LUISS

DEPARTMENT OF ECONOMICS AND FINANCE

CHAIR OF IO & COMPETITION THEORY

Addressing climate change through carbon pricing: an analysis of the EU Emission Trading System

Prof. Gian Luigi Albano

SUPERVISOR

Francesca Caporali (256011)

CANDIDATE

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Introduction

Climate change is the most urgent issue our society has to face as a whole. The reason why the climate crisis is so critical is that it can cause dangerous consequences in all aspects of human life. For instance, globally rising temperatures can result in food shortages and eventually famines, while increasing sea levels, together with extended drought periods, can lead to disastrous floodings; in turn, these catastrophes increase the probability of diseases and can also provoke socio-political problems such as mass emigrations due to unhabitability of certain regions. Because of all these reasons, starting from the end of the past century, many government regulations and other measures have been adopted over the years, and are becoming increasingly ambitious in their goals of counteracting climate change.

The great relevance of this topic in the international debate, in this historical moment, is the reason why we have chosen to analyze the solution adopted in the EU. Indeed, this thesis wants to provide a comprehensive overview of the European Union Emission Trading System (EU ETS), the scheme implemented in the EU starting in 2005 to tackle the issue of the climate crisis, following the imposition of binding emission targets in the Kyoto Protocol. The goal of the ETS is to reduce European emissions released in the process of burning fossil fuels, and its establishment was particularly important since it was the first international system to allow for emission trading, and it was thus a source of inspiration for the development of similar schemes.

In order to deliver a deep analysis of the system, this thesis will be divided into three parts: the first chapter will focus on the presentation of the problem of climate change from an economic point of view (describing it as a negative externality and explaining the issues associated with providing the proper incentives to internalize it), and it further describes the problem of imposing a proper cost on CO_2 emissions, which consists in calculating the social costs that pollution imposes on the society. Finally, the EU ETS is introduced, starting from the illustration of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, which were the preliminary steps to the implementation of the system in Europe, and proceeding with a brief overview of the functioning of the system, and the phases it has been through until now.

The second chapter provides an economic analysis that wants to compare the functioning of cap-and-trade systems and carbon taxes, the two main measures that can be adopted to reduce emissions: the comparison is mainly based on the functioning of each system and on the distributional effects that their implementation can have on the members of the society. Furthermore, the downfalls of each measure are analyzed.

In the last chapter, the focus moves to one of the main problems associated with the EU ETS: the price volatility of emission permits. This last section explains how price fluctuations can undermine the reaching of an efficient outcome for the system, and provides a concise description of the factors that determine it. An analysis of price volatility as a consequence of the financial crisis of 2008, and the Covid-19 pandemic is provided, followed by the impact of financial actors on the fluctuations. Furthermore, a synthetic overview of the solutions to the problem is presented. Finally, a quantitative analysis is performed in order to determine how some factors can influence the price of permits.

CHAPTER 1

The EU Emission Trading System

In this first section, we are going to look at climate change from an economic point of view, in particular, defining it as a market externality, and explaining why governments and institutions should intervene to address this issue. Then, we will provide an overview of the most important steps in the creation of a market for emissions by illustrating the United Nations Framework Convention for Climate Change and the Kyoto Protocol. Moving forward, we will focus on the Emission Trading Scheme developed by the European Union to meet international requirements imposed by the aforementioned treaties, explaining its functioning throughout its different phases and the way it now allocates emission permits under a cap.

1.1 Climate Change as a global externality

Climate change is probably the hardest challenge we are facing as a species: its consequences affect various aspects of our lives, since it leads to increasing temperatures, damages to agriculture, rising sea levels, diminishing biodiversity, droughts, as well as decreasing labor productivity, and risks to health. Because of these costs that we incur, and that will mostly affect future generations, climate change can be considered a negative externality.

When we talk about an externality, we are referring to an activity that generates costs (when negative) or benefits (when positive) that fall on unrelated third parties, that are not captured by market prices: for this reason, externalities result in market failures. In particular, the costs imposed by climate change, can be indicated in the amount of greenhouse gas emissions including methane, nitrous oxide, and, most importantly, carbon dioxide, which are released in the process of burning fossil fuels.

A peculiar feature of climate change, however, is that it can be considered as a “global externality”: indeed, as it is also clear when we refer to it as “global warming”, its consequences affect the whole planet. As pointed out by William Nordhaus, the issue caused by this characteristic is two-fold: first of all, when dealing with a global externality, markets, as well as national governments or institutions, are unable to successfully eliminate the problem since a single nation would not be effective enough in counteracting the rest of the world’s levels of pollution. Moreover, when a country takes actions in order to reduce its emissions, it can only enjoy a small part of the benefits, as they mostly spill over to other nations, leading to the occurrence of free riding, which is the phenomenon befalling when a party can take advantage of the work of someone else, without contributing to the costs[1]. The solution to both these concerns can be found in the implementation

[1] Nordhaus, William. 2019. "Climate Change: The Ultimate Challenge for Economics." *American Economic Review*, 109 (6): 1991-2014.

of international policies that induce all national governments to cooperate toward a common goal; indeed, an "I will if you will" strategy leads to decreasing levels of free riding, while also increasing ambition and effort[2].

1.2 Why pricing carbon is important

We have established that since climate change is a negative externality, whose costs do not reflect on market prices, there is a lack of incentives for polluters to reduce their emissions. Carbon pricing plays a major role in providing these incentives: it refers to initiatives that put an explicit price on GHG emissions[3] and it allows the social costs imposed on society through pollution to be internalized by polluters. In this way, the burden of the costs shifts from third parties to those responsible for the emissions, under the principle of "the polluter pays".

This being a market failure, there is a need for governments and institutions to intervene and establish policies that put some kind of price on carbon. There are two different ways a policy can approach the issue: the first is a cap-and-trade system, in which a maximum number of emissions (cap) is set ex-ante and pollution permits are allocated; the permits are then traded in a secondary market. The allowances can be either granted for free or through an auction. The second way is through imposing a carbon tax, which directly increases the economic costs of carbon emissions for polluters.

For an economically-optimal outcome, the costs imposed on the polluters should be exactly equal to those imposed on the society through emissions, in order to fully reabsorb the externality: calculating these costs, however, is rather difficult.

1.2.1 Social cost of carbon

Assigning a price on emissions is extremely challenging. An estimate, referred to as the "social cost of carbon" (SCC) is calculated to indicate the economic damages resulting from the emission of a marginal unit (ton) of GHG, including impairments to health and crop losses. Alternatively, it can also be interpreted as the value of the benefit resulting from reducing GHG emissions by a ton.

Different models have been developed over time to calculate the SCC; among those, we find the Greenhouse Gas Impact Value Estimator (GIVE), designed by researchers from Berkley University in collaboration with the no-profit organization Resources For the Future, which is structured in four sequential modules, each affected by the previous. The first is the Socioeconomic Module, which regards future projections about GHD emissions, and both population and GDP growth. The second module is the Climate one, which, based on the output of the previous section, makes projections of climate change outcomes such as increasing temperatures, sea levels rising, and changes in ocean ph. These variations in terms of climate are then translated into economic damages through a Damage

[2] MacKay, D., Cramton, P., Ockenfels, A. *et al.* Price carbon — I will if you will. *Nature* **526**, 315–316 (2015).
[3] World Bank. What is carbon pricing?

Module, considering health, agriculture, energy, and coastal impairments: at this point, we have an output in terms of undiscounted marginal damages of emissions. This result is lastly discounted in the Discounting Module: in this section, a discount rate is used to obtain the present value of the costs, so as to allow a comparison between current and future costs and benefits. Depending on the value assigned to the discount rate, we have a final output indicating the SCC.

The SCC, however, is highly sensitive to the future projections used, bringing uncertainty to the calculation of the costs, which is therefore very volatile. As shown by Table 1, changing the discount rate used in the calculations strongly affects the final result: indeed, a higher discount rate attributes lower importance towards the future, resulting in a lower estimate for the social costs of the emissions.

DISCOUNT RATE	**GLOBAL SCC (\$/ton of CO_2)**
2.5%	75
3%	50
5%	14
7%	5

Table 1.1: Estimates of SCC in 2020 given different discount rates.[4]

Through the "Social Cost of Carbon" data tool[5], which uses the GIVE model, we can see the SCC values for different "Shared Socioeconomic Pathway" scenarios, ranging from the most optimistic (SSP1), to the most pessimistic (SSP5). We can then generate two different values for social costs for two different values of the discount rate. Given a discount rate of 2%, we obtain the results shown in Figure 1: the SCC ranges from \$77 to \$266. Otherwise, we can consider a higher value for discounting, equal to 3%; in this case, we obtain a different result: the SCC value ranges from \$36 to \$107 (Figure 2).[6]

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[4] Affordable Clean Energy Rule Regulatory Impact Analysis (2020)
[5] Prest B, Rennert K., Newell R., Wingenroth J. — Social Cost of Carbon Explorer (2022)
[6] Prest, B. C., Rennert, K., Newell, R.G., Wingenroth, J. (2022). Social Cost of Carbon Explorer. Resources for the Future

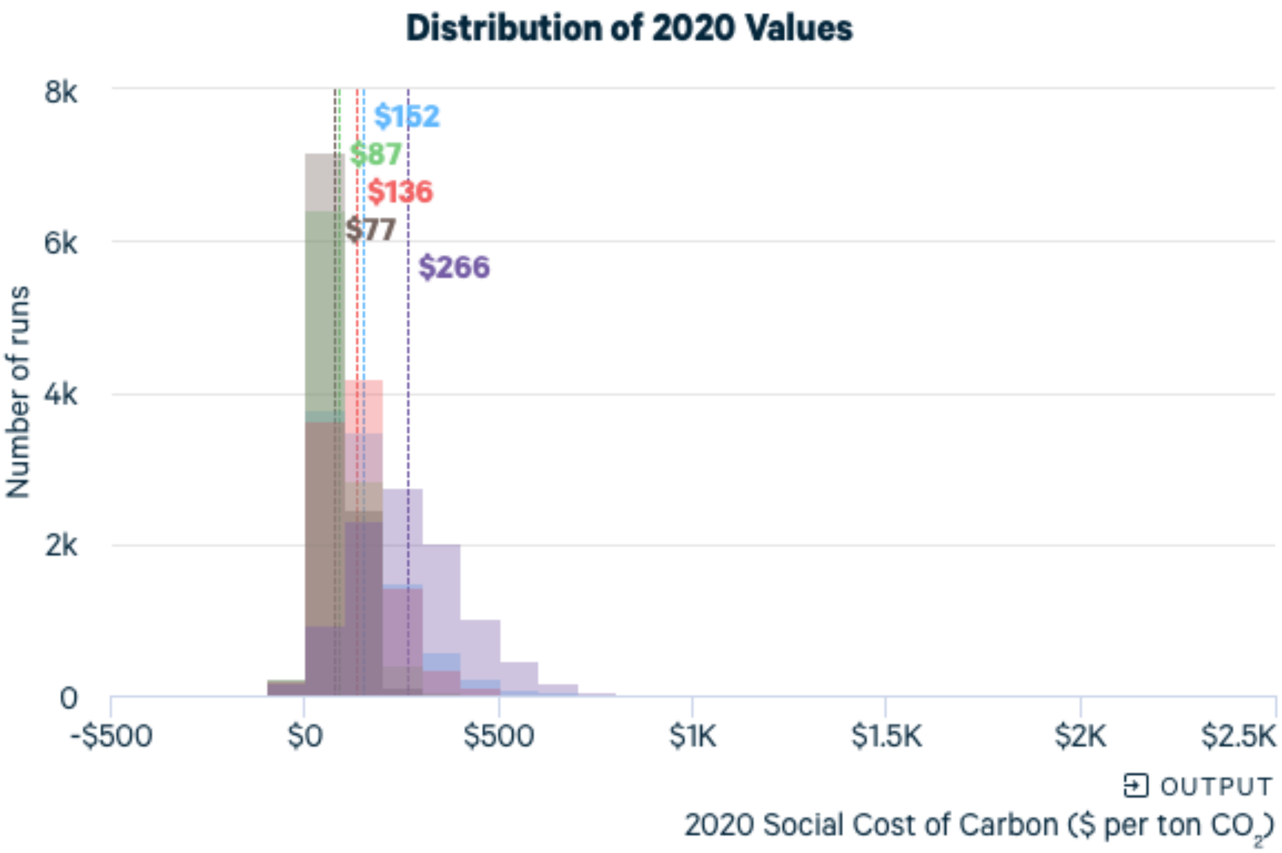

Figure 1.1: Distribution of 2020 values for the Social Cost of Carbon using a discount rate of 2%

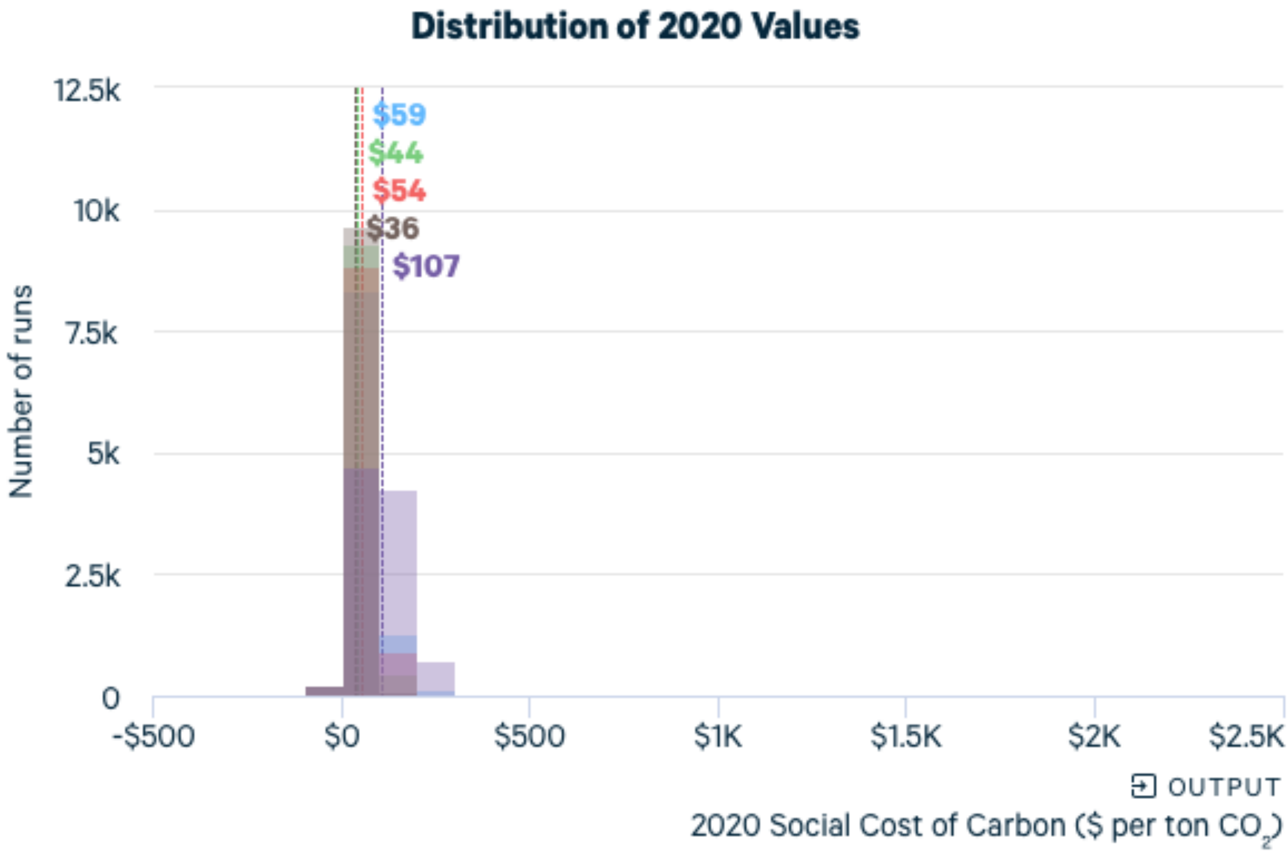

Figure 1.2: Distribution of 2020 values for the Social Cost of Carbon using a discount rate of 3%

Due to the high uncertainty in performing these calculations, usually, for a given year, different values are obtained using different parameters. Another example is given by the table below which shows low, central, and high estimates of the SCC over time, according to the parameters used for UK policy analysis.

£/tC	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Low	35	45	55	65	75	85	95
Central	70	80	90	100	110	120	130
High	140	150	160	170	180	190	200

Table 1.2: Example outputs for the SCC over time, using parameters agreed for the UK policy analysis[7]

Furthermore, the cost of carbon should also differ based on the geographical areas: indeed, different regions will experience different consequences resulting from climate change.

1.3 The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol

In June 1992, an international conference, known as the United Nations Framework Convention on Climate Change and ratified by 195 countries, was held in Rio de Janeiro, regarding the potential risks of climate change. As stated by Article 2 of the treaty, the ultimate objective of the convention was to "achieve […] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"[8]. It entered into force on 21 March 1994: we can say that the Convention was ahead of its times in considering climate change as a compelling threat and in trying to take measures on an international level. The idea behind the UNFCCC is that, since industrialized countries (referred to as "Annex I Parties") are accountable for most of the emissions, they are expected to be more proactive in cutting carbon, while also providing financial support, through grants and loans, to developing economies (Non-Annex I Parties) so as to foster climate change activities: thereby economic development is ensured in a sustainable way. The Convention, however, did not impose specific actions aimed to reduce pollution and climate change but provided an opportunity for signatory countries to adopt subsequent constraining provisions to meet the emission reduction goals through other international treaties.

[7] Watkiss P. — The Social Cost of Carbon. OECD (2020)
[8] United Nations Framework Convention on Climate Change (1992)

Among these agreements, the most important is undoubtedly the Kyoto Protocol of 1997[9], which represents the first concrete action towards the objective: indeed, it set precise constraints on the emissions of the participating countries. The protocol imposed binding targets to limit greenhouse gas emissions Annex I countries and finally came into effect on 16 February 2005. Based on emissions of greenhouse gases on a base year, each country was given a certain number of assigned amount units (AAUs; each corresponding to an allowance to emit one metric ton of carbon dioxide), and an emission target. The protocol also allows the addition and subtraction of allowances under the "Kyoto Mechanism", through trading of emissions, Joint Implementation (JI), and Clean Development Mechanism (CDM).

- Emission trading enables Annex I countries to trade Kyoto units in order to redistribute pollution quotas without affecting the total cap initially imposed.
- Through joint implementation, Annex I parties can invest in projects aimed to cut emissions in other Annex I countries to gain emission reduction units (ERUs).
- The Clean Development Mechanism grants credits following emission reduction projects in Non-Annex I countries: unlike emission trading and joint implementation, CDM increases the total amount of permits.

1.4 The European Union Emission Trading Scheme (EU ETS)

The EU ETS is the scheme adopted by the European Union to comply with the limitations set by the Kyoto Protocol. It falls within the category of cap-and-trade systems, and it was the first international trade scheme to ever be implemented. It was established through the enactment of Directive 2003/87 EC, which regulated its functioning, including specifications regarding the allocation of permits, how they can be transferred, as well as participation criteria, and guidelines for monitoring and reporting emissions. Indeed, it entails strict surveillance, detailed records to be submitted, and verification requirements to be met.

To this day, the EU ETS comprises several sectors and gases, and covers about 40% of the EU's GHG emissions. It currently includes carbon dioxide emissions from electricity, heat, and energy-intensive sectors, and it was recently revised to encompass the aviation sector for flights inside the European Economic Area. Moreover, it also covers nitrous oxide emissions, and perfluorocarbons deriving from the aluminum industry.

1.4.1 Phase 1 (2005-2007) and Phase 2 (2008-2012)

The first phase of the EU ETS, from 2005 to 2007, was set up to test the system before having to comply with the targets imposed by the Kyoto Protocol. In this period, 95% of the permits were

[9] Kyoto Protocol Reference Manual on accounting of emissions and assigned amount (2008)

grandfathered (granted for free) through national allocation plans: each Member State was required to indicate the total amount of permits to allocate, to be approved by the Commission. At this point, the allowances were only covering carbon dioxide emissions and the scheme did not include some of the highest carbon-emitting sectors, such as aviation and aluminum production.

Nevertheless, it was successful in giving a price to carbon and most importantly in providing data on emissions in order to adjust the cap of the allowances for the following period: indeed, in phase two, the cap was lowered. Furthermore, the penalty for non-compliance increased from €40 to €100, it was extended to include also nitrous oxide emissions, and the grandfathered allowances were reduced to 90%. The beginning of this term coincided with the implementation of the Kyoto Protocol.

1.4.2 Phase 3 (2013-2020) and Phase 4 (2021-2030)

The introduction of phase three marked a turning point for the system: grandfathering allowances were replaced to a large extent by auctioning under an EU-wide cap; moreover, the scheme expanded to include more greenhouse gases and more sectors. During this time frame, the total number of allowances decreased by 1.74% every year.

We are currently in phase four of the program: the European Union aims to reduce its GHG emissions by 55% compared to 1990 by the end of this term, which implies that the emissions resulting from sectors covered by the EU ETS should decrease by 43% (compared to 2005 levels). During this period, the Union-wide cap will decrease by 2.2% annually, starting from a total of 1,571,583,007 allowances. The system will be strengthened to avoid carbon leakages, which occur when companies dislocate production to countries where policies do not impose costs on carbon emissions: allocations will be granted for free to those sectors prone to relocate.

Moreover, in July 2021, the Commission adopted some legislative proposals which have the broader goal of reaching climate neutrality by 2050.

1.4.3Auction Design

The allocation of permits occurs through auctions, which are designed accordingly to Commission Regulation No 1031/2010. The auctions take place on a platform, where bidders submit their offers, without being able to see the submissions made by other participants: it is therefore a closed bidding process. The clearing price of allowances is the price at which the total volume of bids equals or exceeds the total volume of allowances up for auction. Every bid that is higher than the clearing price is accepted. These bids are assigned bid volumes beginning with the highest bid and are ordered by price in descending order. At the end of every year, participants are required to return enough allowances to cover their emissions: if the permits initially allocated are not sufficient, a party can either buy more on the secondary market from parties holding a surplus of allowances, or acquire extra quotas through other auctions. On the other hand, parties detaining a surplus of permits can either sell or bank them in order to use them in the future.

The use of the revenues generated from the permit sales is determined by the Member States and must be reported to the European Commission; however, in 2008, Member States committed to devoting at least half of the amount to fund measures to counteract climate change, in both the EU and developing countries.

CHAPTER 2

Pricing carbon: an economic analysis

As we have already mentioned, governments and institutions can approach carbon pricing in two ways: either through a cap-and-trade system or a carbon tax. In this second chapter, we will analyze both methods in order to compare them by determining the benefits and drawbacks of each. We are going to start by evaluating cap-and-trade systems, under which the EU ETS belongs, and we will continue by investigating carbon taxes.

When implementing an environmental policy, policymakers should aim to accomplish specific efficiency objectives. On the one hand, they should look at cost-efficiency, which entails conceiving means to reach their environmental goals at the lowest cost. On the other, they should also set carefully the level of abatement desired, since both too stringent and too soft measures could be counterproductive.

Furthermore, there are also equity concerns that need to be considered, such as distributional effects resulting from different types of policies.

These efficiency and equity objectives, which are often in contrast with each other, are the criteria for evaluating policies, and therefore the aspects that we will deeply analyze in this section.

2.1 Cap-and-Trade Systems

We have already given an overview of the functioning of cap-and-trade systems in the previous section. Essentially, cap-and-trade works by setting a maximum amount of level of pollution, which is translated in a certain number of emission permits allocated either through grandfathering or auctions. The permits are later traded in the market in order to allow for redistribution between the actors.

Cap-and-trade systems allow price smoothing over time through bankable permits. It is however important to carefully set the initial cap on the level of emissions, since a too-low cap would imply a lower supply of permits and higher prices, leading to too-high marginal costs of abatement, while if it is set too high, the emission reduction goals cannot be achieved.

If we apply the Independence property stated by Coase, under given conditions, a cap-and-trade system will lead to a final allocation of pollution permits that is cost-effective (optimal), independently of the initial allocation. Indeed, Ronald Coase, in his notorious work “The Problem of Social Cost” (1960), stated that in the absence of transaction costs, bargaining between parties in a market in the presence of an externality will lead to a Pareto efficient outcome; specifically, this result will be achieved regardless of the initial allocation. This independence property is however in reality affected by a number of conditions, including not only transaction costs, but also market power and structure, uncertainty over future prices of permits, conditional allowance allocation (in this case allocation depends on the previous period: firms do not minimize their costs but consider additional profits from selling their allowances), non-cost minimizing behavior (occurring when firms do not equate the cost of allowances with marginal costs of abatement), and regulatory treatment.[10] However, despite these market distortions, Hahn and Stavins (2011) report the validation of the independence property, making cap-and-trade systems an efficient way of approaching the problem of pricing carbon emissions.

2.1.1 How to allocate emission allowances: grandfathering versus market mechanisms

In a tradable-permits system, allowances are generally allocated in two ways: they can be either grandfathered or auctioned.

Grandfathering refers to the distribution of permits free of charge, directly from governments to companies, based on their historical level of emissions. As already stated, when the EU ETS was first implemented, the vast majority of the permits were allocated this way, and only later on auctions were introduced as the primary allocation method. Grandfathering, however, is widely criticized for a number of reasons.

First of all, Cramton and Kerr (2002) claim that it allows for biased distribution in favor of preferred political groups and therefore increases governmental control over distribution[11]. Grandfathering has moreover been criticized as it does not consider previous abatement efforts and rewards high-emission polluters[12]. Furthermore, additional concerns are expressed by Jonathan Nash[13], who argues that grandfathering goes against the "polluter pays" principle in two ways: first of all by offering a government subsidy to polluters, who not only enjoy free emission permits, but can also trade them in a secondary market in exchange for cash; second of all by creating an unnatural incentive for incumbent firms not to exit the market, preserving them from the competition by new entrants (that will not be granted grandfathered emission permits). Nash indeed advocates the allocation of allowances through auctions to overcome the inconsistency with the aforementioned principle.

Woerdman, Aruri, and Clo[14], however, contradict Nash's view by claiming that grandfathering is consistent with the "polluter pays" principle, since using allowances implies an opportunity cost, equal to the price at which they can be sold. Indeed, when a company receives permits free of charge, it can sell them instead of using them to cover its emissions, and it thus provides an incentive to abate pollution. Moreover, they assert that grandfathering does not lead to a distortion in competition: they

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[10] Hahn R.W., Stavins R.N. — The Effect of Allowance Allocations on Cap-and-Trade System Performance, The Journal of Law & Economics 54, no. 4 (2011)

[11] Cramton, P., Kerr, S. (2002). Tradeable Carbon Permit Auctions. How and Why to Auction Not Grandfather. Energy Policy, 30, 333-345

[12] ETS Handbook, European Commission

[13] Nash, J. (2000). Too Much Market: Conflict between Tradable Pollution Allowances and the Polluter Pays Principle. Harvard Environmental Law Review, 24 (2), 465-536

[14] Woerdman, E., Aruri, A., Clo, S. (2008). Emissions Trading and the Polluter-Pays Principle: Do Polluters Pay under Grandfathering. Review of Law and Economics, 4 (2), 565-590

argue that it represents a lump-sum subsidy and therefore it does not affect neither output nor pricing levels.

They nevertheless agree in regarding grandfathering as not consistent with the principle under an equity (not efficiency) point of view, since instead of allowing governments to raise revenues from permit sales, it delivers a capital gift to polluters.

On the other hand, auctioning satisfies the principle both under an efficient and an equity perspective. Indeed, these equity issues are taken up by Cramton and Kerr, who point out the fact that auction revenues could be used to create efficiency gains. In their work, the authors also suggest ways to allocate emission permits through auctions. In particular, they individuate sealed-bid auctions and ascending auctions as the most efficient allocation mechanisms.

In sealed-bid auctions, an aggregate demand curve is built by adding all bids from different actors, and the clearing price is determined by the price level of the interception of the demand and supply curve; bids lying below this price are rejected.

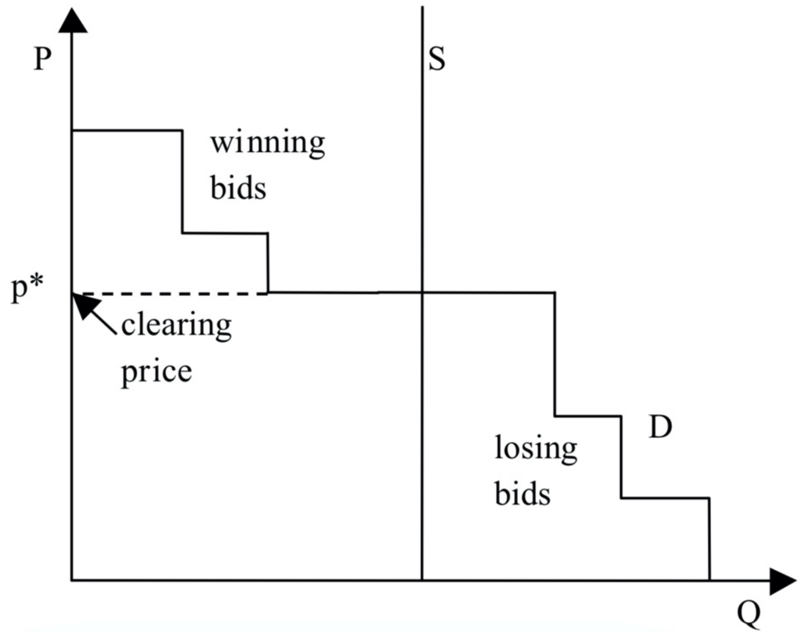

Figure 2.1: Clearing price in sealed-bid auctions[15]

At this point, one of two pricing methods can be applied: through a uniform price, all the successful bidders pay the same clearing price, while the adoption of "pay-your-bid" pricing, makes bidders pay the amount they offered. Cramton and Kerr point out that neither pricing method leads to a completely efficient outcome, since in both cases bidders have an incentive to shade their bids, meaning

[15] Cramton, P., Kerr, S. (2002). Tradeable Carbon Permit Auctions. How and Why to Auction Not Grandfather. Energy Policy, 30, 333-345

that they find it more convenient to make an offer lower than their personal valuation for the permits in order to lower the price. However, in the paper it is also stated that overall uniform pricing would be preferable, since it provides a stimulus for small bidders to participate; this is the methodology used in the EU Emission Trading System.

Ascending auctions, on the other hand, are considered to bring additional benefits. In particular, open competition allows for price discovery: in this way, bidders can gain information on prices from others' bids, and can consequently adjust the value of their offers. The bidders with the highest willingness to pay will win the auction. Information revealing prevents the "winner's curse", the phenomenon occurring when the winner of an auction ends up paying a higher price than the actual value of the object.

Ascending auctions can be structured with demand schedules or with ascending clock. The former is organized as a multiple-round sealed-bid auction, which is repeated up to the point where no bidder is willing to raise his offer; in the latter, the clock shows the price for the current round, and each bidder indicates the quantity he is willing to buy for that price level. The following round will entail a higher price, and the auction will terminate once the aggregate demand is inferior to the supply. The permits will then be allocated at the second price.

It needs to be noted that not even ascending auction will lead to an efficient result, since also in this case, bidders have an incentive to shade: in this specific scenario, larger actors will have a greater incentive to shade and as a result, the final allocation will imply overallocation to small actors and sub-optimal allocation to larger players.

2.1.2 Distributional effects of auctions and grandfathering

A distributional effects analysis concerns the assessment of the impact in terms of overall costs and benefits of an action (in this case an environmental policy) on the members of the society.

The distributional effects of a cap-and-trade system vary on the basis of how the permits are allocated. In this case too, auctions are preferred to grandfathering. Grandfathering only allows for redistribution of wealth to those who directly receive the permits. On the other hand, when permits are sold through an auction, the costs of production increase, leading to price effects that impact consumers, owners of capital, and workers. The incidence of this effect on each group mostly depends on their elasticities. The extent to which a certain individual or group will bear the costs will depend on the elasticity of demand relative to the elasticity of supply: in general, the group with relatively lower elasticity will bear a higher part of the costs. In particular, if producers face a supply curve relatively less elastic than consumers' demand curve, then they are able to pass on the increase in costs to consumers through an increase in prices. The figure below shows a scenario in which the consumers face a relatively more elastic demand curve. P_0 shows the price level without distortions. When a company pays for emission permits, a disruption between what is received by producers (P_s) and what is paid by buyers (P_D) arises: this difference is the cost of allowances. In this case, the consumer loss is much greater than the consumer loss.

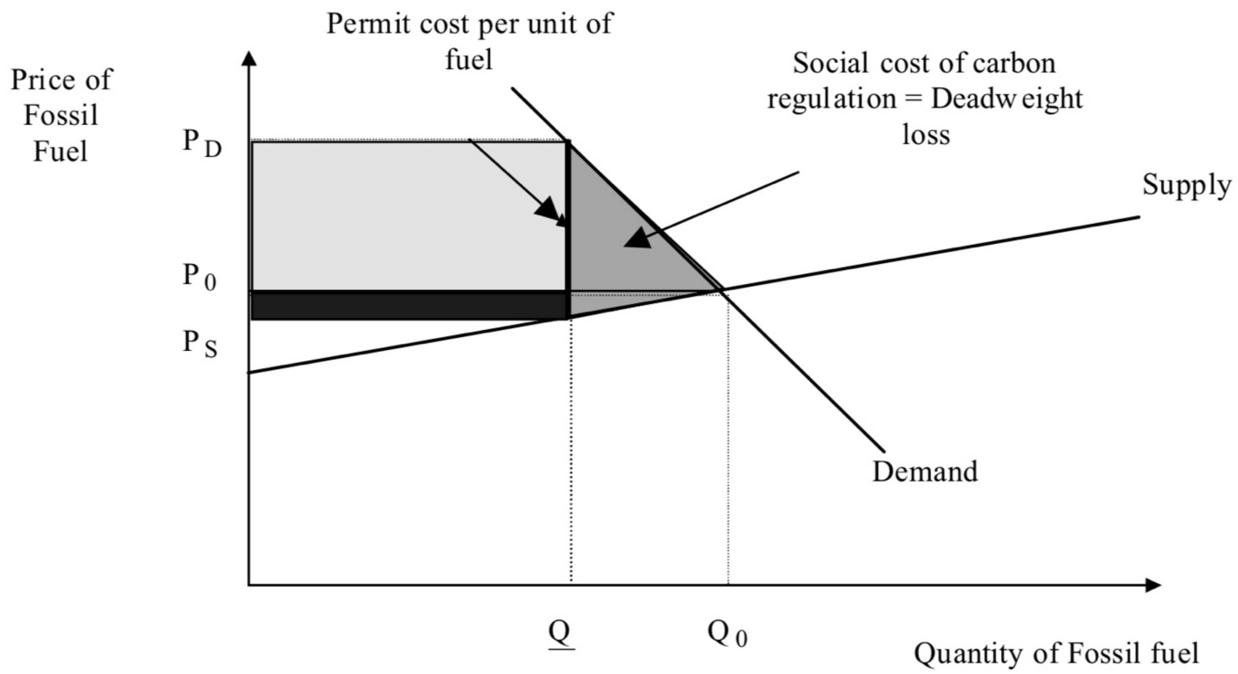

Figure 2.2: Distributional effects[16]

At this point, the distribution effects resulting from an auction are inconsistent with the polluter pays principle and therefore the same resulting from grandfathering. However, it needs to be noted that selling auctions enables the government to collect revenues, that can be used to offset the negative price effects, and is therefore preferable (nonetheless it needs to be noted that revenue recycling is effective only to a certain extent in cap-and-trade, since the revenues are often earmarked).

2.1.3 Pitfalls of cap-and-trade

Cap-and-trade systems obviously present also disadvantages when compared to carbon taxes. First of all, determining the price of permits through demand and supply mechanisms can bring on problems regarding price volatility. This problem, which we will further analyze in the next chapter, discourages investments to innovate in greener solutions and causes inefficiencies by increasing abatement costs. However, volatility may be partially offset by hybrid systems that include for example price ceilings or price floors, that transform the price into an exogenous variable (similarly to a carbon

[16] Cramton, P:, Kerr, S. (2002)

tax), allowing the schemes to be more compatible with other environmental policies, and to reduce uncertainty.

Furthermore, though we have established auction superiority over grandfathering, the first might be harder to implement, since the latter is overall preferred by companies, which would rather be given permits for free than having to pay for them, and is therefore more politically acceptable.

Cap-and-trade systems have also risen concerns regarding competitiveness, since they are thought to make industries included in the scheme less competitive on the international level by increasing their costs; as a consequence, we might observe episodes of carbon leakage. However, several empirical studies have shown that the implementation of the EU ETS has had no or trivial impact on competition.

Lastly, collecting revenues from selling permits through auction is often less effective than a carbon tax in counteracting the loss of welfare provoked by rising prices, as the gains are usually devoted to environmental use.

2.2 Carbon Tax

A carbon tax is a taxation on emissions equal to the marginal social cost of pollution (SCC). It is a "Pigouvian Tax", a type of levy that takes its name from the economist Arthur Cecil Pigou, who assessed a discrepancy between private and social costs and benefits in his book "The Economics of Welfare" (1920).
According to Pigou, without externalities, we find that Marginal Private Costs are equal to Marginal Social Costs, while in presence of a (negative) externality, Marginal Social Costs exceed Marginal Private Costs: in order to internalize the externality, a tax equal to the MSC should be levied: in this way the inefficiency is corrected.

Implementing a Pigouvian tax allows to reach a cost-effective outcome, especially if the SCC is highly elastic: the consumers bearing lower abatement costs are expected to reduce pollution more than consumers facing high abatement costs. However, governments are not aware of the marginal abatement costs of each consumer, therefore, a Pigouvian tax allows to set a fee on consumption, given which each consumer will reduce pollution to the desired level.
A Pigouvian tax allows for economic efficiency as long as the amount charged matches the marginal social cost, which we have already discussed in Chapter 1 (SCC). However, we have already mentioned the difficulties associated to calculating this value in practice.

Carbon taxes also provide the advantage of exogenous prices, which prevent price volatility.

2.2.1 Double Dividend Theory

The implementation of a carbon tax, under certain circumstances, might bring benefits not only to the environment, but also to the economy: this is known as the "Double Dividend Hypothesis". This theory claims that by increasing carbon taxes and reducing other (distortionary) taxations, keeping government revenue unchanged, it would be possible to benefit from both a better environmental condition and an improved economic situation. Other kinds of taxation suffer indeed from inefficiencies, leading to "deadweight losses", which are the result of the price difference paid by consumers and collected by producers that lead to an increase in government revenues smaller than the consumer welfare produced. If higher carbon taxes are levied on polluters, the resulting revenues can be recycled and used to replace the revenues of otherwise used distortionary taxes. To achieve this outcome, it is not enough to set the tax equal to the SCC, but it needs to also encompass a "Revenue Effect", which represents the gain in welfare reached through the reduction of distortionary taxes.

The existence of a double dividend is however widely questioned: while there is a consensus in recognizing the positive effects of a carbon tax on the environment, the effects on the economy are rather ambiguous. For instance, the presence of an "Interdependency Effect" is suggested: in particular, McKitrick argues that a higher carbon tax would lead to higher production costs, and therefore higher prices and lower real wages; this would, in turn, imply a fall in labor supply and an increase in deadweight loss, thus increasing and not reducing the tax distortions, and causing a loss in welfare.

In general, we can say that the occurrence of a double dividend mainly relies on the circumstances and the ways in which the carbon tax is implemented.

2.2.2 Distributional effects

Analyzing the distributional effects of a carbon tax, Wang et al. (2016) report that this impact can be divided into two categories: on households, and across production sectors. Studies conducted on developed countries demonstrate that carbon taxes can be (weakly) regressive: this means that income level and tax burden are inversely proportional, and the costs weigh more on low-income individuals. The effect is however much more ambiguous in developing countries. Roumeen Islam also points out how, even when progressive, a carbon tax would lead to an increase in costs for emitting companies, which would reflect in higher prices for their products, and still affect more low-income individuals since it would make the consumer basket more expensive.

As regards production sectors, countries relying to a large extent on fossil-fuel-based energy will clearly suffer more from the implementation of a carbon tax: however, there is the risk that the shock could have repercussions on the economy as a whole, leading to decreasing GDP and increasing unemployment. On the one hand, this would accelerate a green transition, on the other it needs to be considered that this shift would take place in the long run, while creating disruptions in the short run. These effects can be reduced through ex-ante measures (by imposing a lower tax rate) or ex-post measures (by recycling tax revenues to alleviate the regressivity of the tax): policymakers face an equity-efficiency trade-off.

2.2.3 Pitfalls of Carbon taxes

Carbon taxes present fewer downsides than cap-and-trade. The prevailing arguments against a carbon tax are that it does not provide certainty regarding the total level of emissions, since it does not put a limit on them; aligning with emission targets can be therefore harder. Consequently, tax rates need to be adjusted periodically in order to meet emission objectives. Furthermore, it can be argued that the introduction of a tax might be problematic since it is generally less tolerated than a cap-and-trade system (particularly in the case where the permits are grandfathered).

2.3 Conclusions

We have carefully analyzed the specific features of both types of carbon pricing. From this evaluation, we can conclude that both methods provide attractive benefits as well as downsides. When policymakers need to choose which one to adopt, they need to take into account specific situations on a national level, and they have to decide which aspects they want to prioritize. We can see a comparison between carbon taxes and cap-and-trade in the table below.

Design issue	Instrument	
	Carbon tax	**ETS**
Administration	Administration is more straightforward (for example, as extension of fuel taxes)	May not be practical for capacity constrained countries
Uncertainty: price	Price certainty can promote clean technology innovation and adoption	Price volatility can be problematic; price floors, and cap adjustments can limit price volatility
Uncertainty: emissions	Emissions uncertain but tax rate can be periodically adjusted	Certainty over emissions levels
Revenue: efficiency	Revenue usually accrues to finance ministry for general purposes (for example, cutting other taxes, general investment)	Free permit allocation may help with acceptability but lowers revenue; tendency for auctioned revenues to be earmarked
Revenue: distribution	Revenues can be recycled to make overall policy distribution neutral or progressive	Free allowance allocation or earmarking may limit opportunity for desirable distributional outcomes
Political economy	Can be politically challenging to implement new taxes; use of revenues and communications critical	Can be more politically acceptable than taxes, especially under free allocation
Competitiveness	Border carbon adjustment more robust than other measures (for example, threshold exemptions, output-based rebates)	Free allowances effective at modest abatement level; border adjustments (especially export rebate) subject to greater legal uncertainty
Price level and emissions alignment	Need to be estimated and adjusted periodically to align with emissions goals	Alignment of prices with targets is automatic if emissions caps consistent with mitigation goals
Compatibility with other instruments	Compatible with overlapping instruments (emissions decrease more with more policies)	Overlapping instruments reduce emissions price without affecting emissions though caps can be set or adjusted accordingly
Pricing broader GHGs	Amenable to tax or proxy taxes building off business tax regimes; feebate variants are sometimes appropriate (for example, forestry	Less amenable to ETS; incorporating other sectors through offsets may increase emissions and is not cost effective
Global coordination regimes	Most natural instrument for international carbon price floor	Can comply with international price floor; mutually advantageous trades from linking ETSs but does not meet global emissions requirements

Source. IMF staff.
Note: Green indicates an advantage of the instrument; orange indicates neither an advantage nor disadvantage; red indicates a disadvantage of the instrument.

Table 2.1: Comparison of Carbon taxes and Cap-and-Trade (ETS)[17]

[17] Perry, I., Black, S., Zhunussova, K. (2022). Carbon Taxes or Emissions Trading Systems? Instrument Choice and Design. IMF Staff Climate Note 2022/006, International Monetary Fund, DC.

In general, a carbon tax provides certainty over prices but not over emission levels; the opposite happens with cap-and-trade, where an emission limit is set ex-ante, but prices are determined through market mechanisms. Cap-and-trade systems are however more difficult to implement, and they are also harder to apply at different stages of the production chain; furthermore, the revenues they gain are often bounded to projects aimed at cutting emissions, and this could prevent the offset of wealth reduction due to higher prices passed on from producers to consumers. On the other hand, it is easier to recycle revenues collected from a carbon tax, which for example can be used to reduce other taxes or the country's deficit, to increase public investment, or to support households. However, taxes are generally less accepted and can be therefore harder to implement. Finally, carbon taxes prevent price volatility, which is in turn a major problem in cap-and-trade (though there are some price stability mechanisms that can be applied).

Nonetheless, some studies report that cap-and-trade and carbon taxes can be equivalent when analogously designed: in particular it is argued that they can provide similar emission reduction incentives and distributional effects. Therefore, the main difference lies in the way in which the environmental policy is designed, rather than in which instrument is adopted. In particular, cap-and-trade systems can be implemented in such a way as to imitate certain benefits of carbon taxes.

Despite the fact that carbon taxes present major advantages in terms of efficiency, cap-and-trade systems tend to be preferred for several reasons: in the case of the EU ETS, for example, the implementation of a carbon tax would have required unanimity since it is not a fiscal union; other countries, on the other hand, have implemented cap-and-trade as it is more likely to gain political acceptance due to the possibility of freely allocated permits.

CHAPTER 3

Price Volatility in the EU ETS

This last section focuses on price volatility in the EU ETS: we will discuss why it represents a problem for the functioning of the system, what are its determining factors, how prices varied, in particular during crises, the impact of financial actors on it, and what mechanisms could help in stabilizing prices.

Since Phase 1 of the EU ETS, problems related to price volatility in the carbon market have jeopardized the ability of the scheme to reach an efficient outcome.

Price volatility represents a problem for cap-and-trade systems for several reasons. In the previous chapter, we assessed how cap-and-trade systems are generally preferred due to higher political acceptance and certainty over emission levels: price fluctuations might undermine both aspects. Specifically, when prices are too low, they do not constitute incentives for companies to further invest toward a green transition, and thus slow down the process of reaching the targets that the European Union wishes to meet. If prices are too high, however, political support might decrease, while compliance costs increase and exposes the system to the risk of carbon leakage (since firms would find it more convenient to move production to unregulated areas to avoid excessive costs). Therefore, when prices are highly volatile, pricing signals are not clear, companies are unable to understand whether it is convenient or not to invest in more environmental-friendly technologies, and their political support is uncertain.

By volatility, we refer to a measure of the price oscillation of a certain financial instrument in a given period of time. It is calculated starting from the logarithmic returns from the time series of prices studied. The logarithmic return can be determined through the natural logarithm of the ratio between the closing price of the *t*-th day (P_t) and the closing price of the *t-1*-th day (P_{t-1}).

$$r_i = \ln\left(\frac{P_t}{P_{t-1}}\right)$$

The historical volatility is computed as the standard deviation of the logarithmic returns in the temporal series of the prices considered. In particular, for the daily volatility, we have:

$$\sigma_d = \sqrt{\frac{\sum_{i=1}^{n}(r_i - \bar{r})^2}{n-1}}$$

while for an annual value, σ_d needs to be multiplied by the square root of the number of trading days in a year, which is around 250.

3.1 Determinants of price volatility

Different factors are to blame for price fluctuations in the EU ETS. First of all, the way in which prices are determined plays a major role: the prices are derived from the interaction of demand and supply, therefore once the European Commission sets the cap on allowances, it has limited control over the final price, which is mainly driven by the demand side of the market.

In Phase 1 of the system, price fluctuations were mainly due to a lack of information, and the immaturity of a newly formed carbon market in Europe. Because of the unavailability of data regarding emission levels in the Member States, and the allocation of permits mainly through grandfathering, a large initial number of allowances was first set. This translated into an oversupply that lowered the price of the permits.

The demand-side factors influencing volatility in the carbon market encompass weather conditions, the price for fossil fuel alternatives, and the economic situation.

- Weather conditions hugely affect the price, since they determine the demand for usage of heat and energy utilities: for example, cold winters will require higher usage of heat implants and therefore higher demand and higher prices for emission permits.
- The price of substitutes for fossil fuels also affects fluctuations in the ETS: if the alternatives reveal to be more expensive, the switching costs for companies increase and this leads to higher demand for permits and once again higher prices.
- Economic conditions and projections can also impact prices: in 2005, too-optimistic economic growth forecasts played a role in the oversupply of allowances, while uncertainty would depress the incentives for firms to invest in alternatives to fossil fuels.

From the supply-side of the economy, the main factor determining price fluctuations is the opportunity to bank or borrow permits. Banking refers to the possibility of covering emissions through unused allowances from a previous period, while borrowing allows a company to use permits from a future period in the present. When actors in the market expect the demand for permits to be high in the future, they tend to keep their unused allowances instead of selling them in the current period, thus reducing the supply and contributing to a price increase. On the contrary, when the supply is expected to be high in the future, firms might prefer to borrow their permits, reducing the price by increasing the supply.

3.2 The financial crisis of 2008

The Global Financial Crisis of 2008 represented the first obstacle in the functioning of the EU ETS provoked by macroeconomic factors. The recession stemming from the crisis led to a reduction in production, resulting in lower demand from companies for emission permits. At this point, the system was in its second phase. The downturn led to a surplus of allowances that accrued in the period spanning from 2008 to 2012, up to the point where it amounted to two billion permits (2012). The excess in supply, led to a drop in prices starting from the end of June 2008, which reached its minimum on February 11th, 2009 (€9.21). Thereafter, the prices started to increase again, but remained overall low, ranging between €13.58 and €18.88 in the following years. The price path from January 2008 to July 2012 is shown in the graph below.

Figure 3.1: Price trend of EU ETS allowances (2008-2012)[18]

As the surplus was expected to further continue, according to the Carbon Market Report of 2012, several counteractive measures were adopted. The short-term measure implemented to balance the demand and supply of allowances was to postpone the allocation of 900 million permits (400 million in 2014, 300 million in 2015, and 200 million in 2016) that were supposed to be auctioned at the beginning of the third phase of the system. This measure is known as "backloading".

To stabilize the situation in the long term, the European Commission established the Market Stability Reserve, which began operating in 2019. A threshold is set at 883 million allowances and on each 15th of May, information regarding the number of permits in circulation is published: if this amount is greater than the threshold, the allowances are put in the reserve (which also contains the backloaded permits). The allowances are allocated if the number in circulation is below 400 million. In particular, if the TNAC (Total Number of Allowances in Circulation) is over the threshold, 24% of them are put in the reserve (after 2023 the rate lowers to 12%). When the TNAC is lower than 400 million, 200 million allowances are released (100 million after 2023). To have additional control over the prices, the MRS is designed to release 100 million allowances

[18] EUA future prices 2008-2012. European Environment Agency (2012).

if the price triples during a period of at least six months compared to the two years before. Finally, starting from 2023, the permits banked in the reserve exceeding the number of allowances sold in the previous year's auction are canceled.

The MSR has two goals: to lessen the existing discrepancy between demand and supply resulting from the financial crisis, and to make the system less sensitive to such shocks in general.

The implementation of the MRS has successfully offset the effect of unpredictable shocks in the economy; however, its design can reinforce the effect of predictable shocks and worsen the situation. When shocks are anticipated, like in the case of new technologies that can bring on a green transition. In the case of anticipated changes, The MRS will actually increase the price reaction if the demand decrease happens after it has ceased accepting allowances but the change is predicted earlier. The price of existing allowances decreases, emissions rise, and the TNAC contracts, Aa a result, the MRS accepts and ultimately cancels fewer permits, boosting the overall supply.

Bel and Joseph (2015) performed an econometric analysis to understand the extent to which the EU ETS and the financial crisis[19] contributed to lowering the level of GHG emissions. The study is based on panel regressions built on historical emission data from EU-25 countries (countries in the European Union from May 1st, 2004, to December 31st, 2006) in a timespan going from 2005 to 2012. The results of the paper show that the reduction in emissions between 2008 and 2009 was on average 10.147 megatons per country, meaning about 86.38% of the total emission abatement of the first two phases of the system. The crisis is shown to have had an impact in the following years as well, since the following year displayed an upturn in emission levels, which was however substantially less severe than the impact of the crisis. The paper illustrates how, of the total abatement between 2005 and 2012 (about 294.5 megatons), only up to 40.76 can be attributed to the implementation of the EU ETS, and this demonstrates the vast impact of the economic downturn. The independent variable representing GDP growth resulted to be positively correlated with the level of emissions (dependent variable): this is consistent with economic logic that wants that during an economic boom, production increases, and with it, emission levels rise. On the contrary, recessions bring on a reduction in production and therefore in GHG emissions.

3.1 The Covid-19 pandemic

The Covid-19 pandemic represented another macroeconomic shock that had a significant impact on ETS prices and consequently on their volatility. The pandemic outbreak in Europe at the beginning of 2020 forced many countries to take preventive measures against the spread of the virus. In particular, quarantines and lockdowns led to a major reduction in the demand for permits, due to the subsequent decrease in production. Reports from GSE (Gestore Servizi Energetici, the appointed auctioneer in Italy) and from EEA

[19] A dummy variable taking on value 1 when the GDP growth rate is negative has been used to represent the recession.

(European Environment Agency) show that the average price for the allowances in the primary market in 2020 was not significantly different from 2019, with a decrease of about 1% (€24.36 against €24.6). The average price, however, does not provide any information regarding the volatility. Indeed, in 2020, the prices were revealed to be highly volatile as a consequence of the pandemic: the data for the first period of the year show a price collapse (reaching €14.6 in March) that was later counterbalanced by an uptrend caused by the delay in the allocation of permits, the impossibility of exercising borrowing, and the increase in the price of gases and other alternatives to fossil fuels (which increased the switching costs from one resource to another). In the last part of the year, however, prices reached what at the time was an all-time high in both the primary (€30.9 on 14th December) and the secondary market (€33.4 on 28th December). The volatility referring to the first annual future contract increased to 51.2%: in particular the greatest increase in volatility occurred between February and March (5.9%), coinciding with the drop in prices related to the lockdown measures.

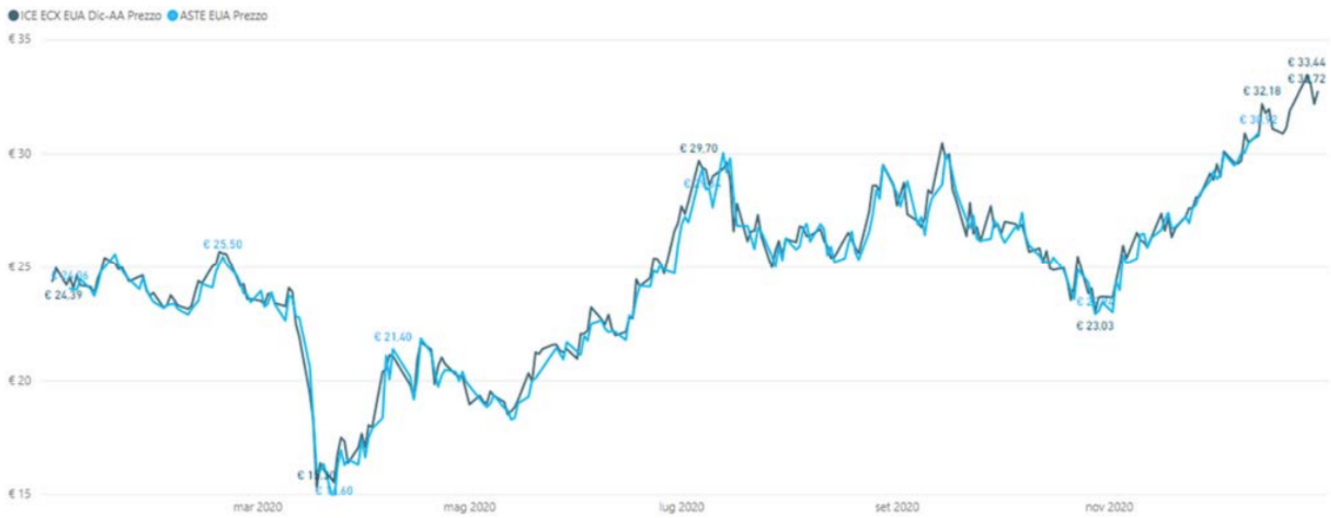

Figure 3.2: Prices for auctioned allowances and first annual futures contract (2020)[20]

Dong et al. (2021) tested the impact of the pandemic and the European Union's recovery plan to boost the economy after the crisis (NextGenerationEU, which provides €806.9 billion, of which 30% is destined for a green transition) on the change in the prices of allowances. The analysis showed that both factors had a significant impact on the dependent variable (allowance futures price), but in opposite directions: the price and the impact of the pandemic were negatively correlated, while there was a positive correlation between prices and the recovery plan[21]. The announcement of ambitious climate policies played a relevant role in

[20] GSE (2021). EU ETS: Rapporto sulle aste di quote europee di emissione - annuale 2020.
[21] The impact of Covid-19 and the recovery plan were structured as dummy variables, taking value 0 before the outbreak of the pandemic and before the announcement of NextGenerationEU.

boosting the optimistic expectations of investors, which expect the demand for permits to increase in the near future, and contributed to rising prices even more than before the pandemic: we can therefore say that it was effective in stabilizing the carbon market.

3.4 Financial actors and speculation

In the secondary market of emission permits, many trading activities take place between financial actors who buy and sell allowances and their derivatives, including spot contracts (that enable the parties to buy or sell the underlying asset at the current price on the same day in which the contract is signed), futures contracts (allowing parties to buy or sell at a certain date at a specified price; the maturity is usually weekly, monthly, or yearly), or options on futures (giving parties the right to purchase or sell an allowance derivative contract at a specified time and price). All these agreements are stipulated on a standard size of 1000 allowances.

The financial actors entering these contracts include intermediaries (banks, investment firms, brokers, credit institutions), and speculators and investors (such as hedging or pension funds, retail investors, trusts).

In the spot market, the financial actors operate as intermediaries for compliance entities, with the final goal of gaining profits; in the derivative market, they take part in hedging and speculative activities. By hedging, the actors in the allowances market can protect themselves from risk: in particular, compliance entities can buy forward or future contracts in order to secure the number of permits they will need to cover their later emissions and financial actors offer them at a premium price.

Speculation, on the other hand, includes activities aimed at earning a profit based on expectations regarding changes in prices, which are performed by both compliance entities and financial actors. Speculation becomes concerning when it pushes prices beyond the scope of what would be anticipated based on market fundamentals. However, when not excessive, speculation in the carbon market ensures that all information regarding supply and demand, as well as potential future changes in supply and demand, are rapidly reflected in permit pricing, which in turn corrects the price signal for all market participants, contributing to price discovery; moreover, it improves liquidity and allows risk transfer: the regulated firms searching for counterparts to hedge their exposure to EUA prices are given liquidity by financial operators. In the absence of these financial actors, the carbon market would show even more price volatility and higher prices.

On the other hand, too much speculation could also lead to higher fluctuations in permit prices, and it is thought to have contributed to the increase in volatility between 2021 and 2022.

In general, the main factors that have affected the rise in prices include higher switching costs with alternative energy sources (such as gas), the economic recovery after the Covid-19 crisis, as well as the expectation of a lower supply of permits (due to a lower cap), and the introduction of NextGenerationEU pushing for a green transition. The rate at which the prices increased, however, gave rise to concerns regarding the role played by financial actors and speculation.

First of all, there is a positive correlation between the prices of allowances and the number of investment funds operating in the European carbon market: the data show that this number has more than tripled between 2018 and 2022, reaching more than 300; in this period also long positions on futures market have also considerably increased. The graph below shows the comparison between allowances sold in the primary and secondary markets between 2012 and 2022 (GSE, 2023).

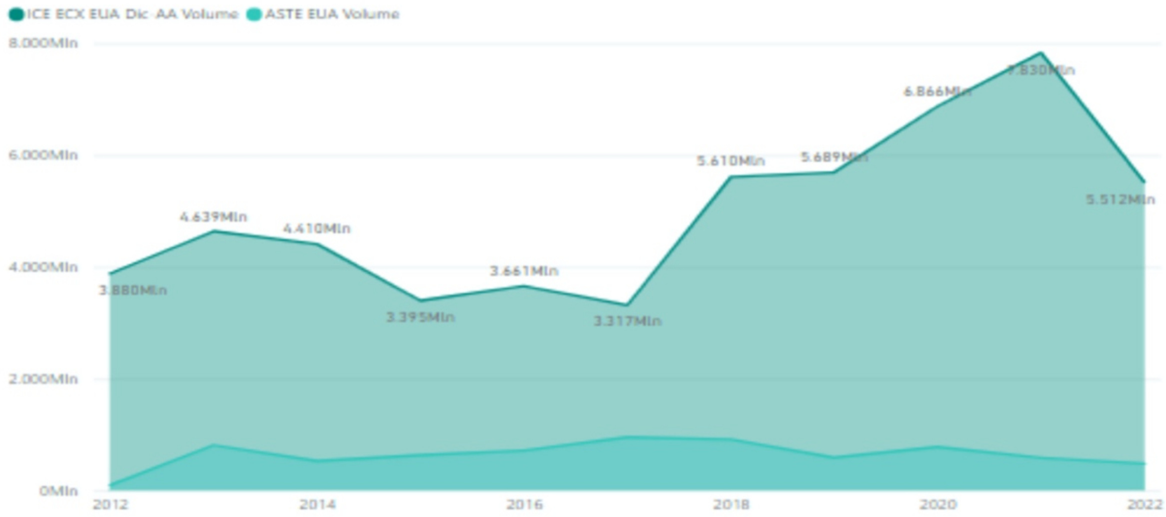

Figure 3.3: Allowances volumes sold on the primary and secondary market (2012-2022)[22]

Another indicator could be the fall in prices following the start of the war between Russia and Ukraine in 2022, which could have been caused by speculators preventively liquidating their positions, thinking it would have not been possible to do it later because of sanctions on Russia. Indeed, the largest increase in prices in 2022 was registered between February and March, when the daily volatility almost doubled, going from 3.74% to 6.24%, while the annual volatility increased from 43% (2021) to 52% (GSE, 2023).

In order to limit the repercussions of excessive speculation on price volatility, different measures can be implemented:

- Taxes on specific transactions.
- Minimum holding period, which would hinder short-term speculation activities.
- Restrictions on financial positions, which could take the form of limits on the number of allowance derivatives that a particular financial actor can own. This measure would prevent cornering and squeezing of the market, which are practices aimed at manipulating prices or creating artificial scarcity to benefit from price movements. Counterarguments against the imposition of such restrictions include the fact that constraining financial actors would decrease liquidity in the carbon market, and in turn,

[22] GSE (2023). EU ETS: Rapporto sulle aste di quote europee di emissione - annuale 2022.

lead to higher price volatility. Furthermore, they would entail even more complexity in the system. ESMA (2022) points out how the impacts of such restrictions cannot be fully anticipated.

- Creation of an autonomous market authority, aimed at monitoring transactions to help avoid market manipulation.

These solutions would help to restrain speculation to an appropriate level, which would allow to benefit from price discovery as well as reduce fluctuations in price.

3.5 Price stabilizing mechanisms

To reduce the risk of the ineffectiveness of the EU ETS, besides the previously mentioned measures used to address speculation, different structural changes can be implemented in order to stabilize prices, and therefore offset price volatility.

The establishment of a price floor and/or a price ceiling would prevent excessive volatility and provide more clear price signals for investors, since the price could only vary within a predetermined range. Specifically, a price floor would help in delivering proper price signals, while a price ceiling would hinder exorbitant costs for compliance entities, especially in the short term.

Another possible solution could be the introduction of daily price volatility limits (such as imposing trading to a certain level above or below the opening price of the market) or circuit breakers (which work by suspending trading following excessive price fluctuations).

Alternatively, the Market Stability Reserve could be revised: in particular, the MRS could be modified to base intake and outtake of permits on prices instead of circulating allowances. This redesign would address the risk of excessive speculation, by adjusting supply subject to the price level.

3.6 Quantitative Analysis

It is possible to test the influence of some factors over the price volatility of permits in the EU ETS by performing a linear regression. In particular, in this paper, we want to test how prices are affected when there is a variation in the supply of permits, in the price of alternatives to fossil fuels, and in the economic conditions.

3.6.1 Data

We considered weekly data for the period spanning from November 2021 to April 2023. The datasets are retrieved from different sources. For the dependent variable, we use spot prices of EUA (European Union Allowances) taken from the European Energy Exchange (EEX). The independent variables include the price of gas (Dutch TTF gas futures), the price of coal (API2 Rotterdam coal futures), and the Eurozone stock index EUROSTOXX50: for these three variables the data were processed by Statista based on information from Intercontinental Exchange (the former two), and investing.com (the latter). Furthermore, a variable showing the supply of permits auctioned was taken into account (data from EEX).

3.6.2 Model

To make the interpretation of the results clearer, all the variables were transformed into logarithmic functions: in this way, a 1% variation in any independent variable, leads to a percentual variation equal to the related coefficient. The model was therefore built in the following way:

$$\log(EUA_t) = \beta_0 + \beta_1 \log(volume_t) + \beta_2 \log(EUROSTOXX50_t) + \beta_3 \log(coal_t) + \beta_4 \log(gas_t) + \varepsilon_t$$

Where:

- "volume" shows the number of allowances auctioned, and therefore represents the supply of permits.
- "EUROSTOXX50" is a market index for the Eurozone which includes 50 stocks: it is used in this model to include the influence of the economic situation on the price of allowances.
- "coal" and "gas" are included to show the influence of prices of alternatives to fossil fuels on the price of emission permits.

By running the regression, we get the results shown in the table below.

Regression results

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	5.70163	3.28169	1.737	0.086980 .
β_1	-0.25854	0.06598	-3.919	0.000214 ***
β_2	0.32592	0.30920	1.054	0.295705
β_3	0.09791	0.05671	1.726	0.088942 .
β_4	-0.16108	0.03879	-4.152	9.64e-05 ***

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.09407 on 66 degrees of freedom
Multiple R-squared:  0.3514,
Adjusted R-squared:  0.3121
F-statistic: 8.94 on 4 and 66 DF,
p-value: 7.852e-06
```

Table 3.1: Linear regression results

3.6.3 Results

From the table, we can observe how each of the independent variables chosen has influenced the price of emission permits.

- The coefficient for the supply of permits auctioned (β_1) is negative, meaning that the price of permits is inversely proportional to the number of permits available. This result is coherent with the economic intuition regarding the relationship between demand and supply, which wants that as the supply increases, the price decreases. In this case, we have that for an increase of one unit in the number of permits, the price decreases by approximately 0.26%. The variable shows a great significance level.
- β_2, the coefficient for the variable EUROSTOXX50, is positively correlated with the dependent variable, however, it is not statistically significant.
- The coefficient for the futures price of coal (β_3) is also positive, but shows a low significance level (10%)
- On the other hand, β_4, the coefficient for the futures price of gas, is negative and highly significant, which indicates that an increase in the price of gas, leads to a decrease in the price of emission permits. This result is counter-intuitive, since we would have expected an increase in the price of gas to increase the demand for emission permits and therefore their price.

The adjusted R-squared for the model is equal to 0.3121, meaning that the variables included in the model are responsible for 31.21% of the variation in the price of permits.

Conclusions

As we have seen throughout this thesis, the European Union Emission Trading System is overall a good tool to approach the problem of climate change and make polluters internalize the social costs imposed by emissions; nevertheless, it is not flawless.

Despite the fact that the system has its weaknesses, it has been successful in achieving the targets it had set, such as reducing emissions by 20%[23] by 2020: estimates from the European Environmental Agency show that emissions in 2020 were cut by 31% with respect to 1990 levels (nevertheless, the extent to which this is imputable to the EU ETS, rather than to the Covid-19 pandemic that brought a reduction in production and therefore in emission levels, is to be ascertained).

Given that the European Union has set ambitious standards regarding its emission reduction in the following years (specifically, cutting emissions by 55%[24] no later than 2030, and reaching climate neutrality by 2050), there might be the need for the system to be revised: a European Investment Bank survey shows that currently, more than half of EU citizens do not believe that their country will be able to meet the targets for 2050.

It needs to be noted that, however, in general, a cap-and-trade system is the best option for the European Union to tackle the problem of the climate crisis: first of all, to meet the challenging objectives that were set, there is a need for certainty over emissions, which such systems provide, rather than certainty over prices (guaranteed by a carbon tax); furthermore, the EU is not a fiscal union, and subsequently, the imposition of a carbon tax across all the member states would be particularly complex.

This research provided an overall picture of the measures that can be implemented to fight climate change, and focused in particular on the EU ETS, explaining its strengths, as well as its weaknesses.

It does, nevertheless, suffer from some limitations: specifically, the quantitative analysis can be further enhanced by expanding the linear regression to encompass more of the factors affecting price volatility. Such variables could include the number of derivative contracts traded in the financial market, as well as weather conditions, and factors showing real economic activities. For this reason, there is a possibility that the results displayed in this thesis are affected by an omitted variable bias. To add more variables, however, it might be appropriate to expand the time span taken into consideration and use data with a lower frequency.

[23-24] All percentages are based on 1990 emission levels.

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