Market Design for the Environment*

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Abstract

The main argument in favor of markets in environmental contexts is the same as in other contexts: their ability to promote efficient allocations and production. But environmental problems bring their own challenges: their underlying bio-physical processes - and the technologies to monitor them - constrain what is feasible or even desirable. This chapter illustrates the main design dimensions in environmental markets, the trade-offs involved and their impact on performance, through the lens of a regulated market for pollution rights (the EU emissions trading scheme) and a voluntary market for the provision of environmental services (the global market for carbon credits). While both markets eventually contribute to climate change mitigation, their organization as a "pollution market", for the former, and as a "provision market", for second, means that different design considerations take precedence. Both markets also face challenges: volatile prices in the EU emissions trading scheme and low trust for voluntary carbon markets. We discuss how alternative design options could address those.

KEYWORDS: Natural capital, ecosystem services, tradable quotas, property rights, pollution, carbon markets, voluntary markets, climate mitigation, externalities, asset design.

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1 Introduction

Nature provides a number of essential goods and services that support our lives and economies (Costanza et al., 1997). These include seafood and timber, life-supporting processes (such as water purification and photosynthesis), regulation of ecosystems (for example, through carbon storage and erosion control), and cultural and recreational services. These goods and services are all subject to externalities, leading to overexploitation, degradation and underprovision. Climate change, biodiversity collapse, eutrophication of oceans and lakes, soil and groundwater pollution are some of the symptoms of our collective inability to manage natural capital sustainably.

Property rights organize our relationship with Nature and determine the types of governance that can be established to conserve and manage this natural capital. When it comes to natural resources and ecosystems, Schlager and Ostrom (1992) distinguish between, on the one hand, the right to access and to use (e.g. obtain the product of a natural resource or release toxic effluents) and, on the other hand, management and control rights (deciding who has access, how usage rights are transferred, ...). Clearly, these rights affect the incentives that individuals face to conserve and develop the natural capital to which these rights apply. Sterner and Coria (2013) describe how these rights differ across countries and contexts and how they have evolved over time as a result of societal demands. To the extent that these property rights can be traded, we have a market.

Environmental markets are not new. In fact, communities and governments have used markets to allocate fishing rights, water withdrawal rights and pollution rights for decades. But improvements in monitoring technology and increasing pressures to address environmental degradation and resource scarcity have expanded their scope of application over time.

This chapter reviews existing and developing uses of markets for natural capital from a market design perspective. We first provide a typology of environmental problems for which markets can provide a solution. This leads us to distinguish between overexploitation, degradation and underprovision problems. Overexploitation and degradation problems happen when the goods and services provided by Nature are not excludable and property rights are shared or nonexistent. Underprovision problems arise when the natural resource, over which well-established access and usage rights exist, creates positive externalities for agents who do not benefit from any property rights to the resource. We argue that each natural resource is characterized by its specific bio-physical process which constrains the definition of what can be traded and the choice of design to support the goals of the market.

We illustrate these considerations in the context of climate change mitigation, where compliance markets for emissions reduction and voluntary carbon markets are playing an increasingly important role. The history of the EU emissions trading scheme over the past 20 years illustrates how apparently small design decisions can impact the performance of a market and the challenges of generating an informative and stable price signal, an important desideratum to foster cost efficiency. The current discussions around the integrity of voluntary carbon markets show the importance of the definition of what is traded, and how technology and Nature constrain it.

An important remark at the outset is that markets may not be the only way, let alone the best way, to address environmental overexploitation, degradation, and underprovision. Ostrom (1990) has powerfully argued that communities can successfully overcome the so-called "tragedy of the commons", where natural resources are overexploited, without the recourse to markets or even price mechanisms. Others have raised the concerns that markets, and the price tag that they bring to the goods and services produced by Nature, are incapable of capturing the complexity of human societies' interactions with Nature (Kosoy and Corbera, 2010) and can even change the way individuals and firms view and interact with it (Bowles, 2016; Sandel, 2012).

In this chapter, we leave these discussions aside and take as starting point the observation that the reach of markets for environmental goods and services is expanding on the ground and that there is, therefore, need for scholarship and expertise to design these markets so that they meet their goals.

2 Typology of environmental problems

It is useful to distinguish three types of environmental problems for which markets can and often already do provide solutions. These problems are defined by the nature of the environmental good or service at hand and existing property rights arrangements.

2.1 Overexploitation of renewable resources

The first category of environmental problems consists of environmental goods and services that are not excludable, or at least difficult to exclude, but rival in use, and for which property rights are shared or nonexistent. This is the classic case of what has been called common pool resources.

Fish stocks in oceans or lakes, game in forests, and water in rivers are all examples of common pool resources. These resources are additionally renewable. Fish, game, and other animal species reproduce. Their natural reproduction rate depends on environmental conditions and is often modeled as a bell-shaped relationship between species density and the population growth rate. At low levels of species density, mating probabilities are low, and so are reproduction rates. Likewise, at high species density levels, the ecosystem's carrying capacity is stretched, and competition for food limits population growth. Maximum sustainable yields are obtained at intermediate density levels when fish or game harvest is equal to the natural growth rate of the population. Harvest in excess of the natural reproduction rate drives species density down. Water withdrawal (from a river or basin) is similar, except that water stock dynamics is determined by hydrological and weather conditions, and users upstream impact users downstream but not those upstream to them.

The prime concern for sustainability in these situations is to ensure that harvest levels and withdrawals (a flow) are set such that the stock of the underlying resource is stable at a desirable level. The challenge is that this condition is unlikely to be met in the presence of multiple users and shared or nonexistent property rights. Each user individually does not account for the externality they exert on other users, potentially leading to the collapse of the natural resource in what has been coined the "tragedy of the commons" by Hardin (1968).

Quotas have long been used around the world to address the risk of overexploitation of renewable natural resources (Costello et al., 2008). Fishermen, hunters, and farmers receive quotas that determine how much they can fish, hunt, or withdraw water. These quotas specify the quantity of the renewable resource holders can harvest or withdraw over a specific period in a particular area. They are coupled with monitoring and enforcement systems. Once a holder has reached their quota, they must cease all harvest and withdrawal activities. The number of quotas can be adjusted over time based on the stock of the natural resource. Effectively, quotas create property rights on the use of the natural resource and address the sustainability issue (making sure catch levels and withdrawals are not too high).

Not all quota systems integrate a market mechanism in their design, either for the initial allocation of these quotas or for participants to exchange quotas among themselves. For example, since 1983, the European Union has allocated fishing quotas to its Member States but leaves it to them to decide how they allocate these to their fishermen. In some countries, quotas are not transferable (van Hoof, 2013).

The main motivation for using markets and market-based mechanisms in these contexts is to enhance the efficiency of the allocation and encourage the sustainable use of scarce natural resources (productive efficiency). Given the increasing pressures on natural resources, we can expect that these efficiency concerns will drive further adoption of markets.[1]

Markets can be useful at three levels. One approach is to allow quota holders to trade them. These are often referred to as Individual Transferable Quotas (ITQ). Users with the highest value for the natural resource will buy quotas from those with a lower value, enhancing efficiency. Another approach, feasible when no pre-existing property rights exist, is to auction these quotas. Again, this will ensure that the quotas end up in the hands of those who value them the most. The price tag will also incentivize users to save the natural resource. Finally, markets can also be used to induce pre-existing property rights holders to relinquish their rights to promote superior allocations (see Paul Milgrom's contribution in this volume).

Depending on pre-existing rights, these markets can be organized by a regulatory authority (public governance) or by the users themselves (private governance). Private governance is more common when the natural resource is geographically circumvented, and users are well-identified and not too numerous. For example, private governance by local fishermen is observed for lobsters, a sedentary species, off the coast of Maine.

[1]See Wheeler et al. (2023) for a similar point in the context of water markets. For good starting points to this literature, see Tietenberg (2002), Newell et al. (2005) for fish markets, and Wheeler (2021) for water markets.

2.2 Pollution and environmental degradation

Environmental degradation problems are mirror problems to overexploitation problems. Environmental quality is a (local) public good, and ownership of the environmental resource is either shared or nonexistent. Because pollution is typically a by-product of an otherwise profitable activity, economic agents will tend to generate too much pollution because they do not bear the full consequences.

Governments use different approaches to regulate pollution, starting from command-and-control approaches, such as imposing a technology standard or forbidding the use of some toxic substances as inputs, to more market-based solutions. Among these, cap-and-trade markets have gained prominence as a cost-effective approach to pollution. This has especially been the case in contexts where polluters are numerous and heterogeneous, the source of pollution is well-defined, measurement and monitoring of pollution is relatively easy, and the pollution's geographical impact is sufficiently large that concerns for pollution hot spots, whereby trading results in pollution being geographically concentrated, are low.

The idea originates with Dales (1968), who imagined a cap-and-trade market for water discharge rights as a cost-effective solution to regulating water quality in lakes. In his solution, public authorities would partition space into regions and cap the yearly volume of waste discharge in each area. They would issue a commensurate amount of "pollution permits" and impose the obligation on polluters to surrender as many permits as their volume of pollution over the year. Permits could be bought and sold. Montgomery (1972) provided a formal proof of Dales' conjecture in a static competitive equilibrium framework, essentially proving cost-efficiency as a corollary of the First Welfare Theorem. In the competitive equilibrium, marginal costs of abatement are equalized across firms. Firms with high abatement costs abate less and buy surplus allowances from firms with low abatement costs.

Early applications of cap-and-trade markets for pollution took place in the 1980s in the US but the first grand-scale experiment was the nationwide 1990 Clean Air Act that imposed a cap on sulfur dioxide emissions from electricity production. The market launch was preceded by extensive testing and fine-tuning of different aspects of the design (see Joskow et al., 1998 and Ellerman et al., 2000 for accounts of the design phase and early performance).

The Clean Air Act provided a template for the introduction of emissions trading as part of the Kyoto Protocol, which, in turn, paved the way for the introduction of the EU carbon emissions trading scheme in Europe in 2005. Carbon emissions are particularly well-suited for a market approach because sources of carbon emissions are heterogeneous and face different abatement costs and carbon's impact on climate is the same independently of where it was emitted. Hence, the cost-efficiency gains from trading are likely to be large and concerns for pollution hot spots limited.

Today, "pollution markets" are used for pollutants as diverse as CO2 (a global, long-lived point-source pollutant mostly connected to the combustion of fossil fuels), other greenhouse gases (all global and point-source pollutants but with different lifetimes in the atmosphere), sulfur dioxide (a regional, short-lived point-source pollutant, produced by the combustion of coal), nitrogen

Table 1: The use of markets for solving environmental problems

	Overexploitation	**Degradation**	**Underprovision**
Typical legacy ownership	Shared or nonexistent property rights	Shared or nonexistent property rights	Private property rights
Policy objective	Ensure sustainable exploitation	Limit pollution	Encourage provision
Role for markets	Efficiency	Cost-effectiveness	Efficiency
Market governance	Public or private	Public	Public or private
Applications	Fishing quotas, water rights, hunting permits	Pollutants at different scales (SO2, CO2, NOx, pollution discharge)	Carbon sequestration, biodiversity, other ecosystemic services

oxides (a local short-lived point-source pollutant that is a precursor to ground-level ozone), nitrogen and phosphorous effluents from farms (a local non-point source pollutant responsible for eutrophication and groundwater pollution), waste water discharges (a local point-source pollutant). In each case, careful consideration must be given, when designing the property rights and the market, to the underlying bio-physical process, the geographical reach of the pollutant, and how to measure it.[2]

Market mechanisms for pollution reduction are not limited to trading of allowances between polluters. Auctions can be used to set the initial allocation of allowances. Auctions are also used to decide which polluting firms should exit the market and the compensation they are eligible for to exit.[3]

2.3 Underprovision of natural capital

Unlike the other two environmental problems reviewed so far, ownership rights on the natural resource are well established for the third category of environmental problems. Think about a forest, a lake or a nature reserve under private ownership. The issue now is that the benefits that this natural resource generates are not entirely captured by its owner. As a result, the owner may not invest in or conserve its natural resource at a sufficiently high level. The challenge, therefore, is to find a way to provide this incentive.

Payment for ecosystem services (PES) is defined as a voluntary transaction where a well-defined environmental service (or a land use likely to secure that service) is bought by one or several buyers from one or several providers on the condition that they secure this service provision (Wunder, 2005; Engel et al., 2008). Put simply, the idea is that the beneficiaries of the environ-

[2]The original article of Dales provides an early illustration of the kind of design questions wannabe market designers need to ask themselves. See also Kerr et al. (2007), Cox et al. (2013) and McDonald and Kerr (2011) for a discussion of design considerations in the context of nutrients trading, Fisher-Vanden and Olmstead (2013) in the context of water quality trading, Teytelboym (2019) for settings with complementarities, and Tietenberg (2010) for a general introduction to markets for pollution.

[3]See for example, the coal exit auctions used in Germany to select which coal power plants to close as part of the country's coal phase-out plan (Srivastav and Zaehringer, 2024).

mental service pay the owner of the natural resource for the difference in value and costs borne by this owner from adapting their practice or use, to conserve or develop the natural resource.

The origins of payments for ecosystem services can be traced back to the 1930s when the United States government paid farmers for soil conservation (Claassen et al., 2008). The practice further developed as intensive agricultural practices increasingly competed with other uses of natural resources. Perrot-Maître (2006), Depres et al. (2008) and Defrance (2015) provide detailed descriptions of the contractual arrangements between, respectively, Vittel and Evian, and the local farmers whose lands run off into the aquifers used to extract these mineral waters. One lesson from these cases is that the financial component of the arrangement is only a small part of the overall negotiation and that these PES can be quite complex and long to negotiate. This effectively rules them out when beneficiaries are numerous and diverse, as in the case of a global public good like climate change mitigation.

An important step forward in terms of scaling up market mechanisms for conservation was the introduction of project-based credits in the Kyoto Protocol, whereby investors in signatory countries could claim carbon credits, eligible for compliance, from emission reduction or removal projects in third countries.[4]

The creation of carbon credits was a major breakthrough because it transformed a non-excludable environmental benefit (climate mitigation) into a private good, used for compliance. While Clean Development Mechanisms and Joint Implementation projects have had their teething problems (Schneider, 2009) – essentially around additionality, measurement and verification – the logic underlying their creation has remained. In 2008, the United Nations launched the Reducing Emissions from Deforestation and Forest Degradation (REDD) program to support conservation projects in the Global South and help channel funding to them through the issuance of credits. Since then, increasing demand for carbon credits from the private sector to support their climate commitments has spurred the development of a sizable voluntary carbon market, a subject to which we return in Section 4.

The potential is enormous: Griscom et al. (2017) evaluate that nature-based climate solutions could contribute 37% of cost-effective emissions reductions through 2030 and Grassi et al. (2017) document that land use and forests contribute a quarter of the emissions reductions planned by countries in their nationally determined plans submitted in fulfillment of their obligations under the Paris Agreement. And, of course, the scope for markets to address underprovision is not limited to climate. The recent Kunming-Montreal Global Biodiversity Framework agreed in December 2022 has, for example, increased interest in biodiversity credits and markets. Table 1 summarizes the discussion of this section.

[4]Specifically, Clean Development Mechanisms (CDM) covered carbon reduction or removal projects in developing countries and Joint Implementation (JI) mechanisms covered carbon reduction or removal projects in developed countries.

3 Compliance carbon markets

Today, carbon markets play a central role in countries' efforts to mitigate their greenhouse gas (GHG) emissions. According to the World Bank's Carbon Pricing Dashboard, 36 carbon markets were in operation in 2024, covering approximately 19% of global GHG emissions. Twenty-five emissions trading schemes were also scheduled or under consideration. In comparison, only 6% of global GHG emissions were covered by a carbon tax in 2024.

As argued in the previous section, the economic case in favor of carbon trading is strong. However, emissions markets' ability to lower total abatement costs hinges upon their ability to generate an accurate price signal that reflects the distribution of firms' opportunity costs and can guide companies' abatement investments. In turn, this depends on their design.

3.1 Market design parameters

There is a wide range of market design parameters that have to be decided when setting up a carbon market. While cost efficiency remains the primary objective, other considerations are also relevant. In this section, we review the main design parameters for compliance carbon markets, underlining the arbitrages that they involve.

Market Scope. A first important design choice is the scope of the market in terms of sectors, geography, pollutants and time. In terms of geography and sectors, theory suggests that the larger the market, the better, given the global nature of the pollutant and the heterogeneity in abatement opportunities across countries and sectors. There are nevertheless some caveats. At the sector level, the availability of a consistent, affordable and accurate monitoring, verification, and reporting system is key to the integrity and environmental efficiency of the emissions trading scheme. The efficiency gains from expanded coverage must be balanced with the increased monitoring and verification costs across ever smaller or less precisely measured emitting sources.

Another caveat is that the unilateral introduction of an emissions trading scheme in one jurisdiction might lead regulated companies to shift their activities (and therefore their carbon emissions) to countries with less stringent environmental policies. This is the well-known pollution haven hypothesis, also referred to as *carbon leakage* in the context of climate change (see Dechezleprêtre and Sato 2017 for a review). Here as well, there is a trade-off between the gains from expanding sectoral coverage and the environmental and economic losses of including sectors with a high risk of leakage.

Expanding the geographical scope by linking carbon markets constitutes a possible solution to carbon leakage. However, when discussing the possibility of linking carbon markets, it is important to take into account the level of design alignment, including the similarities in policy objectives, between the two systems, and the increased transmission of political or economic shocks across jurisdictions in case of linking (Flachsland et al., 2009; Fankhauser and Hepburn, 2010; Doda et al., 2019).[5]

[5]See also Ranson and Stavins (2016) for a policy discussion.

While CO2 is the most common greenhouse gas, other gases contribute to global warming (e.g., methane and nitrous oxide). Including other GHGs can bring additional cost efficiency gains, but requires reliable conversion factors and a consensus on which ones to use.[6]

Finally, allowing regulated companies to trade allowances across compliance periods (i.e., to save carbon allowances for future use or to borrow allowances from future compliance periods) provides further cost efficiency gains, as it allows firms to exploit intertemporal arbitrage opportunities (Rubin, 1996; Schennach, 2000; Newell et al., 2005). Depending on the nature of the pollutant, unrestricted banking and borrowing of allowances may not be socially desirable, however. For example, CO2 is a stock pollutant and therefore, the time path of emissions matters. Allowing firms to delay their investments in abatement (through massive allowances borrow-ing) may increase total social damages.[7] Allowing for unrestricted banking and borrowing can also affect companies' trading and compliance behavior. Banking and borrowing reduce the incentives for firms to participate early in the market, slowing down the price discovery process. Borrowing, combined with the ability of the regulating authority to adjust the stringency of the climate policy in the future, might also result in the so-called *ratchet effect* and *hold-up problem* (Hepburn, 2006). First, borrowing allowances from future compliance periods might result in a scarcity situation later on and be used to signal to the regulator that the environmental policy is too costly. This could lead to the negotiation of a more lenient target for the next compliance phase (ratchet effect). Second, the payoffs from long-term investments in clean technologies depend on the stringency of future climate policies. As regulators have the discretion to adjust (relax) the cap after the investments have been made (hold-up problem), borrowing might be used to delay these investments.

Market cap. The economically efficient market cap reflects the level of pollution that equates the marginal social and economic benefits of the polluting activity with its marginal environmental costs. In practice, uncertainty and measurement challenges on both sides of this trade-off imply that the market cap is a political decision. Still, it does make sense for the cap to adjust to economic conditions and new information. When abatement costs are lower than expected, the efficient level of the cap decreases. Likewise, if the economy is booming, it may make sense to raise the cap.

Hybrid mechanisms, which combine price- and quantity-based instruments, have been proposed to regulate pollution in the presence of uncertainty (Roberts and Spence, 1976). In the context of cap-and-trade markets, hybrid mechanisms take the form of price collars (Pizer, 2002; Burtraw et al., 2010). Practically, such hybrid mechanisms work as a regular cap-and-trade market so long as the allowance price is between the floor and ceiling prices. When either the floor price or the ceiling price are reached, the scheme behaves like a tax and regulators inject or remove allowances as needed to support the price.[8] Alternatively, one can condition the injection or

[6] To aggregate different greenhouse gases, the Paris Agreement relies on the *Global Warming Potential* (GWP) produced by the IPCC. The GWP is a conversion factor from physical units of greenhouse gases to CO2 equivalent, accounting for how long these greenhouse gases remain in the atmosphere. The current GWP conversion factors are those calculated for 100 years (CO2 has a normalized value of 1, and every other gas has a value that corresponds to their warming power relative to CO2 during that time frame) (Denison et al., 2019).

[7] In the scenarios assessed in the last IPCC report (2023), limiting global warming to 1.5°C requires immediate action and global GHG to peak before 2025 at the latest.

[8] Regulators' intervention can be capped too. This is the case when the price collar is implemented through an allowance reserve and a pre-set maximum number of allowances that can be added to the market when the

removal of extra allowances on the quantity of allowances in circulation, rather than on the observed price (quantity collars). If placement in the reserve is temporary and allowances can be canceled, the total cap on emissions is affected (Kollenberg and Taschini, 2016, 2019).

These hybrid mechanisms adjust the cap in the intended direction: they tighten the cap if abatement costs are lower than expected, as evidenced by low prices or excess allowances in circulation, and, reversely, they increase the cap if abatement costs are higher than expected.

However, these adjustments, with thresholds of intervention set ex-ante, may not be efficient ex-post. The literature has explored more sophisticated cap adjustment mechanisms that account for the information revealed by the operation of the market. Pizer and Prest (2020) and Burtraw et al.(2022) make the point that dynamic adjustments of the cap, based on price realizations, are welfare-improving. Karp and Traeger (2024) propose the use of a price-responsive conversion factor between allowances to emissions to account for new information.

Allowances allocation. Regulators are faced with three alternatives to allocate allowances to regulated firms. They can allocate them for free, auction them, or sell them for a fixed fee. Auctioning allowances forces all market participants to actively participate, whereas free allocation makes it possible, when banking is allowed, for firms with surplus allowances not to interact with the market. This, in turn, can hamper price discovery. Consignment auctions, where firms receiving an initial allocation of free allowances are required to submit some of them to an auction, have the price discovery advantage of auctions while reducing the overall costs to market participants (see Burtraw and McCormack 2017 and Khezr and MacKenzie 2018). Such auctions have been used at the launch of the sulfur dioxide market in the United States and Joskow et al. (1998) argue that they contributed to price discovery.

Free allocation of allowances, and in particular grandfathering under which allocations are based on past emissions or output, may also lead to a perverse ratchet effect where companies have an incentive to emit more in the short-term to increase their future allocation (Böhringer and Lange, 2005; Harstad and Eskeland, 2010).

Nevertheless, free allocation of allowances is common in the early stages of carbon markets. It alleviates concerns about international competitiveness and contributes to early acceptance by market participants. This choice is further supported by the idea that the initial allocation of allowances has no impact on the performance of the market, a property known as the independence property and initially shown by Montgomery (1972). However, the independence property relies on the absence of market frictions and fails in the presence of market power (Hahn, 1984) and transaction costs (Stavins, 1995). Zaklan (2023) has empirically tested the independence property in the context of the EU ETS and found it to hold for large emitters in the power sector, but not for small ones.

Compliance. Existing compliance markets have adopted different rules regarding compliance. Some, like the EU ETS, have annual compliance cycles, but others have longer cycles. Holland and Moore (2013) show that compliance timing does not impact expected compliance costs as long as there is intertemporal price arbitrage for allowances. This is the case if market

price ceiling is reached (Murray et al., 2009; Fell et al., 2012). In that case, the price can rise above the ceiling price, unless there is some rationing when the reserve is empty.

participants are not subject to borrowing constraints, for example, and if there is no price cap. If not, compliance timing matters and impacts abatement costs.

The nature and level of the non-compliance penalty can also have very different implications. If the payment of the penalty is an alternative to surrendering missing allowances, this penalty effectively acts as a price ceiling. This is not the case if non-compliant firms have to pay the penalty but are still obliged to surrender the allowances corresponding to their past emissions (see Stranlund 2017 for a review of the literature on enforcement in emissions markets).

[place Table 2 about here]

Market organization and legal status of allowances. As illustrated in Table 2, market organization and the legal status of emissions allowances vary considerably across jurisdictions. Allowances can be considered as a physical asset, as an administrative authorization to emit CO2, or as a financial instrument. This has important consequences. Commodities and financial assets are treated differently from an accounting and tax perspective. In Europe, for example, commodities are subject to a value-added tax (VAT) but financial assets are not. Markets for commodities and for financial assets are also regulated differently.

The way the market is organized (i.e. who is allowed to trade, where, and what type of assets) also affects its ability to aggregate information about the distribution of abatement opportunities and generate a stable price signal. There is a long and rich literature in finance on the impact of market design on information aggregation and the price discovery process (see O'Hara 1998 for a review).

3.2 A market design perspective on the history of the EU ETS

We illustrate these design considerations in the context of the EU ETS, the oldest and, to this day, largest carbon market in value in the world. The market was launched in 2005 as a trial phase before the 2008-12 Kyoto compliance period. The market covered the carbon emissions from around 11,000 installations from the power and energy-intensive industrial sectors, representing about 45% of the greenhouse gas emissions of the European Union.[9] Since then, the market has continued to be organized in phases, each with clear rules (sectors covered, initial allocations, total cap, etc) announced a few years before (see Table 3 for an overview). The market is currently in its fourth phase (2021-2030).

The history of the EU ETS is a vivid illustration of the importance of design and the continuous need to adjust it as circumstances change (on this, see also Alvin Roth's contribution in this volume). This was not anticipated by the early architects of the EU ETS who envisaged a limited role for market design:

"*The legal framework of the ETS does not lay down how and where trading in allowances should take place. Companies and other participants in the market may trade directly with each other or buy and sell via a broker, exchange or any other type of market intermediary that may spring up*

[9] For an early account of the EU ETS, see Ellerman et al. (2010).

Figure 1: Evolution of the EUA spot price (April 2005-July 2024)

Source: `https://tradingeconomics.com/`

to take advantage of a new market of significant size. The price of allowances will be determined by supply and demand as in any other market." (European Commission, 2005)

As a result, and unlike the US sulfur dioxide market, the EU ETS benefited from very little support, beyond the creation of allowances and the registries to record ownership and transfers of allowances. This hands-off approach changed over time as new problems arose and changes in rules were required. Today, thorough discussions take place several years before the beginning of a phase to evaluate the performance of the market and potential reforms.

As a background to the discussion in this section, Figure 1 plots the observed allowance prices between April 2005 and December 2023. These prices have been extensively commented upon in the specialized press and the academic literature (see e.g. Ellerman et al. 2010, Quemin and Trotignon 2021, and `https://carbon-pulse.com/` for industry coverage). During the first phase, the price increased from around 10 euros in March 2005 to nearly 30 euros in April 2006. The price then dropped to around 10 euros within three days, upon the release of verified emissions in several countries that showed them to be significantly below allocations. The allowance price then slowly converged to zero as it became increasingly clear that there were excess allowances in the market, which could not be banked for the second phase. The allowance price shortly rose again afterwards but remained relatively low until 2018. Since 2018, the price has been steadily increasing. It exceeded 100 euros per ton in February 2023, and was around 70 euros per ton by mid-2024.

Market Scope. Experience, improved data, and advances in monitoring have enabled the gradual extension of the EU ETS to more countries, more greenhouse gases, and more sectors.[10] In the second phase of the EU ETS, credits generated by Clean Development Mechanisms and Joint Implementation projects under the Kyoto Protocol could be used for compliance, with restrictions on the quantity. These credits were phased out in phase III following concerns about their reliability (Schneider, 2009).

In 2023, as part of the Fit-for-55 package, the EU decided to create a new ETS to cover emissions from fuel combustion in buildings and road transport (ETS2). The new market will come into force in 2027.[11] Instead of simply expanding the scope of the existing ETS, the EU opted for a separate market to balance the efficiency gains from carbon trading with distributional and political considerations. Indeed, abatement costs in the buildings and road transport sectors are expected to be higher than those in the sectors covered by the current ETS. Integrating both markets, therefore, would result in higher prices and lower (proportionally) emissions reductions in these new sectors. This would delay the long-term investments needed in these sectors to reach the EU climate ambitions and run the risk of exacerbating carbon leakage in the existing ETS sectors. The two markets approach that the EU has adopted has the additional benefit of providing time for all stakeholders to ramp up their market readiness and avoid disruptions for the existing ETS (see European Commission, 2021, and Edenhofer et al., 2021, for a discussion of this and other considerations).

Market cap. An evolution of the EU ETS that has been driven by lessons learnt from past performance is the approach to cap setting. Initially, the allocation of allowances was decided at the national level, under guidelines from the European Commission. This decentralized process determined the EU-wide cap, as the sum of the national caps. It contributed, at least partially, to the over-allocation of allowances: each Member State in isolation was tempted to be more lenient with its domestic firms. Since phase III, the cap is set at the European level. An annual linear reduction rate applies (initially set up at 1.74% of 2008-2012 baseline emissions). Allowances are no longer allocated on a national basis but, instead, through auctions or to individual installations.

However, setting the cap at the EU level was insufficient to avoid excess allocations. Following the 2008 financial crisis, industrial activity and carbon emissions slumped. At the same time, Member States and the EU enacted other climate policies that reduced baseline emissions. Annual carbon allowances issued began to exceed actual annual emissions. A large surplus of allowances built up through banking. Prices went down.

At that time, there was no mechanism to adjust the cap to changes in economic conditions. In 2015, the EU decided to backload the issuance of some of the allowances to the end of the phase

[10]During the discussions over the ETS market reform for phase III, the availability of accurate monitoring and reporting system was explicitly mentioned as one of the reasons why shipping could be included in the EU ETS, while other sectors (such as agriculture) were not considered. CO2 emissions from aviation have been included in the EU ETS since 2012, but international aviation was exempted due to concerns regarding competitiveness and carbon leakage. The exemption was established to allow time for the adoption of a global deal at the UN level, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

[11]Compared to the existing ETS that regulates direct emitters (point sources), the ETS2 will regulate precursor activities to emission sources (i.e. fuel suppliers rather than households or car drivers).

to support prices, and to introduce a market stability reserve (MSR), starting from 2019. Under the MSR, allowances are temporarily removed from the market (and set aside in a reserve) when the number of allowances in circulation is above a threshold, while allowances are injected (from the reserve) when the number of allowances in circulation is below a threshold.[12] The long-term cap neutrality (as allowances are only temporarily removed from the market) of the MSR raised concerns that it would not help increase the price of allowances and might instead increase its volatility (Perino and Willner, 2016; Kollenberg and Taschini, 2019). In 2018, the MSR was complemented by a cancellation mechanism (implemented in 2023), fixing the maximum volume in the MSR to 400 MtCO2e.

Recent research suggests that these market interventions contributed to the increase in carbon prices observed since 2018 (Bruninx et al., 2020; Quemin and Trotignon, 2021). However, these articles also emphasize that the MSR can trigger feedback loops that disrupt the normal operations of the market in the presence of a tightening cap (see also Perino et al. 2022). Specifically, when firms expect a stricter cap in the future, it is rational for them to start abating more today and bank allowances to equalize marginal abatement costs across periods as much as possible. But banking increases the number of allowances in circulation and triggers removals given the existing rules of the MSR, further tightening the cap (for a detailed discussion of the MSR and its properties, see Borghesi et al. 2023)

[place Table 3 about here]

Allowances allocation. Allowances were initially allocated freely to regulated entities based on past CO2 emissions. This discouraged participation by small compliance traders who faced high transaction costs and could save unused allowances or borrow the equivalent of one year of allowances instead of interacting with the market (Jaraitė-Kažukauskė and Kažukauskas, 2015; Baudry et al., 2021).

In their review of the EU ETS in preparation for phase III, the European Commission recognized the limitations of free allocations and the efficiency benefits of auctioning (European Commission, 2008). But they remained concerned about carbon leakage and competitiveness. For this reason, the European Commission opted for a hybrid allocation scheme. Auctions became the default allocation mechanism, but sectors at risk of carbon leakage continued to receive some of their allowances for free. The allocation rule was adapted, however. Instead of allocating allowances based on past emissions, allowances were allocated based on a benchmark made of the top 10 percent best performers (in terms of carbon intensity).[13] As a result, firms in sectors at risk of carbon leakage whose carbon intensity was higher than the benchmark received fewer allowances than they needed and had to buy the difference in the market.

[12] Formally, the total number of allowances in circulation (TNAC) is defined as the supply of allowances - (Demand + MSR). The supply of allowances consists of the allowances banked from the previous phase, allowances issued for the current phase, and the allowances in the New Entrants Reserve. The demand is determined by the number of allowances that have already been surrendered for compliance or canceled.

[13] A benchmark is defined for each product sold by sectors covered by the EU ETS. Performance is measured in terms of emissions intensity (tons of CO2 equivalent per unit of output) in 2007-2008. The product benchmark is the average GHG emission performance of the 10 percent best-performing installations that produce this product. See Stenqvist and Åhman (2016) for details.

While a combination of free allocation based on benchmarking and auctioning is an improvement compared to the initial allocation methods chosen in the EU ETS, Martin et al. (2014) argue that this is still inefficient. The new rules protect firms with the highest probability of relocating their activities, i.e. carbon-intensive and trade-exposed industries. Efficiency, instead, requires taking the expected aggregate damages from relocation into account. They show that the efficient compensations (in the form of free allowances) equalize the marginal propensities to relocate, weighted by the damages caused by their relocation, across firms.

The latest development in the free allocation - carbon leakage debate is the introduction of a *Carbon Border Adjustment Mechanism* (CBAM), taking effect in 2026. Instead of granting free allowances to sectors exposed to international competition, as a way to ensure that domestic and foreign firms face a common level-playing field in the EU, the CBAM charges imports from select sectors for their carbon content, unless they have been subject to an equivalent carbon price in their home country. Free allowances will be phased out accordingly. In essence, the CBAM puts domestic and foreign firms on an equal footing in the EU, but this time they both face a carbon price.[14]

Market organization and legal status of allowances. As was the case for the decisions regarding the cap on emissions, the original infrastructure of the EU ETS was decentralized. National registries recorded ownership and transfers of allowances. These national registries were linked together through the Community Independent Transaction Log. The decision regarding the legal status of allowances was also left to Member States. Some countries viewed them as commodities, subject to VAT, while others considered them as financial assets.

During the second phase, several national registries were hacked and allowances were stolen. Additionally, some traders took advantage of the difference in legal treatment of emissions allowances across countries, resulting in a massive VAT carousel between EU countries (Interpol, 2013; Robert, 2012). Fraudsters bought tax-free allowances in one country, sold them in another Member State where they were subject to VAT, pocketed the VAT, and then disappeared without ever paying it back to fiscal authorities. According to some estimates, these fraudulent activities led to a loss of tax revenues of around 5 billion euros (Berrittella and Cimino, 2017). In response, operations were centralized in 2012 into a single EU registry managed by the European Commission. Furthermore, allowances are considered financial instruments and have been regulated under the Markets in Financial Instruments Directive (MiFiD II) since 2018.

3.3 The challenge of producing stable informative signals

The cost-efficiency argument in favor of cap-and-trade schemes rests on their ability to produce prices that are informative of economic conditions and of firms' current and future abatement opportunities. Cronshaw and Kruse (1996) and Rubin (1996) have extended Montgomery (1972)'s efficiency result to a dynamic setting with no uncertainty. They show that arbitrage across periods leads to prices being equated across time periods, up to a discount factor. In practice however, there is some uncertainty about the state of the economy and future emissions. In

[14] See `https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en` for a description and Ambec (2022) and Cosbey et al. (2019) for analyses.

that case, prices are updated following the arrival of new information. Schennach (2000) shows that, in the full information equilibrium, prices follow a martingale: current prices are equal to expected future prices, up to discounting. New information arrival does lead to price changes but these are typically muted because shocks are spread over all future compliance periods (Cantillon and Slechten, 2018). In other words, we do not expect the kind of price movements seen in Figure 1.[15] Volatility is surprisingly high in the EU ETS, given the absence of storage costs and the high intertemporal fungibility of EU allowances. For example, in 2018-19, the coefficient of variation of EU allowance prices was between 0.3-0.4. This is much higher than for other major commodities for which storage costs are typically larger, including oil (0.23), gas (0.16), and base metal (0.12).

This level of volatility is a concern for the cost-effectiveness of the market, given that price uncertainty reduces investment incentives (Dixit and Pindyck, 1994; Bloom et al., 2007). There is a need to understand and address price volatility in the EU ETS.

A number of explanations have been proposed. Quemin and Trotignon (2021) have hypothesized that regulated companies do not fully exploit arbitrage opportunities over time due to shortsightedness. Long-term hedging markets could help mitigate the impact of shortsightedness but they are underdeveloped for this purpose. For example, in 2024, the Intercontinental Exchange (ICE), the dominant platform for European allowances trading, did not list any futures contracts beyond 2030. This is considerably shorter than the typical horizon for investments in abatement technologies (e.g. installing a new blast furnace in a steel mill). Moreover, liquidity decreases rapidly along the maturity curve.

A second explanation is that overlapping policies lead to large shocks in business-as-usual emissions that even intertemporal arbitrage cannot smooth (Borenstein et al., 2019). This raises questions about the ability of cap adjustment mechanisms, and the reformed MSR in particular, to account for these overlapping policies (Perino et al., 2019).

Market participation and rules regarding who is allowed to trade are another explanation that has been proposed for the high level of volatility observed in the EU ETS. Non-compliance entities (e.g. financial intermediaries, speculators, or hedgers) now make up a large share of allowances trading on the European carbon market. Participation by non-compliance traders brings liquidity and can help small emitters access the market (Cludius and Betz, 2020). Financial intermediaries also provide hedging services to compliance traders. However, Quemin and Pahle (2023) argue that the non-regulated entities that have recently entered the EU ETS are very different from the financial intermediaries and market makers present so far. The new traders are mostly investment funds, that trade for other reasons not directly linked to compliance (e.g. hedging against inflation, greening their portfolio, or diversifying the risk of their portfolio ...). Their presence may induce excess volatility relative to market fundamentals due to spillover effects from shocks in other markets, an argument made by Sockin and Xiong (2015) in the context of commodity markets.

[15] In the presence of constraints on borrowing, prices can rise suddenly following an increase in emissions. However, given the timing of issuance of allowances in the EU ETS, borrowing constraints are unlikely to bind for most firms as compliance firms can effectively borrow the equivalent of one year of allowances.

Concerns regarding the financialization of carbon markets and its effect on price volatility have also been raised recently by the European Commission.[16] The choice made by the EU regarding who has access to the EU ETS is very different from the choices made in other jurisdictions (see Table 2). In the Korean emissions trading scheme, only designated market makers are allowed to trade allowances to ensure a level-playing field for all traders. In the Chinese market, non-compliance firms are excluded. It is an open question to what extent these different rules on participation facilitate price discovery by compliance traders.

A fourth explanation relates to the microstructure of the EU ETS. The EU ETS has historically been and is still today a highly fragmented market, weaving together centralized exchanges, dealers, brokers, and other financial intermediaries (Borghesi and Flori, 2018; Karpf et al., 2018). While fragmentation does not necessarily result in inferior price discovery or higher price volatility (Jensen, 2007; Chen and Duffie, 2021), Cantillon and Slechten (2024) find that, in the EU ETS, it hampered the ability of market participants to get a full picture of the prevailing balance between supply and demand in the market, and failed to ensure an equal level-playing field among traders. In turn, incomplete information aggregation is likely to lead to overreaction to new information. This raises several design questions regarding the way those markets are organized: Should we have a centralized exchange? Should we have market makers?

Relatedly, carbon markets, typically characterized by annual compliance cycles, tend to be thin, which contributes to price volatility. There have been suggestions to lower the frequency of the market to pool liquidity, or implement staggered compliance cycles to ensure that there is sufficiently liquidity throughout the year.

Finally, in ongoing work, we explore the impact of risk management practices as a potential driver of price volatility. Interviews and descriptive analysis of trading behavior suggest that compliance and non-compliance traders are subject to risk management constraints, accumulating spot allowances close to futures maturities. These risk management constraints introduce an endogenous borrowing constraint on the market and lead the price to deviate from market fundamentals and over-react to shocks on the availability of allowances.

4 Voluntary carbon markets

Voluntary carbon markets bring together projects that reduce carbon emissions or remove carbon from the atmosphere, and individuals, companies or public entities eager to offset their emissions, typically on a voluntary basis.[17] Projects are diverse: some are based on nature (our focus here), some are based on technology. Some reduce emissions relative to a business-as-usual situation (emissions avoidance), others *physically remove* carbon from the atmosphere (carbon

[16]The Commission asked the European Securities and Markets Authority (ESMA) to analyze the trading of emission allowances. The final report concluded that "*the emergence of new participants (and instruments) with buy and-hold strategies warrants future monitoring to the extent that they may lead to a reduction in the supply of physical emission allowances available for trading, even though the available evidence suggests that their impact is only limited so far.*" (European Securities and Markets Authorities (ESMA), 2022).

[17]An exception is the aviation sector which can use some of these credits to meet their obligations under the Carbon Offsetting and Reduction Scheme (CORSIA).

removal). For example, low-carbon cookstoves qualify as a technology-based carbon avoidance project. Planting trees is a nature-based carbon removal project.[18]

Projects generate carbon credits, which are then traded on the market. Buyers can hold them for resale later on, or "retire" them, i.e. redeem them against their own emissions. In that case, the credit can no longer be traded.

In 2023, 261 million carbon credits were issued and around 170 million were retired in the voluntary carbon market globally (one carbon credit represents one ton of carbon) (World Bank, 2024). To put this in perspective, the yearly cap on emissions from stationary installations in the EU ETS was 1,485 million tons the same year.[19] Many observers remain bullish about the voluntary carbon market, however, with new participants and intermediaries joining the market *en masse*. First, the number of companies taking voluntary action to reduce their emissions is increasing. These companies typically need to complement their internal mitigation efforts by carbon offsets. Second, ongoing negotiations around Article 6 of the Paris Agreement will expand the possibilities for countries and companies to use carbon credits to meet their climate mitigation commitments.[20]

4.1 Project qualification and market governance

A number of conditions are imposed on projects before issuing credits. These conditions seek to ensure that the project and the emissions reductions that go with it would not have happened without funding (additionality condition), that the claimed emissions reductions are properly measured (baseline accuracy and absence of leakage conditions) and permanent (permanence condition).[21] Credits are recorded in a registry for traceability and to avoid any risk of double counting. Projects meeting these conditions can reassure buyers that the credit they buy corresponds indeed to one ton of carbon avoided or removed.

The market is supported by an ecosystem of standard setters, certifiers, registries, and trading platforms. Standard setters play a major role. They define what projects can generate credits and set the methodologies to assess the amount of carbon avoided or removed. Independent standard-setting organizations, such as Verra and Gold Standard, are responsible for the majority of credits issued. They coexist with public international, national and regional crediting mechanisms, such as the Clean Development Mechanism (CDM), established by the Kyoto Protocol, and the California Compliance Offset Program.

The main categories of projects eligible for crediting are forestry and land use, renewable energy, energy efficiency/fuel switching, waste disposal and household devices. Each category is itself

[18] While both types of projects reduce net emissions, carbon removal projects tend to be viewed more positively, among others, because their additionality claims are considered more reliable. See Tanzer and Ramírez (2019) for details.

[19] `https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/emissions-cap-and-allowances_en` (accessed July 30, 2024).

[20] Article 6 of the Paris Agreement describes ways in which countries can "pursue voluntary cooperation" to reach their climate targets. Article 6.2 deals with bilateral and multilateral exchanges between countries. Article 6.4. lays the basis for a global carbon market supervised by the United Nations. It will eventually replace the Clean Development Mechanism.

[21] Leakage refers to the increase in emissions outside of the accounting boundary of a project, as a result of the project. For example, if forest protection in one area leads to a shift of logging to another area.

divided into subcategories of projects, each with its own methodologies. Credits remain uniquely identified by their projects and their vintage. Buyers know, when they buy a credit, the identity of the project that generated this credit.

Standard setters work with a network of independent certifiers that apply the standard's methodology to evaluate projects and propose the number of credits to be issued. Registries document credited projects and retirements and ensure that projects are not credited twice. They contribute to market transparency.[22]

In 2022, the market was dominated by bilateral deals between project developers and end buyers but intermediaries, exchanges and funds had recently entered and were offering their services to this growing market (World Bank, 2022, 2023).

4.2 Challenges

As of today, the voluntary carbon market is best characterized as immature: liquidity and transparency are low, and prices are dispersed and volatile. Credits from carbon removals for example, such as afforestation, trade at a premium relative to nature-based avoidance projects (preventing deforestation) or renewable energy projects. Even within these categories, price differences prevail. The nature of credits traded and buyers' preferences for direct contact with credit-issuing projects are part of the explanation. Attempts by exchanges to bundle credits meeting specific requirements have met with resistance from market participants eager to avoid adverse selection (World Bank, 2023).

More damaging for the market, a number of scientific articles have raised concerns about the tangibility of the climate benefits provided by certified projects. Researchers have documented large and systematic over-crediting (Haya et al., 2020; West et al., 2020; Badgley et al., 2022; Gill-Wiehl et al., 2023), absence of additionality (Schneider, 2009; Calel et al., 2021), and leakage (Heilmayr et al., 2020). These concerns were further publicized when a syndicate of investigative journalists reported in January 2023 that more than 90% of rainforest carbon offsets certified by Verra, one of the largest standard setters, were worthless.[23] These, and subsequent developments such as increasingly frequent large scale forest fires, have led to large drops in prices for nature-based credits, from around 16 USD per ton at the end of 2021 to 1 USD per ton in July 2024.[24]

4.3 Market design options

The tribulations of the voluntary carbon market illustrate the complexity of designing markets for environmental goods and services. Scale - the main benefit that markets bring - requires some form of standardization and legal certainty about the asset traded. For technical and

[22] Typically, these registries are paired with certification bodies, but a database, developed by the Berkeley Carbon Trading Project at UC Berkeley, aggregates the projects from the largest four registries, essentially covering most of the voluntary carbon credit market.

[23] https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe

[24] Source: S&P Global Platts.

economic reasons, these have until now eluded the voluntary carbon market: project-based emission reductions are measured with uncertainty and subject to revisions, exposing buyers to reputational and legal risks.

The pragmatic route of certification *cum* market segmentation taken so far has only partially addressed these concerns, as evidenced by the continued dominance of bilateral trades between project developers and buyers and the underdevelopment of the secondary market.

Researchers have proposed different solutions to address the credibility issues with which the voluntary carbon market is confronted. Proposed solutions cover project design and qualification, credit use and measurement. For example, Mason and Plantinga (2013) propose to use contract menus, into which project developers self-select, to address exaggerated additionality claims (see also Li et al., 2023, and Aspelund and Russo, 2023). Streck (2021) proposes to address leakage with a combination of project design, intended to minimize leakage, and standards imposed on users of credits. Filewod and McCarney (2023) recommend that upper-bound estimates of leakage be systematically used (unlike today) to derate the estimated carbon saved or avoided. In addition, they argue that such credits should not be used for compliance. In non-compliance settings, these credits should only be used to offset emissions that are themselves quite poorly estimated, such as beyond-value chain emissions.

Balmford et al. (2023) suggest replacing the usual buffer approach to the risk of impermanence of nature-based credits, whereby a buffer is added to the issued carbon credits in case the carbon savings do not materialize (e.g. because of a forest fire) by a dynamic accounting approach tracing changes in carbon stocks over time and issuing or canceling credits accordingly. Their approach, which capitalizes on recent advances in near-time granular satellite imagery and data processing, has the added benefit of encouraging project developers to preserve and conserve the project's benefits.

Developments on the ground point to the direction of stricter standards on credits and standard harmonization, on the one hand, and stricter conditions on disclosure and use by buyers to prevent green-washing, on the other hand.[25]

While these developments are likely to improve the integrity of current voluntary carbon markets, they will, in effect, restrict market size, focusing it on the high-quality segment. Moreover, these developments do not address more conceptual questions about the nature of carbon credits and the contractual arrangements supporting them. One such concern is the intrinsic intellectual difficulty of having different prices for carbon credits that have the same face value (one ton), and the continued market fragmentation that results. Another concern is to what extent carbon reduction and carbon removal projects are best served by production-based financing, such as the one provided by voluntary carbon markets, which reward a flow of emissions reductions, rather than project finance that funds the investment upfront.

[25] See World Bank (2024) for an overview, and European Commission (2022) and European Commission (2023) for recent legislative initiatives in the EU.

5 An agenda for market design research

Nature is essential for our lives and economies. Yet, our ways of living have gradually encroached on Nature to the point that several tipping points have been reached (Richardson et al., 2023). In this chapter, we have reviewed areas where markets are used or being considered to address environmental overexploitation, degradation and underprovision.

The starting point of any such scheme is a sound understanding of the bio-physical process underlying the environmental problem at hand. This bio-physical process determines what can be traded and the arbitrages which any market designer must make. For example, the fact that carbon dioxide is a stock pollutant means that the trajectory of emissions over time, and not only their level at any point in time, is what matters. This implies that constraints on borrowing are a good idea, despite preventing some intertemporal cost optimisation. Likewise, the fact that carbon dioxide is also a global pollutant means that boundary issues and leakage should be first-order considerations. When it comes to nature-based provisions of carbon emissions reduction, their non-permanence requires that crediting be adapted over time. More generally, defining the object of trade can prove very difficult for nature-based solutions because natural capital typically comes as a bundle of services and attributes that may be space and context-dependent (Griscom et al., 2017; von Jeetze et al., 2023). As our discussion has illustrated, this complexity is a challenge for building thick and liquid nature-based markets. Progress in measurement and technology will help, but more sophisticated asset designs and tailored market designs are also needed.

5.1 Asset design, maturity alignment and risk sharing

When it comes to limiting environmental over-exploitation and degradation or increasing the provision of environmental services, it is natural to focus on flows (emissions of a pollutant, removal of carbon, catch of fish). Therefore, unsurprisingly, most environmental markets reward or penalize these flows.

The issue, however, is that reducing environmental over-exploitation and degradation, or increasing the provision of natural capital, sometimes requires heavy upfront investments. This is, for example, the case for decarbonising industry. The difference in the timing of the investment and the timing of its benefits may limit investment if investors are credit-constrained or risk-averse.

Appropriate asset designs can play a role. In compliance markets, investment subsidies, possibly awarded through auctions, are an alternative mechanism to foster investment in abatement technologies.[26] In voluntary carbon markets, project finance, which funds the owner to invest in conserving or developing their natural capital, rather than pays them for the service flow from their investment, reduces investment risk and alleviates credit constraints. In the same spirit, Aldy and Halem (2024) argue that treating carbon offsets as bonds, which will generate a coupon only if the benefits materialize, can shift some risks to the buyer. Flammer et al. (2023)

[26] An independent and separate argument for considering subsidies for R&D or research procurement is that R&D is subject to a knowledge externality (see e.g. Acemoglu et al. 2012 and Willian Arnesen and Rachel Glennerster's chapter in this volume).

discuss the role of blended finance - where private investment capital is blended with public or philanthropic capital - in biodiversity conservation.

The right level of risk-sharing walks a fine line between risk insurance and incentives. Keeping some risk with investors is desirable if the flow benefits depend on their care in maintaining the natural capital they invested in. For example, guaranteeing a purchase price for carbon credits, much like contracts-for-differences or feed-in-tariffs do in electricity markets, protects investors from market risk, over which they have little control, but not from production risks, over which they have agency.

5.2 Accounting for policy overlap

A challenge that all environmental markets will increasingly face as governments ramp up action on climate and biodiversity is their interactions with overlapping policies. As discussed in Section 3.3, interactions with other policies can generate large uncertainty about future prices in pollution markets, reducing incentives for investment. In provision markets, evolving policies may impact the counterfactual against which a project is assessed to evaluate its environmental benefit, generating risk for project developers (Aldy and Halem, 2024). Market designs need to account for these interactions and hedge market participants from unnecessary risks.

5.3 Should voluntary and compliance markets be integrated?

Integration between voluntary and compliance carbon markets is an area of intense policy interest. Ongoing negotiations on Art. 6 of the Paris Agreement and pending legislative proposals in the EU and the UK pave the way for the eventual use of carbon credits for compliance. Proponents argue that pooling sources of emissions mitigation and carbon removals will encourage investment in carbon removals and mitigation and contribute to greater cost-effectiveness of climate action.

The question is what conditions to put on these credits and on their use so that integration does not harm the integrity of compliance markets. Past experience with CDM and JI projects provides a cautionary tale about the risks and benefits of such integration. Clearly, raising standards and improving measurement and monitoring to increase accuracy, ensure additionality, and limit leakage can be part of the solution.

Still, the most exacting standard for nature-based carbon removals will never be able to guarantee permanence. For these nature-based carbon credits, Balmford et al. (2023) suggest using a dynamic accounting system to correct dynamically for the changes in carbon stocks over time. Alternatively, Edenhofer et al. (2023) suggest derating these carbon credits for the non-permanence of the carbon removals associated with them, and creating a European Carbon Central Bank to cover any remaining liabilities.

Distinguishing pollution markets from provision markets provides a complementary perspective and cautions against integrating nature-based credit removals into emissions reduction compliance markets. The reason is that these markets pursue different goals: the former aim to encourage the provision of nature-based carbon removals, the second aim to reduce emissions from human activities. This matters because existing Paris-aligned emissions trajectories treat these two goals *separately* and require both to be met simultaneously. Making nature-based carbon removals also count towards emissions reduction in the other sectors, as implied by market integration, would amount to double-counting. Interestingly, the discussion at the EU level about market integration only concerns industrial carbon removals at this stage and thus avoids this double-counting trap (European Commission, 2024). The UK proposal does not.[27]

[27] "UK ETS consults on integrating carbon removal", Carbon Pulse, May 23, 2024, https://carbon-pulse.com/289140/

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Table 2: Carbon market design choices around the world

	EU ETS (2005)	**California ETS (2012)**	**Korea ETS (2015)**	**China ETS (2021)**
Market Scope				
Sectoral Coverage	Domestic Aviation, Industry, Power	Industry, Power, Transport, Buildings	Domestic Aviation, Industry, Power , Waste, Transport, Buildings	Power
Number of entities	9,000+ entities	400+ entities	680+ entities	2,100+ entities
Pollutants covered	CO2, N2O, PFCs	CO2, CH4, N2O, SF6,	CO2, CH4, N2O, PFCs, HFCs, SF6, HFCs, PFCs, NF3, and other fluorinated GHGs	CO2
% of GHG covered	38% of GHG	75% of GHG	74% of GHG	44% of GHG
Allowances Allocation	Daily auctions	Quarterly auctions	Free allocations + some auctions	Free allocations
Status of allowances	Financial instrument	Limited tradable authorizations	Not defined	Physical asset
Market organisation				
Secondary market	OTC + EEX, ICE, and Nasdaq	OTC + ICE + CME	OTC + KRX	Shanghai EEE
Derivatives market	EEX, ICE, and Nasdaq	ICE and CME	-	-
Who can trade?	Compliance traders + others (investors, brokers, other service providers)	Compliance traders, holders of offsets, firms offering clearing services	Compliance traders, authorized market makers, brokers (position limit)	Compliance traders
Average Price	83.10 USD/tCO2e	28.08 USD/tCO2e	17.99 USD/tCO2e	8.20 USD/tCO2e

This table was created based on information from the International Carbon Action Partnership (2023). The average price for the EU ETS, California ETS, and Korea ETs are the average auction prices in 2022. The average price for the China ETS is the average secondary market price in 2022.

Table 3: A brief History of the EU ETS

	Phase I (2005-07)	**Phase II (2008-12)**	**Phase III (2013-20)**	**Phase IV (2021-30)**
SCOPE	EU, 5 industrial sectors	Norway, Iceland and Liechtenstein	Integration of aviation, and new gases added (N2O and PFCs)	Phase-in of maritime transport (2024), separate ETS for buildings & road transport (2027)
FUNGIBILITY	Bankability and limited borrowability within phase	Allowances can be banked for the future		
LINKAGES		International credits from CDM and JI	International credits phased out (no new project), Linkage to Swiss ETS (2020)	
MARKET CAP	EC guidelines, national choice		Top-down cap setting Backloading of allowances Market stability reserve (2019)	Accelerated decrease in cap
ALLOCATION	Grandfathering		Auctions as default allocation Free allocation for some sectors based on benchmarking	Phase-out of free allowances (phase-in of CBAM starting in 2026)
INFRASTRUCTURE	National Registries		Single EU Registry	
OTHER EVENTS		Hacking events, VAT fraud, Economic crisis creates a market glut	Market regulated under MiFID	Fit-for-55 reforms (2023)