known as Assigned Amount Units (AAUs).

[2] Clean Development Mechanism – where tradable carbon credits are awarded to projects to reduce greenhouse gas emissions that are hosted in developing countries and that complete a formal approval process. These credits are known as Certified Emissions Reductions (CERs).

[3] Joint Implementation – where the credits are awarded to similar projects, only they are hosted in developed countries or those with economies in transition. These credits are known as Emission Reduction Units (ERUs).

[4] Australia's centre-left government announced a one-year delay and major changes to its carbon trading plans on May 4, citing the global economic recession for the need to set back the start date until July 2011 (http://communities.thomsonreuters.com/Carbon/296251).

Table 1 Carbon Prices in Different Carbon Markets

Name	Average price in 2008
EUA – European emission allowances	13.52–29.38 €/tCO2
CER – Certified emission reduction	8.00–13.00 €/tCO_2 (no registred projects) 12.00–13.00 €/tCO_2 (registred projects)
ERU – Emission reduction units	14.00 €/tCO_2
RGGI allowances (RGAs)	3.41 $/short t$CO_2$
NGAC – New South Wales Greenhouse Gas Abetment Credits	3.75–8.05 A$/t$CO_2$
AEU – Australian emission unit (2011–2012)	19.00–23.00 A$/t$CO_2$
Voluntary credits (traded OTC)	2.50–12.20 $/t$CO_2$
CFI CCX – Chicago Climate Exchange	1.65 $/t$CO_2$

Notes: Voluntary credits values are volume weighted averages for 2007. Ecosystem Marketplace & New Carbon Finance, 2008.

Source: Point Carbon (January 9, 2009): *Carbon Market Monitor. 2008: Year in Review.*

The effect of these trading mechanisms is to introduce a price for carbon, placing a cost on emissions and a value on reductions. Additionally, even if developing countries have not capped their emissions, they participate in emissions trading via CDM. Indeed, under this mechanism, certified projects in developing countries yield credits from emissions reductions to developed countries that can be traded within their cap-and-trade schemes. Thus, the linkages created by emissions trading can introduce a price for carbon even in countries that have not capped their emissions. Through the CDM mechanism, a global price has emerged which is paid for all emissions reductions, irrespective of the costs incurred for the emissions reduction, while adjustments to the price only reflect the project, country, and other risk components.

3. The Determinants of Carbon Prices

Climate change is inherently a long-term, uncertainty-ridden challenge on the scientific, technological, and economic side. The fact that there will be ongoing new allocations and targets means that investors will only have a short foresight into the ETS when committing themselves to a 20–30 year investment (Reinaud, 2007). This represents a risk that irreversible investment decisions will be based on pre-implementation expectations of climate change policy, and that the actual marginal cost of abatement may differ from those expectations. Uncertainty may therefore lead to a delay in investment, thus impacting on the overall level of CO_2 allowance prices. This is why it is fundamental for companies, investors, and traders to have a reliable pricing and evaluation model which allows efficient trading strategies, risk management, and investment decisions to be implemented in the carbon market.

As previously discussed, many countries and regions already have a carbon trading scheme which sets a domestic carbon price. Hence, because countries and regions might pursue climate policies of different levels of ambition, cover different sectors, and use different allocation rules, different carbon prices may prevail in different carbon markets. In this context, *Table 1* provides an overview of the different carbon prices currently prevailing in various markets.

The main driving factors of CO_2 allowance prices can be divided into two macro categories: (i) policy and regulatory issues, and (ii) market fundamentals that directly concern the production of CO_2 and thus demand and supply of CO_2 allowances.

The first category has a long-term impact on prices. For instance, the EU ETS is created through political decisions and has to be framed in law, which must then be implemented through a series of regulatory and operating guidelines. This can potentially have an impact on the market price and its future developments. As a result, the market responds to occasional price signals from issues such as the number of European emission allowances (EUAs) issued, the EU "linking" Directive[5] which allows for the use of Kyoto credits in the scheme, as well as rules on banking EUAs from one trading phase to the next. It is a matter both of domestic policy directly connected with mitigation measures and of climate policies at the international level; for instance, what happens when the Kyoto Protocol's first commitment period ends on December 31, 2012 will have a great influence on CO_2 prices in the existing and proposed ETS.

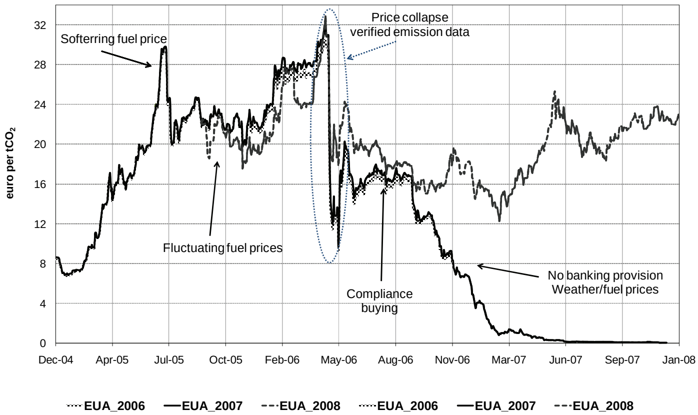
Uncertainty about future policy developments is indeed a major determinant of carbon prices. The Kyoto Protocol in its current form lasts only until 2012 and the outcome of the negotiations in Copenhagen in December 2009 is still very uncertain. During the last Conference of the Parties (COP 14) in December 2008, many fundamental issues were debated that will affect the future carbon market architecture, such as the adoption of emissions targets for large developing countries, the inclusion of credits from avoided deforestation and carbon capture and sequestration, and the potential commitment by the US. The uncertainty related to these matters induces high uncertainty in the future dynamics of carbon prices (see the next section for a quantitative analysis).

On the domestic policy side, changes in policy directives or regulations may have substantial consequences on the actual demand and supply of permits and thus on the short-term price behavior of emission allowances. In the EU ETS, these could be decisions and announcements concerning the National Allocation Plans (NAPs) that set the rules and reduction targets, allocation procedures, and limitations on the use for compliance of other credits. Generally, a cap-and-trade scheme such as the EU ETS defines a policy-driven market, because the demand for carbon abatement is ultimately a function of the level at which policymakers set the cap and of the modalities for compliance that they allow. The balance between the overall cap and demand for these allowances by emitters covered by the scheme then determines the market price for allowances. If market participants set lenient caps, allowance prices are low. On the other hand, stringent caps push up prices so as to induce additional measures to reduce emissions.

A market event that shows such correlation occurred in April 2006, when the publication of verified emissions data for 2005 triggered a massive price drop. The total volume of allowances allocated to emitters exceeded emissions in the year, confirming early concerns of a lack of scarcity of allowances. The verified emissions data was leaked a few days before its official publication, which created profitable opportunities for some market participants with insider information. Consequently, surplus EUAs flooded the market and prices crashed 60% within one week from a high of around €30/tCO_2 to €11/tCO_2 (see *Figure 1*). Such a collapse is unlikely to

[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004L0101:EN:HTML

Figure 1 European Emission Allowances (EUAs) Price: 2005–2008



Source: Own calculation based on data from Point Carbon.

occur in Phase 2 of the EU ETS (2008–2012), mainly because the caps set in the NAPs for this phase are more stringent than in the first one, and because of the banking provision.

On the policy side, another decision that can play an important role in carbon price dynamics is the length of the trading period for which cap-and-trade schemes are implemented. For instance, a longer trading period will enhance price stability, especially considering that if the trading periods are too short and there is a scarcity of allowances in the system the price will be too sensitive to climatic conditions such as a cold winter or short-term economic cycles. With longer trading periods these impacts would be averaged out over more years and would thus have less impact. In addition, longer trading periods will mean more time for investors to respond to high allowance prices with investments in low or zero-carbon technologies, thus reducing emissions and eventually prices. The length of a trading period could be indirectly defined also through the provision of borrowing or banking. Because borrowing is generally not allowed, banking is a very important feature influencing the supply--demand balance within one period. Indeed, with a bankability provision for an unlimited period, in the case of excess supply in the market, entities are induced to save allowances and thus ensure continued scarcity and positive prices.

During the first trading period, which was designed as an EU ETS pilot phase, banking of allowances was not allowed in order to protect the integrity of the second--phase market from potential difficulties in the pilot phase, and to ensure that the volume of allowances in the second trading period was in accordance with the Kyoto target. By contrast, for Phase 2 and Phase 3, the bankability provision implies that any EUAs that are not used in Phase 2 can be carried over into Phase 3. This has very significant implications for the pricing of Phase 2 allowances, because expectations about a much tighter cap in Phase 3 make Phase 2 allowances more valuable.

The demand for permits is affected by two other main determinants: economic growth and weather. For the first one, in a positive economic growth scenario, increasing production levels imply an increase in emissions, which then implies a higher demand for permits (and higher permit prices). On the other hand, weather is a critical key driver especially because power generation represents the majority of the total EUA allocation; as a consequence, factors that affect power generation are bound to affect the supply and demand of EUAs. A hot summer and a cold winter lead to an increase in energy demand and to corresponding higher emissions and price.

On the supply side, some market factors play a key role in EUA price formation. For example, commodity prices (coal, oil, and gas) are crucial in determining the relative attractiveness of different fuels for power generation, and hence the amount of CO_2 emitted. As for the EU ETS, short-run abatement options are mainly based on fuel-switching to lower emitting fuels or energy efficiency measures. Fuel-switching options are strongly influenced by fuel prices, which therefore have a strong influence on the permit price. For instance, shifting from coal power stations to gas power stations would be required to deliver emissions reductions. At the same time, if natural gas prices increase, the carbon price at which it is economical to replace production of coal power stations by gas power stations also increases. Hence, market participants trade CO_2 allowances at higher prices. As natural gas prices continue to rise, the carbon price required to switch would have to be even higher.

On the other hand, a falling price of gas relative to coal reduces the theoretical coal-to-gas switching cost, implying a fall in the CO_2 price. The differential between coal and gas prices is likely to remain an important factor also in the future, at least until carbon capture and sequestration (CCS)[6] becomes widely available.

Finally, the external supply of CERs and ERUs is also an important factor affecting carbon prices. Through the Linking Directive, the EU legislation allows conversion of CERs into EUAs, even if for a limited amount. This limitation is set in order to ensure that countries not only buy project credits to meet their emissions targets, but also pursue policies to reduce their domestic emissions. Because the CDM market is surrounded by large uncertainties over the future supply of credits and risk premiums related to the development of each project, CERs are in general cheaper than EUAs. Hence, linking is likely to have a downward effect on the EUA carbon price. *Table 2* provides an overview of the carbon price determinants just described.

4. Carbon Price Scenarios

Risk managers and traders constantly hedge their positions against the uncertainty related to carbon prices: they are interested not only in the long-term dynamics of emission allowance prices, but also in their short-term values. In this section, we therefore analyze several carbon price scenarios in both the short and long term, taking into account the aforementioned characteristics of CO_2 allowances and the various determinants of carbon prices.

[6] The inclusion of CCS and a higher share of renewable energy in the energy mix will increase the abatement potential and influence the permit demand and price too. On the other hand, carbon pricing is an important component of technology policy and can be sufficient to move innovation forward, playing, for some sectors, a core role in improving innovation and diffusing more energy-efficient and lower-carbon technologies. Considering that CCS is more expensive than other conventional approaches it will only be commercially viable where conventional technologies, which produce carbon emissions, face higher costs from carbon pricing.

Table 2 Carbon Price Determinants

	Economic	Financial
Short term	Temperature (extreme) Discount rate	Relative fossil fuel price Oil, coal and gas price Energy substitutability possibilities
Long term	CDM and JI credits supply Uncertainty about the future regulations Economic growth Banking and borrowing of permits Overall allocation	Costs of abatement efforts/technologies

4.1 Short-Term Assessment

As previously discussed, where a carbon trading framework has been clearly established – for example, within the EU ETS after the NAPs have been set – price formation is subject to market forces. Prices reflect uncertainties about technologies, demand, and availability of input factors.

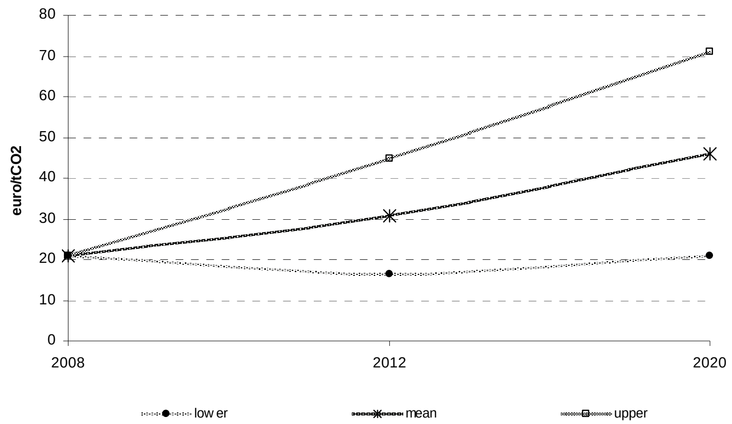
While price uncertainty is typical of many markets, carbon price uncertainty has some special features. Firstly, there are no natural lower bounds for carbon prices or expectations of reversion to the mean in the long term. This is in contrast to most commodities, where marginal production costs set natural price floors. Secondly, the lack of a long price history implies that it is impossible to extrapolate future prices on the basis of past experience, which is used in other markets to inform management and financing decisions. Finally, there are not yet any historical data on supply and demand balances, which were available for markets such as electricity and allowed for the approximation of historical performance (Neuhoff, 2008). Another important differ-ence between energy commodities and CO_2 allowances is that there is no daily or hourly need for emission allowances, while industrial installations rely on a steady energy supply to operate. Thus, installations subject to the EU ETS only need to hold allowances matching their emission levels once a year (Uhrig-Homburg and Wagner, 2006).

While the qualitative effect of most important factors influencing EUA prices is well known, the strength of their influence and their possibly time-varying correlations still raise a lot of questions. At least aspects concerning the regulatory framework – such as explicit trading rules (e.g., intertemporal trading), the linkage of the EU ETS with the market for project-based mechanisms, or other schemes in the future that may have an important impact on prices – cannot be incorporated into short-term models because they are the result of a long negotiation process.

In a short-term model, EU ETS emissions reductions mostly result from the switch between coal and gas in power production. Therefore, the gas price and coal price have a significant impact on CO_2 price uncertainty.[7] In particular, the level of fuel prices has a two-sided impact on carbon markets, as it simultaneously affects the business-as-usual emission projections and the availability and cost of fuel-switching opportunities.

[7] According to IDEACarbon (2008) a 10% drop in the price of gas would trigger a fall in the EUA price of about 9%.

Figure 2 EUA Price Forecast for Phases II and III



Source: Own calculation based on data from sources described in the *Appendix*.

For our analysis, we considered several studies that propose short-term carbon price scenarios (see the *Appendix*), particularly for EUA prices, in order to obtain a reliable estimate of the price for the second (2008–2012) and third phase (2013–2020) and assess the level of uncertainty in the short term through an estimate of the standard deviation.

The questions usually asked in these studies are as follows. Will there be oversupply of permits/credits in the market? Are there new potential players on the demand side, such as the aviation sector? Is the market long or short? Is the market in a growing phase?[8] By answering these questions, a price scenario can be identified. By averaging all the price projections proposed in the publications produced by the organizations listed in *Table 3* (in the *Appendix*), we obtain the results shown in *Figure 2*.

It can be seen that the price dispersion is not too large and that the expected price in 2020 is about €45 per tonne of CO_2.

4.2 Long-Term Assessment

In a similar way, we analyzed the output of several climate economy models to obtain a long-term price evaluation. Usually, a baseline scenario representing

[8] In recent months, many of the sources analyzed (namely, JP Morgan, Deutsche Bank, Société Générale, and IDEACarbon) have changed their estimations because of the financial crisis, which has influenced the carbon market, causing much more uncertainty in it. In particular, the recessionary impact during the middle of phase 2 could reduce demand for permits plus the appetite to buy credits, which partly offsets the lower issuance; an immediate consequence of the slowdown will be a fall in EUA and CER demand. As European industry reduces its output, its carbon emissions will fall; the economy will also consume less energy, so emissions in the power sector will fall too. The effect is dampened by the fact that buildings are still being heated and the lights are still on, even if machines are running at less than full capacity. According to IDEACarbon (2008) a (persistent) 10% fall in annual GDP growth – say from 2% to 1.8% – would reduce the system-wide shortfall (emissions-to-cap) by no more than 2.5%. This in turn would lead to a 4.0–4.5% drop in EUA prices. Over this longer period, the effect of a slowdown today is much smaller. Average growth is reduced only to 1.95% per annum, fairly close to the long-term trend. The downward correction in the average EUA price we should therefore expect is no more than about 3.5% – or just under one euro per tonne.

a world in which there is no climate policy after 2012 is obtained from each model. Then, in order to achieve a cost-effective atmospheric stabilization of CO_2 (or of all GHGs) the models require the inclusion of a carbon price through a cap-and-trade scheme or a carbon tax. Model-based analyses usually assume an idealized, flexible, comprehensive, least-cost approach to reducing emissions. Hence, stabilization costs are significantly lower than those obtained in the context of real-world policy, where countries set different levels of policy stringency, do not cover all sectors, do not include all GHGs, or employ more costly policy instruments.

For example, limiting mitigation to CO_2 (rather than focusing on all GHGs) could roughly double the CO_2 prices needed to achieve a given stabilization goal (Newell and Hall, 2008). Another example is provided by Paltsev et al. (2009), who show how excluding emissions from some sectors, such as agriculture, services and households, thus forcing more reductions in the capped sectors, implies a CO_2 price that is about 30% higher.

Under different assumptions about growth, technological options, and substitutability, or fuel prices, different carbon prices can be obtained. The more stringent the stabilization target, the higher the CO_2 price required to achieve it, and vice versa.[9] The larger the set of countries which is assumed to be committed to emission reduction, the lower the carbon price. Each model experiment considers different policy measures to reach a stabilization target, which are indirectly drivers of the carbon price. As already mentioned, the reference scenario itself has a large influence on the carbon price produced when running the model. Despite these difficulties, we have compared the results of different model experiments in a meaningful way (see the *Appendix*).

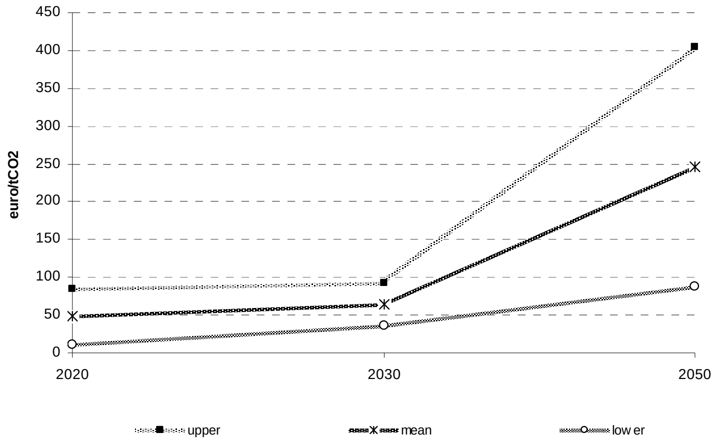
While the short-term evaluation of carbon prices focuses mostly on financial variables and fuel prices, the long-term evaluation crucially depends on the regulatory and policy framework, such as international policy for the post-Kyoto phase or the global effort to reduce emissions. Additionally, there is high uncertainty regarding the fact that some countries might not yet be prepared to sign a deal at the required level of stringency, and even if all countries pursue climate policies at similar levels of stringency, they might prefer to give different emphasis to the role of carbon pricing in their domestic climate policy mix. Hence, during the initial years, we might observe carbon prices that differ across regions and, in this case, only in the long term would similar technologies and policies move carbon prices to similar levels across countries.

In the model experiments considered in this paper, a global carbon price, or at least a unique price for countries signing an international agreement on emissions reductions, is assumed. Note that a global carbon market would achieve a lower carbon price than a fragmented or partial market, because of higher possibilities of equalizing abatement costs around the world.

Another level of uncertainty in the model experiments is given by the share of low or zero carbon energy in the energy mix. In particular, the model projections

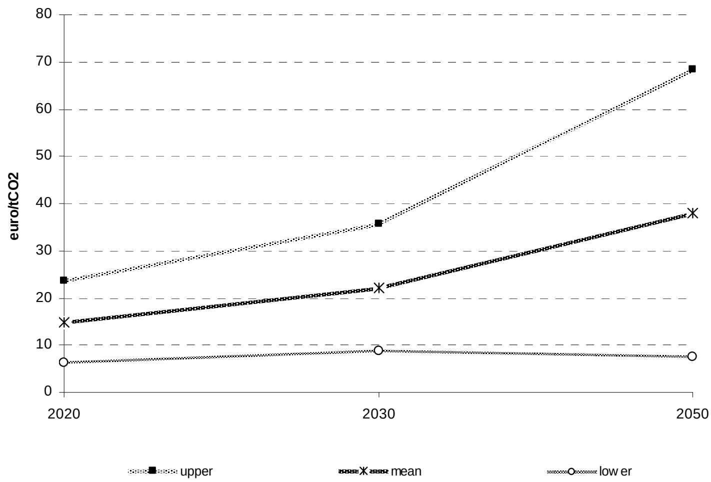
[9] Models suggest that the global carbon price level needed for stabilization at 450 ppm CO_2 could be 3–14 times higher by 2050 than the price level needed to stabilize at 550 ppm, assuming emissions reductions are implemented cost-effectively. Likewise, a less stringent 650 ppm CO_2 target could be achieved with CO_2 prices that are 50–75 percent lower than the prices modeled for a 550 ppm target, since considerably less action would be required relative to baseline expectations. See (Newell and Hall, 2008).

Figure 3 CO_2 Emissions Price: 450 ppm CO_2 Stabilization



Source: Own calculation based on data from sources described in the *Appendix*.

Figure 4 CO_2 Emissions Price: 550 ppm CO_2 Stabilization



Source: Own calculation based on data from sources described in the *Appendix*.

include changes in both the type and amount of fuels used in the power sector; the stabilization scenarios usually show a trend toward lower overall energy use, reduced use of fossil fuels, and increased use of renewable electricity and biofuels, nuclear energy, and fossil-fuel-based electricity production with carbon capture and storage.[10] However, the shares of these technologies differ across the models, thus affecting the resulting carbon prices.

All the model projections show CO_2 prices rising gradually through the mid--century. Longer time horizons imply a higher variance. In particular, *Figure 3* and *Figure 4* show the median of our results and the upper and lower levels for the 450 and 550 ppm stabilization scenarios. In the 450 ppm scenario, the average price is about €60 in 2030 and about €250 in 2050. The price is much lower in the 550 ppm scenario. The variance, measured by the standard deviation, is much higher in the 450 ppm stabilization scenario than in the 550 ppm scenario.

5. Conclusions

Although there is not yet a global carbon market, but rather a fragmented market which generates different prices, we used a large set of model experiments to provide an assessment of future carbon prices. In such a context, assumptions about the future international climate policy, or about the future availability of carbon-free technologies, play a crucial role in determining the equilibrium CO_2 price.

Nonetheless, studies show some degree of convergence in their projections of future carbon prices, with uncertainty increasing with the length of the time horizon. Uncertainty also increases with the stringency of the long-term emission reduction target. For example, in the case of a more stringent goal, such as the 450 ppm stabilization target, the uncertainty is higher than in a 550 ppm scenario.

Higher uncertainty does not mean that the models analyzed in this paper are not reliable analytical tools. It rather underlines the crucial influence of a large set of key variables (economic, financial, political, etc.) which have to be taken into account in order to identify a consistent carbon-price scenario. The existing models can hardly account for all of them, and rather focus on a subset of them. Therefore, additional research effort would be necessary to produce better and more comprehensive climate economy models.

APPENDIX

A1. Overview of Commercial Studies Considered for the EUA Price Projections

For carbon price projections in the short term (up to 2020), we analyzed estimations published by consultancies and analysts listed in *Table 3*. With the introduction of the European Trading Scheme, several market players, such as consultants specializing in support services to the carbon market or banks with carbon trading desks, buy and sell carbon permits for their clients (e.g., energy companies). In contrast with the global models presented below, which estimate a global carbon price, these projections tend to focus on a particular type of carbon credit: the European Emission Allowance (EUAs) for the second phase (2008–2012) and the third phase (2013–2020).

In particular, the analyses contained in the studies mentioned in *Table 3* consider as the main factors for assessing the future evolution of EUA prices the supply of international offsets from CDM and JI, the availability of cheap domestic abatement measures, and the amount of banking of carbon assets from Phase II to Phase III,

[10] Other important aspects correlated to CO_2 price uncertainty and considered in the models analyzed in this paper are:
- the introduction of new credits (i.e., REDD),
- the allocation of CO_2 permits,
- limited or unlimited use of credits from flexible mechanisms,
- banking allowed or not allowed.

Table 3 Overview of Commercial Studies Considered in the EUA Price Projections

Company	Year
Fortis	2008
JP Morgan	2008
New Carbon Finance	2008
Deutsche Bank	2008
PointCarbon	2007
Societe Generale	2008
Daiwa	2009
Idea carbon	2008

Table 4 Overview of Studies Considered in the Long Term Carbon Price Analysis

Author(s)	Model Name	Model type	Stabilization level (in CO_2 only)
Bosetti et al. (2009)	WITCH	Hybrid	450
Paltsev et al. (2009)	EPPA	Top-down	450 and 550
Tol (2009)	FUND	Top-down	450 and 550
Blanford et al. (2008)	MERGE	Hybrid	450 and 550
Elzen Den et al. (2009)	IMAGE/TIMER + FAIR	Hybrid	450 Co_2e
Jacoby et al. (2008)	EPPA	Top-down	450
Nordhaus (2008)	DICE	Top-down	450 and 550
Babiker et al. (2008)	EPPA	Top-down	550
Bernard et al. (2005)	GEMINI	Top down	550
Russ et al. (2006)	POLES	Bottom-up	550
	Message	Bottom-up	
	DNE21	Bottom-up	
	GMM	Optimisation model	
	AIM	Top-down	
	GEM-E3	Top down	
US CCSP (2006)	IGSM	Top-down	450 and 550
	MiniCam	Hybrid	
	Merge	Hybrid	
Bosetti et al. (2008)	WITCH	Hybrid	450

which could encourage market players to buy the surplus of allowances in order to bank them for the following phase.

A2. Overview of Studies Considered for Long-Term Projections of Carbon Prices

The carbon price analyzed in section 4.2 is a global carbon price determined on a single global carbon market which equals the marginal abatement cost of the last abatement option in the least-cost abatement, thus assuming a perfect carbon market where no limits are set on the use of international offsets. This is a simplification of the real situation, in which a number of carbon markets are emerging, thus leading to a fragmented global carbon market.

Most of the studies analyzed for the long-term carbon price scenario (*Table 4*) are based on top-down models, which include both Computable General Equilibrium models (EPPA, AIM, GEM-E3, IGSM) and Optimal Growth models (DICE, FUND). A few studies used bottom-up models (DNE21, MESSAGE, GEMINI, POLES) while the remainder are based on hybrid models which integrate a bottom-up description of sectors responsible for emissions measures with a top-down description of the economy (WITCH, MERGE, MINICAM, IMAGE).

The different nature of the models can explain part of the differences found in permit prices. According to Russ et al. (2006), the general equilibrium models tend to produce lower permit prices, since, unlike energy models, they allow for adjustments in the whole economy. Optimization models with perfect foresight yield smoother trajectories without steep increases for permit prices as compared to models that operate with "myopic anticipation" of future events and decisions.

It is a matter not only of the type of model, but also of different assumptions for the baseline scenario – different economic and population growth and technological developments – and for the stabilization scenario – limitations of the mitigation portfolio with respect to CCS, forest sinks, nuclear and renewable – and the associated uncertainty.

Many of the studies considered explore the carbon price for both CO_2-only stabilization targets – 450 and 550 parts per million (ppm) – and for all GHGs. The stabilization scenario at 450 ppm of CO_2 in the atmosphere yields higher carbon prices than less ambitious stabilization scenarios such as those aiming at 550 ppm. Given that the present CO_2 concentration level is about 385 ppm, it is easy to understand that a high carbon price is necessary to induce investments and technological change sufficient to keep concentrations below 450 ppm.

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