10 Effective Institutions against Climate Change

Christian Gollier and Jean Tirole*

We are faced now with the fact that tomorrow is today. Over the bleached bones and jumble residues of numerous civilizations are written the pathetic words "Too late."

—Martin Luther King, New York, April 4, 1967

Climate Change Is a Global Commons Problem

Before discussing efficient institutions against climate change, let us restate the obvious.

We Must Put an End to the Waiting Game

If no strong collective action is undertaken soon, then climate change is expected to dramatically deteriorate the well-being of future generations. Although the precise consequences of our inaction are still hard to quantify, there is no question that a business-as-usual scenario would be catastrophic. The 5th Report of the IPCC (IPCC, 2014) estimates that the average temperature would increase by somewhere between 2.5°C and 7.8°C by the end of this century, after having already increased by almost 1°C over the last century. Our emissions of greenhouse gases (GHGs) have never been larger than today. Limiting the increase in temperature to 2°C is thus an immense challenge, with a still increasing world population and, hopefully, more

* We are grateful to François-Marie Bréon, Dominique Bureau, Bruno Bensasson, Frédéric Chevalier, Peter Cramton, Axel Ockenfels, Christian de Perthuis, Steven Stoft, and Martin Weitzman for helpful comments. This chapter is an extended version of another article, "Negotiating Effective Institutions Against Climate Change," which appeared in *Economics of Energy & Environmental Policy*, Vol. 4, No. 2, pages 5–27, 2015, http://dx.doi.org/10.5547/2160-5890.4.2.cgol. Reproduced by permission of the International Association for Energy Economics (IAEE).

Box 10.1
Past and Current Emissions of Anthropogenic CO_2

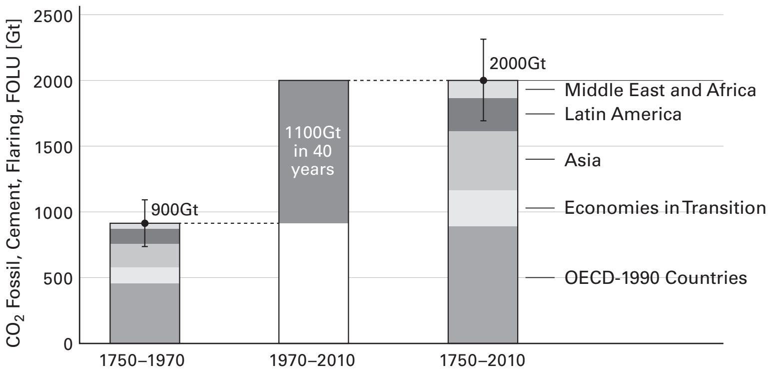

Figure 10.1
Emissions of CO_2 since 1750.
Source: IPCC (2014).

Despite the emergence over the last three decades of solid scientific information about the climate impacts of increased CO_2 concentration in the atmosphere, the world's emissions of GHG have never been larger, rising from 30 $GtCO_2eq$/year in 1970 to 49 $GtCO_2eq$/year in 2010. According to the IPCC, about half of the anthropogenic CO_2 emissions between 1750 and 2010 occurred during the last four decades, due mainly to economic and population growth and to the dearth of actions to fight climate change.

countries accessing Western standards of living. It will require radical transformations in the way we use energy, heat and locate our houses, transport people, and produce goods and services.

Two "Good" Reasons for Inaction

Most benefits of mitigation are *global* and *distant*, whereas costs are local and immediate. The geographic and temporal dimensions of the climate problem account for the current inaction.

Climate change is a global commons problem. In the long run, most countries will benefit from a massive reduction in global emissions of GHGs, but individual incentives to do so are negligible. Most of the benefits of a country's efforts to reduce emissions go to the other countries. In a nutshell, a country bears 100% of the cost of a green policy and receives, say, 1% of the benefits of the policy if the country has 1% of the population and an average exposure to climate-related damages. Besides, most of these benefits, however small, do not accrue to current voters but to future generations.

Consequently, countries do not internalize the benefits of their mitigation strategies, emissions are high, and climate changes dramatically. The free-rider problem is well known to generate the "tragedy of commons" (Hardin, 1968), as illustrated by a myriad of case studies in other realms. When herders share a common parcel of land on which their herds graze, overgrazing is a standard outcome because each herder wants to reap the private benefit of an additional cow without taking account of the fact that what he gains is matched by someone else's loss. Similarly, hunters and fishers do not internalize the social cost of their catches; overhunting and overfishing led to the extinction of species, from the Dodo of the island of Mauritius to the bears of the Pyrenees and the buffalos of the Great Plains. Diamond (2005) shows how deforestation on Easter Island led to the collapse of an entire civilization. Other illustrations of the tragedy of commons can be found in water and air pollutions, traffic congestion, or international security.

Ostrom (1990) showed how small and stable communities are in some circumstances able to manage their local common resource to escape this tragedy, thanks to built-in incentives for responsible use and punishments for overuse. These informal procedures to control the free-rider problem are obviously not applicable to climate change, whose stakeholders include the 7 billion inhabitants currently living on this planet and their unborn descendants. Addressing the global externality problem is complex because there is no supranational authority that could implement the standard internalization approach suggested by economic theory and often employed at the domestic level.[1]

A country or region that would contemplate a unilateral mitigation strategy would be further discouraged by the presence of the so-called "carbon leakages." Namely, imposing additional costs to high-emission domestic industries makes them noncompetitive. This tends to move production to less responsible countries, yielding an international redistribution of production and wealth with negligible ecological benefit. Similarly, the reduction in demand for fossil energy originating from the virtuous countries tends to reduce their international price, thereby increasing the demand and emissions in nonvirtuous countries. This other carbon leakage also reduces the net climate benefit of the effort made by any incomplete club of virtuous countries. Its intertemporal version is called the green paradox. It states that a commitment to be green in the future leads oil producers to increase their production today to cater to today's nonvirtuous consumers. Because carbon sequestration is not a mature technology, mitigation is a threat to the oil rent, and its owners should be expected to react to this threat.

We Must Accept That Climate Mitigation Is Costly in the Short Run

The good news is that an efficient international climate agreement will generate an important social surplus to be shared among the world's citizens. The political economy of climate change, however, is unfavorable: The costs of any such agreement are immediate whereas most benefits will occur in the distant future, mainly to people who are not born yet and a fortiori do not vote. In short, climate mitigation is a long-term investment. Many activists and politicians promote climate mitigation policies as an opportunity to boost "economic growth." The fact that no country (with the exception of Sweden) comes remotely close to doing its share should speak volumes here: Why would countries sacrifice the consumption of goods and leisure to be environment-unfriendly? The reality is bleaker, in particular for economies in crisis and in the developing world. In reality, fighting climate change will imply reducing consumption in the short run to finance green investments that will generate a better environment only in the distant future. It diverts economic growth from consumption to investment, not good news for the well-being of the current poor. Carbon pricing, if implemented, will induce households to invest in photovoltaic panels on their roof or purchase expensive electric cars, actions that yield no obvious increase in their own well-being, to the detriment of spending the corresponding income on other goods.

To be certain, countries may perceive some limited "co-benefits" of climate-friendly policies. For example, green choices may also reduce emissions of other pollutants (coal plants produce both CO_2 and SO_2, a regional pollutant); in a similar spirit, countries may encourage their residents to eat less red meat not so much from a concern about global warming but because they want to reduce the occurrence of cardiovascular diseases. Substituting dirty lignite by gas and oil as the main source of energy had enormous sanitary and environmental benefits in Western countries after World War II, for example by eliminating smog from London. Therefore, *some*

Box 10.2
Climate Change and the Oil Rent

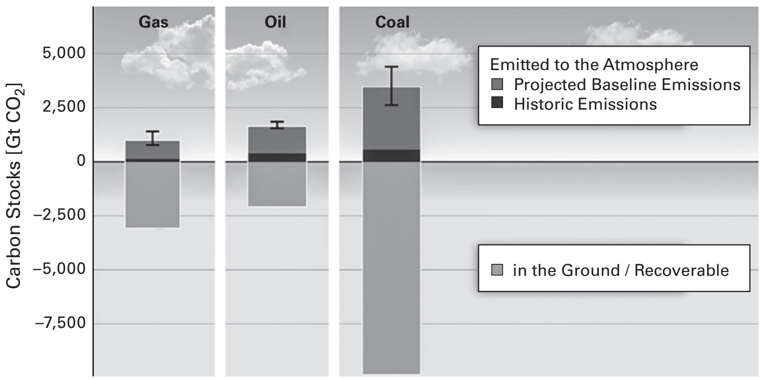

Figure 10.2
Past consumption and current reserves of fossil fuels.
Source: Figure 1.7 in IPCC (2011)—simplified by Working Group 3 Technical Support Unit.

One of the most difficult challenges of climate change comes from the existence of a large fossil fuels rent currently owned by resource-rich countries. This rent exists because of the relative scarcity of the reserve of these non-renewable resources and the expectation of a future exhaustion or at least steeply increasing marginal costs of extraction. The problem is that these reserves are large, as shown in figure 10.2. The cumulated consumption (dark blue) of gas, coal, and oil since the beginning of the Industrial Revolution has been quite limited compared with the stock of these resources. Adding consumption until the end of this century (light blue) in the business-as-usual scenario will still leave most of the stock in the ground. The burning of the entire stock of fossil resources on this planet within the next two centuries or so would certainly devastate our planet by raising GHG concentration way above the acceptable limits. If an efficient and a credible climate policy would be implemented one day, this would imply the annihilation of the fossil fuels rent. Its strategic and geopolitical consequences shed some light on the difficulty to reach an international agreement involving oil-rich countries.

actions are to be expected from countries with an eye on national interest only (not to mention the political benefits of placating domestic and international opinion). But these "zero ambition" actions (to use a phrase coined by Robert Stavins) will be insufficient to generate what it takes to keep global warming manageable.

Overall, fighting climate change yields short-term collective costs, thereby creating a political problem for benevolent decision makers who support an ambitious international agreement. To sum up, without a collective incentive mechanism, one's investment in a responsible mode of living will hardly benefit one's well-being. Rather, and assuming away leakages, it will benefit distant generations who mostly will live in other countries. It is collectively efficient to act but individually optimal to do little.

A Uniform Carbon Price Is Necessary

Economic Approach versus Command-and-Control

As we have discussed, the core of the climate externality problem is that economic agents do not internalize the damages they impose on other economic agents when they emit GHGs. The approach[2] that economists have long proposed to solve the free-rider problem consists of inducing economic agents to internalize the negative externalities they impose when they emit CO_2 ("polluter pays principle"). This is done by pricing it at a level corresponding to the present value of the marginal damage associated with the emission and by forcing all emitters to pay this price. Because GHGs generate the same marginal damage regardless of the identity of the emitter and the nature and location of the activity that generated the emissions, all tons of CO_2 should be priced equally. By imposing the same price to all economic agents around the world, one would ensure that all actions to abate emissions that cost less than that price will be implemented. This least-cost approach guarantees that the reduction of emissions that is necessary to attain the global concentration objective will be made at the minimum global cost. In contrast with this economic approach, "command-and-control" approaches (source-specific emissions limits, standards and technological requirements,[3] uniform reductions, subsidies/taxes that are not based on actual pollution, vintage-differentiated regulations, industrial policy, etc.) usually create wide discrepancies in the implicit price of carbon put on different emissions. This has been shown empirically to lead to substantial increases in the cost of environmental policies.

Western countries have made some attempts at reducing GHG emissions, notably through direct subsidization of green technologies: generous feed-in electricity tariffs for solar and wind energy, bonus-malus systems favoring low-emission cars, subsidies to the biofuel industry, and so on. For each green policy, one can estimate its implicit carbon price (i.e., the social cost of the policy per ton of CO_2 saved). A recent study by the Organization for Economic Co-operation and Development (OECD) (2013) showed that these implicit prices vary widely across countries and also across sectors within each country. In the electricity sector, OECD estimates range from less than 0 to 800 €. In the road transportation sector, the implicit carbon price can be as large as 1,000 €, in particular for biofuels. The high heterogeneity of implicit carbon prices in actual policymaking is a clear demonstration of the inefficiency of this command-and-control approach. Similarly, any global agreement that would not include all world regions in the climate coalition would exhibit the same inefficiency by setting a zero carbon price in nonparticipating countries.

Although economists are broadly suspicious of command-and-control policies for good reasons, they also understand that these policies may occasionally be a second-best solution when measurement or informational problems make direct pricing complex and/or when consumers discount the future too much. This is the classic justification for housing insulation standards for instance, but command-and-control is best avoided when feasible.

Carbon Pricing and Inequality

Income and wealth inequality at the domestic and international levels is often invoked to dismiss uniform carbon pricing. The problems raised by inequality around the world are ubiquitous in analyses of climate change, as discussed by Posner and Weisbach (2010). On the one hand, if poor people emit proportionally more CO_2, carbon pricing will worsen inequality starting today (Cremer et al., 2003). On the other hand, poor people may also be more vulnerable to climate change, so reducing emissions will reduce inequalities in the future. However, because international and national credit markets are imperfect, poor people may face large discount rates, making them short-termist and focused on their immediate survival to the detriment of the long-term climate risk. This means that the social cost of carbon will be smaller in these countries, even when accounting for future damages abroad.

International inequality raises the question of the allocation of the climate-mitigation burden. For example, the principle of common but differentiated responsibility is redistributive because wealthier countries typically contribute more to the accumulation of GHGs in the atmosphere. This issue is certainly important, but its solution should not be found in a Kyoto Protocol-like manipulation of the law of a single carbon price. The non-Annex 1 parties of the Kyoto Treaty had no binding obligation, and their citizens faced no carbon price. This derailed the ratification of the protocol by the US Senate. The Clean Development Mechanism (CDM) designed in Kyoto was aimed at alleviating the imperfect coverage problem; it met with limited success and anyway was not a satisfactory approach due to yet another leakage problem. For example, Annex 1 countries' paying to protect a forest in a less developed country increases the price of whatever the deforestation would have allowed to sell (beef, soy, palm, or wood) and encourages deforestation elsewhere. The CDM mechanism also created the perverse incentive to build, or maintain in operation longer than planned, polluting plants to later claim CO_2 credits for their reduction.[4]

The Kyoto Protocol's attempted solution to the equity problem was to exonerate non-Annex 1 countries from carbon pricing. But using price distortions to reduce inequalities is always a second-best solution. Policies around the world that manipulate agricultural prices to support farmers' incomes end up generating surpluses and highly inefficient productions. The same hazard affects climate policies if one lets redistributive considerations influence carbon price signals to economic agents. At the national level, one should instead use the income tax system to redistribute income in a transparent way when this is possible. At the international level, one should organize lump-sum transfers to poor countries. This can be done by using the revenues generated by carbon pricing. Given that today we emit approximately 50 $GtCO_2$ yearly, a carbon price at \$40/tCO_2 would generate a rent of \$2,000 billion per year, or approximately 3% of the world GDP.

Computing the Right Price Signals

Most infrastructure and R&D investments to reduce GHG emissions have in common that they are irreversible (sunk) costs and yield a delayed reduction of emissions over an extended time span. Energy retrofit programs for residential building reduce emissions for decades, and hydroelectric power plans last for centuries. As a consequence, what triggers an investment in these sectors is not the current price of CO_2 but the expectation of high prices in the future. The right price signal is thus given by an entire path of carbon prices. Two factors call for a carbon price that is increasing with time. First, if the damage function is convex, our inability to stabilize the concentration of CO_2 within the next 100 years would imply that the marginal climate damages of each ton of CO_2 will rise in the future. Second, if we impose a cap on GHG concentration in the atmosphere that we should never exceed, then the determination of the optimal emission path under this maximum quantity constraint is equivalent to the problem of the optimal extraction path of a nonrenewable resource. From Hotelling's rule, the carbon price should then increase at the risk free rate (Chakravorty et al., 2006). Any climate policy must also address the various commitment and credibility problems associated with the fixation of the long-term carbon price schedule. This challenge is reinforced by the current uncertainties affecting the marginal damage function, the optimal GHG concentration target, and the speed at which green R&D will produce mature low-carbon energy technologies. This question is addressed later.

Over the last two decades, governments have commissioned estimates of the social cost of carbon (SCC). In France, the Commission Quinet (Quinet, 2009) used a real discount rate of 4% and recommended a price of carbon (/tCO_2) at 32 € in 2010, rising to 100 € in 2030 and between 150 € and 350 € in 2050. In the United States, the US Interagency Working Group (2013) proposed three different discount rates (2.5%, 3%, and 5%) to estimate the SCC. Using a 3% real discount rate, their estimation of the SCC is $32 in 2010, rising to $52 and $71, respectively, in 2030 and 2050.

Two Economic Instruments for Price Coherence

Two prominent strategies for organizing an efficient, uniform pricing of CO_2 emissions involve a carbon price and a cap-and-trade mechanism, respectively.[5] Both proposals allow subsidiarity, and neither directly

Box 10.3
The Social Cost of Carbon

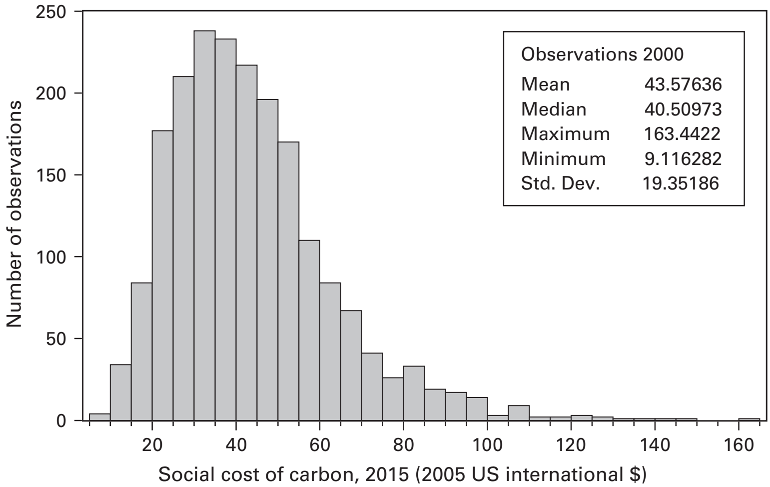

Figure 10.3
Density function for the SCC (in $/tC).
Source: Nordhaus (2011).

Although the fifth report of the IPCC (IPCC, 2014) does not contain much information about it, there is now a sizable literature on the social cost of carbon. To send the right signal to economic agents, the carbon price must be equal to the present value of the marginal damages generated by the emission of one more ton of CO_2. Estimating the SCC is complex because most of these damages will materialize only in the distant future and are uncertain. The time and risk dimensions raise the problem of the choice of the discount rate. If future climate damages were statistically independent of world GDP growth, a relatively low real discount rate of 1% should be used to discount these damages to the present (Gollier, 2012; Weitzman, 1998, 2001). However, most standard integrated assessment models such as the DICE model are such that climate damages are positively linked to consumption growth (Dietz et al., 2015). For example, Nordhaus (2011) uses the outcome of Monte-Carlo simulations of the RICE-2011 model with 16 sources of uncertainty to conclude that "those states in which the global temperature increase is particularly high are also ones in which we are on average richer in the future." Using technical terms from finance theory, this implies that the climate consumption-based CAPM beta is positive and the relevant climate discount rate is closer to the mean return of equity than the risk-free rate (Gollier, 2014).

To illustrate the uncertainty affecting the SCC, we reproduce in figure 10.3 an analysis performed by Nordhaus (2011). He used his RICE integrated assessment model with uncertain parameters related to the discount rate and the climate sensitiveness. Figure 10.3 reproduces the density function for the SCC of 2015, expressed in dollar per ton of carbon. Notice that 1 ton of carbon generates 3.7 tons of CO_2, so that the Nordhaus's mean estimate of the SCC at \$44/tC corresponds to \$12/tCO_2, which is considered relatively small compared with other estimates existing in the literature.

concerns national taxes or national cap-and-trade. Both rely on an international agreement that is reasonably encompassing and therefore on an "I will if you will" approach discussed in this book. They both require some strategy for enforcement; indeed, the implementation of credible and transparent mechanisms to measure emissions is a prerequisite to any efficient approach to climate change mitigation or, for that matter, to any policy.

Carbon price Under the first strategy, a minimum average price by country on all emissions around the world would be agreed on and collected by individual countries. All countries would be using the same price for GHG emissions.[6] The carbon price of a country would be computed as the carbon revenue divided by the country's emissions; the price could correspond to a carbon tax[7] in the special case of a taxation approach, but quite generally it could emerge from a variety of policies (tax, cap-and-trade, standards, etc.). Indeed, not all emissions in practice are subject to a carbon tax or Emission Trading Scheme (ETS) price. As Cooper (chapter 5, this volume) notes, less than half of the European emissions are subject to EU ETS trading.

An international negotiation on a global carbon price has the advantage of linking each region's mitigation effort to the efforts of the other regions. As explained in Cramton, Ockenfels, and Stoft (chapter 12, this volume) and Weitzman (chapter 8, this volume), each country will internalize in its vote for the level of a uniform price the positive impact of a larger equilibrium price on the global reduction of emissions, thereby raising the potential ambition of the international agreement. Under this scheme, a supranational supervision of the national carbon-pricing requirement at the internationally agreed level is thus necessary, as we discuss later. The compensation issue would be dealt with through a green fund.

Cap-and-trade Under the alternative cap-and-trade strategy, the agreement would specify a worldwide, predetermined number (the cap) of tradable emission permits. The tradability of these permits would ensure that countries face the same carbon price, emerging from mutually advantageous trades on the market for permits; the cross-country price here would not result from an agreed-on price of carbon but rather from clearing in this market. To address compensation, permits would be initially allocated to the different countries or regions, with an eye on getting all countries on board (redistribution).

Failed or Unsatisfactory Attempts at Pushing the Economic Approach

The cap-and-trade system was adopted, albeit with a failed design, by the Kyoto Protocol. The Kyoto Protocol of 1997 extended the 1992 UNFCCC that committed participating countries to reduce their GHG emissions. The Treaty entered into effect on February 16, 2005. The Annex-B parties committed to reduce their emissions in 2012 by 5% compared with 1990 and to use a cap-and-trade system. Kyoto participants initially covered more than 65% of global emissions. But the nonratification by the United States and the withdrawal of Canada, Russia, and Japan, combined with the boost of emerging countries emissions, reduced the coverage to less than 15% in 2012. The main real attempt to implement a carbon pricing mechanism within the Kyoto agreement emerged in Europe, with the EU ETS. In its first trading period of 2005–2007 ("phase 1"), the system was established with a number of allowances (the so-called Assigned Amount Units [AAUs]) based on the estimated needs; its design was flawed in many respects and in any case far inferior to that which had been adopted in the United States in 1990 to reduce SO_2 emissions by half. In the second trading period of 2008–2012, the number of allowances was reduced by 12% to reduce the emissions of the industrial and electricity sectors of the Union. This crackdown was offset by the possibility given to the capped entities to use Kyoto offsets (mostly from the CDM described earlier) for their compliance. In addition, the deep economic crisis that hit the region during the period reduced the demand for permits. Moreover, large subsidies in the renewable energy sector implemented independently in most countries of the

Union reduced further the demand for permits. In the absence of any countervailing reaction on the supply of permits, the carbon price went down from a peak of 30 €/tCO_2 to around 5€/tCO_2 today. This recent price level is without a doubt way below the social cost of carbon. Therefore, it has a limited impact on emissions. It even let electricity producers substitute gas by coal, which emits 100% more carbon (not counting dirty microparticles) per kWh. An additional problem came from the fact that the ETS covered only a fraction of the emissions of the region. Many specific emitters (e.g., the transport and building sectors) faced a zero carbon price. During the third trading period (2013–2020), the EU-wide cap on emissions is reduced by 1.74% each year, and a progressive shift toward auctioning of allowances in substitution of cost-free allocation is implemented.

Over the last three decades, Europeans have sometimes believed that their (limited) commitment to reduce their emissions would motivate other countries to imitate their proactive behavior. That hope never materialized. Canada, for example, facing the prospect of the oil sands dividend, quickly realized that their failure to fulfill their commitment would expose them to the need to buy permits[8] and preferred to withdraw before having to pay them. The US Senate imposed a no-free-rider condition as a prerequisite for ratification, although the motivation for this otherwise reasonable stance may well have been a desire for inaction in view of a somewhat skeptical public opinion. Sadly enough, the Kyoto Protocol was a failure. Its architecture made it doomed to fail. Nonparticipating countries benefited from the efforts made by the participating ones, in terms of both reduced climate damages (free-rider problem) and improved competitiveness of their carbon-intensive industries (carbon leakage).

Other cap-and-trade mechanisms have been implemented since Kyoto. A mixture of collateral damages (we mentioned the emissions by coal plants of SO_2, a local pollutant, jointly with that of CO_2), the direct self-impact of CO_2 emissions for large countries like China (which has 20% of the world population and is exposed to serious climate change risk), and the desire to placate domestic opinion and avoid international pressure all lead to *some* carbon control. Outside the Kyoto Protocol, the United States, Canada, and China established some regional cap-and-trade mechanisms. In the United States, where per capita GHG emissions are 2.5 times larger than in Europe and China, two initiatives are worth mentioning. In the Regional Greenhouse Gas Initiative (RGGI), nine Northeast and Mid-Atlantic US states

Box 10.4
CO_2 Price on the EU ETS Market

Figure 10.4
Evolution of carbon price on the EU ETS.
Source: Climate Economics Chair from ICE ECX data.

Figure 10.4 illustrates the failure of the EU ETS to establish a stable and an ambitious carbon price in the EU. The instability of the Kyoto coalition is one plausible explanation for why the EU did not attempt to push the price of permits up on the ETS market after the failure of the Copenhagen Conference in December 2009 in a depressed economic environment.

created a common cap-and-trade market to limit the emissions of their electricity sector. Here also, the current carbon price is way too low at around \$5/tCO_2 (up from the price floor level of \$2/tCO_2 during 2010–2012). From 2015 to 2020, the CO_2 cap will be reduced by 2.5% every year. The system will release extra carbon allowances if the carbon price on the market exceeds \$6/tCO_2. A similar system exists in California to cover the electricity sector, large industrial plants, and more recently fuel distributors, thereby covering more than 85% of the State's emissions of GHGs.[9] In 2014, China established seven regional cap-and-trade pilots officially to prepare for the implementation of a national ETS. The fragmented cap-and-trade systems described earlier cover almost 10% of worldwide emissions, and observed price levels are low. This is another illustration of the tragedy of commons.

These regional or national ETSs could be used in the future under any international commitment regime, either a universal carbon price or a cap-and-trade mechanism.

Some countries have implemented a carbon tax. The most ambitious country is Sweden, in which a carbon tax of approximately 100 €/tCO_2 was implemented in 1991. France recently set its own carbon tax at 14.5 €/tCO_2. Both of these taxes are used for various purposes, such as raising revenue or addressing congestion externalities and road safety. They also now can be used to comply with an international commitment to cap-and-trade or to a carbon price. Outside Europe, some modest carbon taxes exist in Japan and Mexico, for example. Except for the Swedish case, these attempts put a carbon price that is far too low compared to the SCC.

Pledge-and-Review: The Waiting Game in the Current International Negotiation

The Copenhagen conference in December 2009 was expected to deliver a new Kyoto Protocol with more participating countries. In reality, the conference delivered a completely different project. The central idea of a unique carbon price induced by international cap-and-trade was completely abandoned, and the secretariat of the UNFCCC became a chamber of registration of noncommittal pledges by individual countries. This change of vision was upheld at the Cancun Conference in 2010 and more recently at the COP 20 in Lima in 2014. The new "pledge-and-review" approach was employed at the Paris COP 21 conference in December 2015. The so-called "Paris Agreement" will be implemented as soon as more than 55 parties to the agreement representing more than 55% of global emissions will have ratified the agreement. Voluntary climate actions (or "intended nationally determined contributions") will be registered without any coordination in the method and in the metric of measurement of the ambition of these actions. Although they are crucial to the credibility of the system, the reporting on and verification of the pledges were not formally decided.[10]

The pledge-and-review strategy has four main deficiencies and definitely is an inadequate response to climate change. First, if implemented, the agreement yields an inefficient allocation of efforts by inducing some economic agents to implement high-cost mitigation actions while others will emit GHGs that would be much cheaper to eliminate.[11] Because the marginal costs of emission reduction are likely to be highly heterogeneous within and across countries, it will be almost impossible to measure the ambition of each country's pledge. In fact, individual countries have a strong incentive to "green wash" their actions by making them complex to measure and price.

Second, the pledge-and-review promises, even if they were credible, are voluntary, so free-riding is bound to prevail. These pledges are expected to deliver much less effort than would be collectively desirable. Following Buhr et al. (2014), "pledge-and-review means that climate change is dealt with the lowest possible level of decision making." As Stiglitz (chapter 6, this volume) notes, "in no other area has voluntary action succeeded as a solution to the problem of undersupply of a public good." In a sense, the pledge-and-review process is similar to an income tax system, in which each household would be allowed to freely determine its fiscal contribution.

Third, even if the pledges were large enough to put the global emission trajectory back on track, the absence of commitment to the pledges would limit their long-term credibility. This fragility makes it tempting for countries to deviate from their pledges. The absence of credibility of long-term pledges will reduce the innovators' incentive to perform green R&D and implement mature technologies, yielding reductions of emissions for a long period of time.

Fourth, the pledge-and-review regime can be analyzed as a waiting game, in which the global negotiation on formal commitments is postponed. Under the Paris Agreement (articles 4 and 14), the parties will meet every five years starting in 2023 to renegotiate their pledges, hopefully in a more ambitious manner. Beccherle and Tirole (2011) show that the free-riding in this waiting game is magnified by the incentive to achieve a better deal at the bargaining table in the future. Building on both theory and past experiences, countries will realize that staying carbon-intensive will put them in a strong position to demand compensation to join an agreement later: the carbon-intensity of their economy making them less eager to join an agreement, the international community will award them higher transfers (either monetary or in terms of free pollution allowances) so as to bring them on board. Moreover, when the damage function is convex, a country committing to a high emission level before this negotiation raises the marginal damages of all other countries and therefore induces them to reduce their emissions more heavily. All in all, these strategic considerations increase the cost of delay beyond what would be obtained in the traditional free-riding model with no expectation about a future negotiation.

Indeed, there has been concern that the current pledges are at a "zero ambition" level, or perhaps even below that level, where "zero ambition" refers to the level that the country would choose simply because of co-damages (local pollutants) and the direct impact of GHG on the country, that is, in the absence of any international agreement.

To conclude this section on a more positive note, the pledge-and-review process might be useful in the second half of this year, provided that (1) ambitions turned out to be strong enough (a big "if" at this stage), and (2) one were to call the countries' bluff and transform or modify their pledges into real commitments. Suppose indeed that the various pledges are in line with a reasonable trajectory for GHG emissions (asserting this requires being able to aggregate/compare the various pledges, as some concern mitigation and others adaptation, and current pledges have rather different time horizons). One could then transform the predicted global trajectory of emissions into an equivalent number of permits; in a second stage, one could allocate permits under the requirement so that countries receive the same welfare as they would if their pledge were implemented. Countries that are sincere about their pledge could only gain from having all countries commit.

Negotiating a Price/Quantity and Negotiating Transfers

Let us now turn to the more satisfactory approach of picking an economic instrument together with measurement and enforcement strategies.

The One-Dimensional Negotiation: Uniform Carbon Price or a Global Emission Target

We can imagine two negotiation processes "I will if you will" with only one decision variable. Negotiators could try to agree on either a universal carbon price or a global emission target. For the sake of the argument, suppose first that all countries were similar in terms of their exposure to climate change, degree of development, endowment in natural resources, tastes, and so on. The free-rider problem inherent to the international negotiation on climate change could then be resolved by negotiating a uniform carbon price.[12] Under this negotiation framework, a "world climate assembly" would vote for a uniform carbon price whose implementation would be left to its individual members. The claimed virtue of this framework is to align the constituents' private interests. Let us illustrate this claim with an example inspired from Cramton, Ockenfels, and Stoft (chapter 12, this volume). Suppose that the world is composed of 100 countries with the same characteristics (population, economic prosperity, growth expectations, industrial structure, etc.). Each ton of CO_2 in the atmosphere generates \$1 of damage in each country. The business-as-usual scenario yields a uniform emission of 10 tCO_2 per capita. Suppose also that 80% of each country's emission can be eliminated at a unit abatement cost of \$50/tCO_2. The abatement cost of the remaining 20% is \$200/tCO_2. In this context, it is desirable that each country abates its emissions by 80% because the global damages of \$100/tCO_2 exceed the cheaper marginal abatement cost of \$50/tCO_2. But the tragedy of commons would prevail in the absence of a binding international agreement because the marginal abatement cost is 50 times larger than the local marginal damages. Suppose that the 100 countries accept to join an international coalition in which they cooperate to enforce the domestic imposition of an internationally harmonized carbon price that is voted by a majority rule. Participants are required to impose the common price as long as all signatories do too. The domestic revenues of the scheme are recycled internally. In this framework, all countries will be in favor of a carbon price of, say, \$100/tCO2, which will induce them to abate their emissions by 80%. This dominant strategy yields the first-best solution and makes all countries better off.

As Cramton and Stoft (2012) point out, an equivalent negotiation process exists that is based on quantities. Suppose that all countries in the coalition accept to negotiate a uniform emission per capita that is voted on by a majority rule. The same subsidiarity rule applies for which green policy should be implemented to attain the national target, and countries are allowed to trade their emissions with others. In this alternative framework, all countries will understand the benefit of imposing an ambitious target for themselves as long as the other countries do the same. It is an optimal for each country to vote for an 80% reduction of emissions. In this example, the two negotiation mechanisms yield the same efficient solution and have the same simple structure of a one-dimensional negotiation, on either a uniform price or a uniform per capita quantity.

Alas, the real world does not look at all like this description. Indeed, countries differ markedly by their exposure to climate change, abatement costs, economic dependence to fossil fuels, willingness to invest in the future, emissions per capita, and so on. These sources of heterogeneity of costs and benefits make the negotiation dramatically more complex.

Consider, for example, the case in which only 10 of the 100 countries are responsible for all emissions. The other countries emit nothing. Under the uniform price mechanism as under the quantity mechanism, conditional on all countries ratifying the treaty, the median voter will be in favor of a \$200/tCO_2 and a zero-emission target for all countries, respectively. This example illustrates two difficulties with the two simple negotiation mechanism examined in this section. First, in line with Weitzman's (chapter 8, this volume) result, there is too much abatement at equilibrium, so these mechanisms do not guarantee a first-best solution.[13] Second, the 10 high-emission countries are likely to quit the coalition because they bear all the cost of mitigation and receive a tiny fraction of the benefits. In economics parlance, their participation constraint is binding. This is why the economists supporting a price negotiation recognize that, due to the heterogeneity among countries, the system is feasible only if some mechanism for side transfers (such as a green fund or an allocation of permits) is designed so as to bring the reluctant countries on board. We concur. Observe that the sizes of the transfers from the 90 green countries to the 10 others that would induce the latter to participate are exactly the same for the two negotiation mechanisms.

Unfortunately, but unavoidably, the green fund (under a carbon price) or the unequal allocation of permits (under cap-and-trade) destroys the simplicity of a single-dimensional negotiation. The green fund must set the net (positive or negative) transfer to the fund for each country and therefore involves dimensionality n + 1 (the number of countries, n, plus 1, the carbon price). In the cap-and-trade mechanism, an unconstrained allocation of permits yields the same dimensionality (n allowances, plus the carbon price). This sharp increase in dimensionality can be avoided by adopting a common formula as the Kyoto negotiators attempted to do. Cramton and Stoft (2012) propose doing this and argue that, by making this the first stage of a two-stage negotiation, countries would find it easier to agree (more on this below).

Summing up, whether the international architecture adopts a uniform carbon price or a cap-and-trade mechanism, cross-country transfers will thus be needed so as to bring reluctant countries on board. As we just discussed, under the carbon pricing approach, the proposed transfer mechanism is to use a fraction of the collected revenue to help developing countries adopt low-carbon technologies and adapt to climate change. This is illustrated by the green fund, which was created at the COP-15 of Copenhagen in 2009. Under a cap-and-trade protocol, transfers operate through the distribution of free permits.

Either way, the design of compensation poses a complex problem: each country will want to pay the smallest possible contribution to the green fund or receive the maximum number of permits.[14] This negotiation is complex and of course a major impediment to reaching an agreement on a carbon tax or a cap-and-trade. However, it must be realized that most international negotiations involve give-and-take, and there have been successful negotiations in the past. A case in point is the 1990 Clean Air Act Amendment in 1990. This arrangement was not imposed by a centralized authority but rather was the outcome of a protracted negotiation, in which the Mid-west states, high emitters of SO_2 and NO_x, delayed jumping on board until they received sufficient compensation (in the form of free permits in that case).[15]

Simplifying the Compensation n-Dimensional Negotiation (Green Fund or Allocation of Permits)

Transparency considerations A green fund may be too transparent to be politically acceptable. The transparency argument requires further thought, but experience here suggests a serious concern. The Green Climate Fund established at COP-16 aims at a *flow* transfer of $100 billion per year by 2020, and four years later had received promises of less than $10 billion in *stock*.[16] As is known from other realms (such as humanitarian relief after a natural disaster or health programs in developing countries), parliaments are known to be reluctant to appropriate vast amounts of money to causes that benefit foreigners. Even successful programs such as the Vaccine Alliance GAVI—which involves a much smaller amount of money—took off only when the Bill & Melinda Gates Foundation brought a substantial financial commitment. Politicians often pledge money at international meetings, only to downsize or renege on their pledge. Substantial free-riding is expected to continue, jeopardizing the build-up of the green fund. In Article 9 of the Paris Agreement, the developed world promised nothing more than to "continue to take the lead in mobilizing climate finance," and this mobilization will "represent a progression beyond previous efforts," whatever that means. Strikingly, the promise is a collective one, which therefore commits no one.

We believe that the transparency issue is one of the reasons that many pollution-control programs around the world adopted cap-and-trade and handled the compensation issue through the politically less involved distribution of tradable permits (often in a grandfathered way). The large transfers to the Midwest implied by the 1990 Clean Air Act Amendment never really made the headlines. To be certain, the transfers made under national cap-and-trade programs are different in their economic and political nature from international payments for international permits; however, in the EU ETS, billions of euros could have been potentially transferred to Eastern European and former Soviet Union countries ("Hot Air") through the allocation of permits in order to convince them to sign the Kyoto Protocol.[17]

The strength of the opaqueness argument in favor of the allocation of permits remains to be tested, and no one has the answer as to whether it would work for climate change. On the one hand, transfers associated with an allocation of free permits are not that hard to compute, and one would imagine that politicians (privately or publicly) opposed to an ambitious climate change agreement would quickly publicize the numbers (if unfavorable to the country) so as to turn their domestic public opinion against the agreement. In fact, the public uproar over the sale of Hot-Air AAUs was such that the UN was forced to restrict their sale. On the other hand, some of the cap-and-trade transfers failed to make the headlines in the past. The jury is still out on this question.

Finally, it should be noted that countries routinely transfer a sizeable fraction of their GDP to foreign investors in reimbursement of their sovereign debt. It would be useful to have estimates of likely shortfalls/surpluses of permits (which of course depend on the initial distribution) so as to have a better assessment of the sums involved.

Reducing the dimensionality of the compensation negotiation Rich and poor countries have always had opposite views on the compensation issue.

Developing countries correctly emphasize ethics and their desire to develop, whereas in the past rich countries were allowed to develop without being hindered by environmental concerns; they demand equal rights per capita or a variant of it. Rich countries invoke Realpolitik and explain that they will not get on board unless permits are grandfathered (as they were in many other instances), or they will contribute only modestly to the green fund. The developing countries' being morally right does not mean they should overstress the equity concern for their own sake; inducing the rich countries to refuse to get on board will make poor countries much worse off. The politics of negotiations are not always aligned with the ethical view, unfortunately; in the driver's seat lay the countries with a high-projected GDP (they will be the high polluters), those with a high abatement cost, and finally those that will suffer the least—or even slightly gain from—global warming. These countries have low incentives to get on board. The Paris Agreement is particularly weak on this by stating, "developing country Parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction [...] in the light of differential national circumstances" (article 4).

The green fund allocation or the formula for the allocation of free permits in the cap-and-trade approach must be acceptable by all.[18] The expectations must also be convergent, and unrealistic demands are to be avoided. Rich countries must be much less selfish and accept to bear a large share of the burden (in reality and not through cheap pledges as they sometimes do). Conversely, a common per capita emission is a complete nonstarter for the developed world. This would involve massive wealth transfers to the less-developed world. As Cramton et al. (2013, chapter 12 in this volume) stress furthermore, the basis for the determination of such transfers is unclear; developed countries will argue that although they are responsible for anthropogenic global warming so far, they also have developed numerous technologies (medical, agricultural, communications, etc.) that are benefiting the less-developed countries. Such an acrimonious debate is unlikely to foster a decent solution to climate change. Moreover, the inconsistent expectations that we observe today are, needless to say, dangerous. As in the case of an impending war, we hope that the various sides will become more reasonable and come to terms with the huge collective gains from reaching an ambitious agreement.

Freestyle negotiations among n countries are exceedingly complex. They are likely to lead to a deadlock, whether the countries negotiate about who will be a contributor or a recipient (and by how much) of the green fund or the allocation of free permits among countries under cap-and-trade. There is a complex trade-off between a simple rule, which prevents individual countries from demanding a special treatment, and a more complex rule, which better accounts for individual willingness to get on board but also make the negotiation captive of specific demands.

To illustrate this, consider the following (simple) rule, which reflects the trade-off described earlier between ethics and Realpolitik in the case of a common carbon price approach. The transfer scheme in this approach is based on a green fund. Cramton, Ockenfels, and Stoft (chapter 12, this volume), Weitzman (chapter 8, this volume), and De Perthuis and Jouvet (2015) propose to finance the green fund on the basis of a one-dimensional bonus-malus system where countries whose per capita emissions lie above a predetermined threshold would transfer funds to countries whose emission is below the threshold. More specifically, let p_i and P denote country i's and the world's populations, and let x_i and $X = \sum_{i=1}^{n} x_i$ denote the current emissions of country *i* and the world. The contribution C_i to the green fund by country *i* would then be determined as follows:

$$C_i = g\left(x_i - p_i \frac{X}{P}\right), \tag{1}$$

where g is a generosity parameter (i.e., how many dollars are transferred per ton of excess emission). Note that the sum of these contributions is equal to 0, as it should.

In a cap-and-trade approach, the transfer is implicit in the allocation of free permits. For conciseness, we state it in terms of intertemporal (total) pollutions. Let q_i denote country *i*'s number of free permits and $Q = \sum_{i=1}^{n} q_i$ denote the total number of permits (as discussed earlier, Q would be computed so as to contain the temperature increase to 2°C). With grandfathering coefficient $\hat{g}$ in [0, 1], the free permits would be allocated according to formula:

$$\frac{q_i}{Q} = \hat{g}\frac{x_i}{X} + (1-\hat{g})\frac{p_i}{P}. \tag{2}$$

Box 10.5
Per Capita Emissions

Table 10.1
National Emissions per Capita in 2011.

Country	tCO_2/cap
Uganda	0.11
Republic of the Congo	0.53
India	1.70
Brazil	2.23
World	4.98
France	5.19
China	6.71
Germany	8.92
Japan	9.29
Russian Federation	12.65
United States	17.02
Qatar	43.89

Source: World Bank.

One of the most challenging aspects of the international negotiation on climate change is the extremely heterogeneous per capita emissions of CO_2, from around 0.1 tCO_2 in the poorest countries to 17 tCO_2 in the United States (table 10.1). The principle of common but differentiated responsibility has many possible interpretations in this unequal world, which has had disruptive effects on the negotiation process since 1992. Because emissions per capita and GDP per capita are strongly positively correlated, the international negotiation on climate change cannot be disconnected from the problems of economic development and worldwide inequalities.

So, the ethical approach prevails if $\hat{g}$ is close to 0, and the Realpolitik concerns are reflected by a large $\hat{g}$ value.

There are many potential criticisms to and improvements on such formulae. For instance, the formulae need not hold in each year but only overall. Under cap-and-trade, developing countries' endowment might be backloaded so as to avoid a situation in which initially they are in expectation big net suppliers of permits in the market for allowances.

But the point we want to make here is that such rules may be a bit too simple. Realpolitik suggests accounting at least somewhat for the exposure to climate change, even if this may be rather unfair. Countries such as Canada and Russia may not get on board under formula (1) or (2), whereas other high-income, high-pollution countries would, provided that the generosity coefficient g is not too high or the grandfathering coefficient $\hat{g}$ not too low.

Price versus Quantity

Given that the pledge-and-review approach was still favored by policymakers at the COP 21, it may be premature to enter the intricacies of "prices versus quantities" (to use Weitzman's 1974 terminology) or "carbon price versus cap-and-trade" (by cap-and-trade we mean the setting of a global volume of emissions, not of individual countries' targets, which would be highly inefficient). We feel that either approach clearly dominates the current alternative. Besides, the question is far from being settled among economists. However, because post-COP 21 negotiations need to be engaged quickly, it is important to discuss these second-stage issues right away.

The choice of instruments has two dimensions: the purely economic question of which system best accommodates scientific and demand uncertainty, a complex question that was treated at a theoretical level in Weitzman's article but on which limited empirical evidence is available[19]; and a political economy dimension, on which we now focus.[20]

On the political economy front, of which we developed one dimension (the transparency of transfers) earlier, we would like to make two points. First, like for any other public policy, international commitments must be feasible; that is, its implementation must not be prevented by the lack of information.

Second, and perhaps more controversially,[21] one may want to leave scope for national policies, although we know that these policies may then deviate from least-cost abatement. Imagine, for instance, that some countries with limited tax-collection-and-redistribution capabilities would want to opt for a low carbon price on cement to make housing affordable to the poorest; then they would want to deviate from the single-price rule; to be certain, governments may be weak and grant excessively low carbon prices to some lobbies, but this is by and large a matter of domestic politics (unless the practice is so widespread that it becomes unlikely that the country will abide by its overall commitment, whatever the agreement is). The rationale for subsidiarity is twofold. First, it gives leeway for governments to convince their domestic opinion (or themselves). Second, other countries care only about how much CO_2 is emitted by the country, not how the number came about.

The Enforceability Problem

Enforcement under a carbon-price commitment

Price implementation. Carbon-pricing proposals allow a large array of regulatory mechanisms that get carbon-pricing credit. To fulfill their price commitment, countries could levy a carbon tax or set a cap-and-trade system and value carbon permits at their market price. Some countries' carbon price will also reflect their green standards (with an implicit carbon value) or count their public investments that have an impact on emissions. Under the principle of subsidiarity, we believe that all these actions should indeed be accounted for to determine the national carbon price, which is the ratio of the carbon revenue over the carbon emission.[22] The net effect is to generate efforts to curb national emissions.

Because most of the climate benefits of this policy accrue abroad, countries currently have no incentive to impose strict carbon usage constraints on their citizens, firms, and administrations; and by and large, except for Sweden, they do not. This will also be the case under any international agreement. Thus, even if enforcement were costless, authorities would still turn a blind eye on certain polluters or underestimate their pollution, thereby economizing on the cost of green policies. This form of moral hazard is particularly hard to avoid in countries that are on the spending side of the compensation scheme (say the green fund), but it also applies to countries on the receiving side, which could be threatened by a withholding of transfers in case of noncompliance. To envision the difficulties faced by the monitoring of compliance, one can refer to the current debate on poor tax collection in Greece.[23] To sum up, the imposition of a common carbon price faces the standard free-rider problem, with local costs and global benefits. Its management requires a strong international monitoring system.

Undoing. Second, another form of moral hazard consists of undoing the carbon tax through compensating transfers; presumably the countries would do this in an opaque way so as not to attract the attention of the international community.

Monitoring local externalities associated with fossil fuels. Burning fossil fuels generates various local externalities, such as the emission of nanoparticles (cardiovascular diseases, asthma, etc.), and, in the case of gasoline, road congestion and the deterioration of road infrastructure. This justifies specific Pigovian taxes whose level depends on the density of population, the value of life, the burning technology, or the average atmospheric conditions, for example. Countries also take advantage of the relative inelasticity of demand to raise revenue. Proponents of the carbon-price approach propose a "zero baseline" in defining the carbon price. That is, they define the carbon price to include all taxes and subsidies on each fossil fuel on each market, implicitly ignoring all other externalities or more generally other motivations for taxing fossil fuels. One problem with this pragmatic strategy is that these other Pigovian prices differ much around the world. Take again gasoline taxation: the distribution of the price of the liter of gasoline at the pump around the world has huge variance: 2 cents in Venezuela, 97 cents in the United States, and 209 cents in Belgium.[24] Under the previously mentioned definition, imposing the same "carbon price" at the world level forces all countries to price local externalities and embody revenue concerns equally, a contradiction with the basic idea of subsidiarity. Monitoring this by the international community is a serious challenge.

Nonprice policies. Third, the carbon-price approach requires finding conversion rates for various policies that impact climate change but are not subject to an explicit price, such as road and housing construction standards, no-till farming, or afforestation and reforestation. These conversion rates may need to be country-specific: a construction standard will impact GHG emissions differently depending on the country's climate; similarly, afforestation may increase rather than decrease emissions in high-latitude areas, in which trees may cover (high-albedo) snow.

Enforcement under a cap-and-trade mechanism Enforcing an international quantity mechanism is relatively straightforward when countries, rather than economic agents, are liable for their national emissions. The anthropogenic emissions of CO_2 by a nation can be derived from a simple carbon accounting by adding extraction and imports and by subtracting exports and the variation of stocks. Carbon sinks from forests and the agricultural sector can already be observable by satellite. Experimental projects from the National Aeronautics and Space Agency (NASA) and the European Space Agency (ESA) to measure the global emission of CO_2 at the country level are promising in the long run.[25] We believe that monitoring the country's CO_2 emissions is easier than monitoring emissions at the point source. Like for existing cap-and-trade mechanisms, agents (here countries) with a shortage of permits at the end of the year would have to buy extra permits, whereas those with a surplus would sell or bank them.

There is one concern about permit trading among nations: some countries (one has in mind China and the United States here) may well enjoy market power due to their share of world emissions. This is a potentially serious issue, which requires oversight and offers some similarity to the control of market power in production or financial rights over transmission on a power grid.[26] In particular, one would want countries to be as close as possible to zero net supply so as to reduce their incentive to affect the world price for permits by restraining the demand or supply.

Price Volatility Under a Carbon Price and Under Cap-and-Trade

Attention should be paid to the question of how to *accommodate uncertainty*. A cap-and-trade approach would compute and issue a worldwide number of permits consistent with the 2°C target. However, there is scientific uncertainty about the link from emissions to global warming. There is also uncertainty about the abatement technology, consumer demand, and so forth. So the number of permits will probably have to be adjusted over time. The market price of permits will be volatile (although presumably less so than under the flawed and unstable attempts at pricing CO_2 so far).[27]

The same concern holds for a carbon price. Due to the same sources of uncertainty, there is no guarantee that the price will initially be set at the "right level," consistent with the overall global warming target. Thus, the tax will need to be adjusted over time as well.

More generally still, any proposal must confront the volatility question because price volatility is likely to be unpopular. One possibility, which a priori does not require public intervention, is to transfer risk through hedging instruments to those who can bear that risk more easily. Another complementary approach is to intervene in markets to stabilize prices. For example, in 2014, the European Commission proposed a "Market Stability Reserve," in which the auction volumes will be adjusted in phase 4 of the EU ETS starting in 2021, so as to create a soft target corridor for banking of EU Allowance units (EUAs). The mechanism will reduce the amount of EUAs that are auctioned if an upper threshold of EUAs in circulation is exceeded and releases them if the EUAs in circulation fall short of a lower threshold. This scheme is meant to be automatic, but its efficiency can be questioned.[28] In particular, one can wonder how it can be made responsive to news in a way that guarantees that the 2°C target is reached. This brings us to the question of the trade-off between flexibility and commitment.

The Potential Time Inconsistency of Carbon-Price and Cap-and-Trade Policies

Whether one opts for a carbon price or for cap-and-trade, one should be concerned by the possibility that, conditional on the accruing news about the climate change process, technology, or demand, the ex-post adjustment be too lax (too low a carbon price, too high a number of tradable permits). To understand why, note that the carbon-price or tradable rights path is designed so as to incentivize long-term investments: in carbon-light housing, transportation infrastructures or power plants, and in green R&D. Ex-post price incentives have served their purpose and now impose undue sacrifices; put differently, optimal environmental policies are not time-consistent. Furthermore, the possibility of administration turnover or news about other aspects (say, public deficit or indebtedness, economic opportunities) may transform climate policy into an adjustment variable, adding to the overall time inconsistency.

This time inconsistency is studied in Laffont and Tirole (1996a, 1996b), who look at the optimal mechanism designed by a centralized authority (the world's nations here) when news will accrue that may vindicate a change of course of action. The optimal mechanism must trade off commitment and adaptation. It can, for example, be implemented through a generalized cap-and-trade mechanism. This mechanism consists of providing authorities with flexibility, provided that the latter commit to compensate permit owners (in cash or Treasury securities). More precisely, authorities must issue a menu of permits with different redeeming values that limit the authority's ability to expropriate their owners by flooding the market with pollution permits. For example, if news led the authority to lower the price of permits (or the carbon tax) from $50 to $40, some $50 and $45 strike price put options on the Treasuries (with agreed-on country keys) would become in the money; at $35, some other options (with a $40 strike price) would also be in the money, and so forth. This approach creates flexibility but constrains it by forcing the authority to partly compensate permit owners. It obviously requires a governance mechanism, whose existence is inescapable in any international agreement.

Cap-and-trade mechanisms can obviously accommodate various automatic mechanisms that react to news accrual. We have not studied when the Market Stability Reserve mentioned earlier or a variant thereof can approximate the optimal adjustment mechanism described in Laffont–Tirole,[29] and we think that economists have not paid enough attention to this aspect, whether they favor carbon pricing or cap-and-trade.

Enforcing a Stable International Agreement: The Carrot-and-Stick Approach to Promote International Cooperation

An efficient international agreement should create a grand coalition in which all countries and regions will be induced to set the same carbon price in their jurisdiction. Under the principle of subsidiarity, each country or region would be free to determine its own carbon policy, for instance, through a tax, a cap-and-trade, or a hybrid. The free-rider problem raises the question of the stability of this grand coalition.[30] An analogy is sovereign borrowing. Sanctions for defaulting are limited (fortunately, gunboat diplomacy has waned), which raises concerns about countries' commitment to repay creditors. The same applies to climate change. Even if a good agreement is reached, it must still be enforced with limited means. The La La Land of international climate negotiations most often ignores this central question.

Naming and shaming is an approach and should be used; but as we have seen with the Kyoto "commitments," it has limited effects. Countries always find a multitude of excuses (choice of other actions such as R&D, recession, insufficient effort by others, commitment made by a previous government, etc.) to not abide by their pledge.

There is no bullet-proof solution to the enforcement problem, but we think that at a minimum two instruments should be employed. First, countries care about gains from trade; the World Trade Organization (WTO) should view noncompliance with an international agreement as a form of dumping, leading to sanctions. Needless to say, the nature of these sanctions should not be decided by individual countries because the latter would then gladly take this opportunity to implement protectionist policies.

In the same spirit, one could penalize nonparticipants through punitive border taxes. This policy would incentivize reluctant countries to jump on board and be conducive to the formation of a stable world climate coalition. Nordhaus (2015) examines the formation of stable climate coalitions when coalitions are able to impose internally a uniform carbon price together with uniform trade sanctions against nonparticipants. For a carbon price around $25 per ton of CO_2, a worldwide climate coalition is stable if a uniform tax of 2% is imposed by the coalition for any good or service imported from a nonparticipating country.

Second, noncompliance with a climate agreement should be treated as committing future administrations and treated as sovereign debt. This policy would involve the International Monetary Fund (IMF) as well. For example, in the case of a cap-and-trade approach, a shortfall of permits at the end of the year would add to the public debt; the conversion rate would be the current market price.

Of course, we are aware of the potential collateral damages associated with such linkages with other successful international institutions. But the real question is that of the alternative. Proponents of nonbinding agreements hope that the countries' good will suffice to control GHG emissions. If they are correct, then the incentives provided through institutional linkages will also suffice a fortiori, without any collateral damage on these institutions.

Putting the Negotiation Back on Track

Despite the mounting evidence about global warming, the international mobilization has been most disappointing. The Kyoto Protocol failed to build an international coalition supporting a carbon price in line with its social cost, and it illustrates the intrinsic instability of any international agreement that does not seriously address the free-rider problem.[31] An international agreement must satisfy three properties: economic efficiency, incentive compatibility, and fairness. Efficiency can be attained only if all countries face the same carbon price. Incentive compatibility can be attained by penalizing free-riders. Fairness, a concept whose definition differs across stakeholders in the absence of a veil of ignorance, can potentially be reached through lump-sum transfers.

The noncommittal Paris agreement was hailed as a diplomatic success. However, it was reached because it opted for the least common denominator, accommodating demands even of some oil-rich countries that are opposed to any carbon pricing. We feel further that the pledge-and-review strategy is doomed to fail. It does not address the fundamental free-rider problem of climate change. The pledge-and-review process is another illustration of the waiting game played by key countries, which are postponing their real commitment to reduce emissions. Countries made sure that their pledge is hard to compare with other pledges and is nonverifiable and nonenforceable. The predicted outcome of this waiting game in terms of emissions of GHGs is potentially worse than the business-as-usual, zero-ambition outcome. We should tackle the climate challenge more seriously.

The Paris agreement did not deliver anything close to a credible, fair, and efficient solution. So what's next? All contributors to this book consider the efficiency objective of a universal carbon price the top priority for the post-Paris negotiation process. We should get the fundamentals right and face the thorny issue of equity. The latter issue is daunting, but any negotiation will have to confront it, and discussing many other topics simultaneously does not facilitate the task. Because national interests are paramount, sooner or later the international community will be confronted with the failure of the voluntary approach used in the Paris negotiations. An alternative roadmap can be described as follows:

- Agree on a single-carbon-price principle and the need to in the measurement infrastructure so to allow for an independent monitoring of countries' overall pollution.
- Agree on a governance and enforcement mechanism (we have proposed that nonparticipating countries be imposed penalties through punitive border taxes administered by the WTO and that participating countries recognize a "climate debt" accounting for the uncovered emissions of the nonabiding countries and administered by the IMF).

If the choice for a single-price policy is carbon pricing:

- Find a price that is agreeable to the international community and limits global warming to the 2°C objective.
- Put in place the monitoring environment, as well as the general principles for conversion of nonprice policies into the price realm, and define criteria that limit undoing.

If the choice for a single-price policy is cap-and-trade (the option we favor because we believe it is easier to monitor):

- Fix a trajectory of emissions that scientists deem consistent with the 2°C objective, and agree on the principle of this worldwide cap trajectory.
- Agree that permits will be allocated to participating countries in line with the aggregate cap.
- Agree on a trading mechanism in which countries will have to match pollution and permits at the end of the year to avoid creating unfulfilled climatic debt.

Under the current circumstances, the implementation of any of these two approaches would constitute a formidable achievement. If none of these solutions works, then let us hope that green innovations will emerge that will make renewable energy cheaper to produce than current fossil energy sources. Otherwise the immensely risky adaptation strategy will be the only alternative remaining solution for future generations.

Notes

1. See, for example, Bosetti et al. (2013). According to Nordhaus (2015), the equilibrium average carbon price that would prevail in a simple global noncooperative game is equal to a fraction h of the first-best price, where h is the Herfindahl index of country sizes (the Herfindahl index h is the sum of the squares of each country's

share in global output; for example, if there are 10 identical countries, h equals 10%). He concludes that the equilibrium average carbon price in the absence of a coordination mechanism to solve the free-rider problem will be in the order of one-tenth of the efficient level.

2. A liability system would not solve the problem. Because of the diffuse and intertemporal nature of the pollution, it is impossible to link current individual emissions to future individual damages. Therefore, a liability system cannot fix the problem. Besides, even if such a link could be established, one would need an international agreement to prevent free-riding.

3. Let us emphasize that we are not necessarily opposed to standards. For example, one could use an economic instrument to encourage insulation by embodying the carbon price into the price of heating fuel and gas housing. However, insulation standards may overcome an informational problem (consumers may be poorly informed about the energy efficiency of their dwelling) and, for owners, do not require a complex computation of intertemporal savings on a carbon price. Our point is that standards are often enacted without a clear analysis of whether the goals could have been achieved more efficiently and a computation of the implicit carbon price involved in their design.

4. The best example is the hydrofluorocarbon-23 (HFC-23), which has a warming effect 11,000 times greater than CO_2, so that destroying one ton of HFC-23 earns 11,000 more CDM certificates than destroying one ton of CO_2. From 2005 to June 2012, 46% of all certificates from the CDM were issued for the destruction of HFC-23. Projects for destroying HFC-23 were so profitable it is believed that coolant manufacturers may have built new factories to produce the coolant gas. As a consequence, the EU banned the use of HFC-23 certificates in the EU ETS from May 1, 2013.

5. Many other variants use an economic instrument. For example, countries could agree on a universal carbon tax (as opposed to a carbon price), leaving no scope for subsidiarity. To do so, a possible strategy would be to set up an international carbon tax collection entity. This, however, is not discussed in existing proposals probably because it could be perceived as too large an infringement on sovereignty or because there are returns to scope in tax collection. Thus, the implementation of the carbon tax would likely be left to individual countries, and the proceeds from the carbon tax would go to the country. We will here focus on the two commonly advocated strategies.

6. This is naturally the same *absolute* level of a carbon price; adding a common carbon price onto the one already in place in each country would not only be inefficient (carbon prices would differ across the world) but also unfair to a country such as Sweden, which has been virtuous prior to the agreement and whose extra contribution relative to other countries would thereby be made perennial.

7. Since Weitzman's (1974) seminal paper, a sizable literature has compared the relative merits of the tax-and-cap approaches, focusing on the economic aspects and often leaving enforcement and political economy aspects aside (the two systems have different implications along these dimensions, as we will discuss later). When the various parameters of the climate change equation (climate science, abatement technologies, demand) are known, a carbon tax and a cap-and-trade system are equivalent because, for a given price target, it is always possible to determine the supply of permits that will support this equilibrium price and conversely. Not so under uncertainty.

8. Under some estimation, it would have cost Canada $14 billion to buy enough carbon credits to make its target.

9. Since early 2014, this market is linked to a similar one established by the Province of Québec. The current price of permits in California is $12/tCO_2$ at the minimum legal price. This fragmented scheme illustrates the strange economics of climate change in the United States, where the minimum carbon price in California is larger than the maximum carbon price in RGGI.

10. Article 13 of the Paris Agreement is particularly problematic from this viewpoint, stating that the transparency framework should recognize "the special circumstances of the least-developed countries […] and be implemented in a facilitative, non-intrusive, non-punitive manner."

11. Notice that Article 6 of the Paris agreement allows for the use of transferable Intended Nationally Determined Contributions (INDCs) through voluntary "Internationally Transferred Mitigation Outcomes" (IMTOs). This is reminiscent of the inefficient Clean Development Mechanism (CDM) contained in the Kyoto Protocol. But some experts see in this Article 6 a hidden intention in favor of an international market for INDCs. This could be feasible only if INDCs were legally binding. Market solutions cannot work in the absence of transparent and legally enforceable property rights.

12. See Cramton and Stoft (2012), Cramton, Ockenfels, and Stoft (chapter 12, this volume), Weitzman (2013, chapter 8, this volume), and the other chapters in this book. Cramton et al. (2013, chapter 12, this volume) suggest defining a country's carbon price as its carbon revenue divided by its carbon emissions. Others recommend a uniform carbon tax. Still others advocate a global cap and trade system leading to a uniform carbon price. At this stage, there is no need to distinguish among the various approaches.

13. Weitzman (chapter 8, this volume) derives an analytical solution for this majority voting scheme on the carbon price when the damage function and the marginal abatement cost function are linear. In that case, the equilibrium price is efficient if and only if the mean and median of the distribution of the country-specific marginal damages are the same.

14. In either case, there is also an issue regarding whether the governments will not steal or make use of the transfers for their own well-being: they may cash in the green fund receipts (or for that matter the carbon tax) or sell permits in the international market to the same effect. This difficulty is inherent to the respect of sovereignty and is not specific to climate policies.

15. See Ellerman et al. (2000) for an extensive analysis of these negotiations.

16. However, Cramton and Stoft (2012) claim that a far smaller amount would be needed to support a carbon price of $30/ton and that donor countries would receive much more for their money than with the current green fund.

17. This a priori gave Eastern European countries the choice between making money by selling permits and not exerting any abatement effort; other countries became reluctant to buy the permits, and the second option became the leading one.

18. Cramton, Ockenfels, and Stoft (chapter 12, this volume) make a similar point for the cap-and-trade initial negotiating approach attempted by Kyoto negotiators, who tried to agree on a uniform reduction of x% relative to 1990 emissions; no such x could be found.

19. Besides, the Weitzman framework does not allow for more complex but reasonable mechanisms, such as dynamic adjustment mechanisms to cope with uncertainty. For instance, the European Commission has recently proposed to create a market stability reserve starting in 2021. The reserve would cope with the current surplus of emission allowances and improve the system's resilience to shocks by adjusting the supply of allowances to be auctioned. It would operate according to predefined rules that would leave no discretion to the Commission or member states.

An economic debate also exists regarding whether price or quantity schemes best insulate countries against uncertainty about climate risk or technology. In theory, hedging instruments should provide an efficient allocation of risk worldwide, but little is known about to the extent to which markets would actually deliver this.

20. We will not expand on another political economy dimension here. Another issue with a carbon tax is the *legal process*. This obstacle is certainly not insurmountable but requires specific attention. First, taxes are usually set every year. What is needed for climate change control is a long-term commitment (think about the SO_2 tradable permits in the United States, which are issued 30 years ahead). Second, taxes are generally the prerogative of parliaments. For example, in Europe, setting up the ETS cap-and-trade scheme required only a majority vote, whereas tax harmonization is subject to the unanimity rule, and therefore a carbon tax would have been almost impossible to achieve. So an exception needs to be made to prevent individual parliaments from undoing the international agreement.

21. Cramton et al. (2013; and chapter 12, this book) also argue in favor of subsidiarity, although on slightly different grounds.

22. We have not studied and therefore will not discuss the question of aggregation of the various efforts along different dimensions. The choice of weights and their relationship to technological progress has been discussed in the literature on price indices (e.g., Diewert 1993); relevant here is also the embryonic literature on price caps (here floor) (Armstrong and Vickers, 2000; Laffont and Tirole, 1999). The optimal response of a country, even in the absence of political economy/favoritism considerations, will not satisfy the law of one price, both within the country (the country-optimal tax depends on good-specific cost and local pollution characteristics) and across countries. However, we do not have an educated guess as to whether these deviations from price coherence impose sizable costs; in comparison with the distortions attached with current pledge-and-review approach, this is without doubt a second-order issue.

23. All symposium authors agree that enforcement should work in two steps: (1) monitor, and (2) impose trade sanctions if necessary. Of course, this is not straightforward. In the last few years, and despite the existence of a program and the presence of the Troika in the country, Greece made little progress in curbing tax evasion. It is difficult for foreigners to impose a tax when the government is reluctant to strengthen it. Although in both cases (sovereign debt and climate agreements), the foreigners have a strong vested interest in domestic tax collection, one could argue that the problem is even more complex in the climate context and that there is no reason to believe that the international community would be much more successful in obtaining compliance of the carbon tax agreement. Indeed, some compliance-prone factors are not even present in the case of climate change: there is no troika in each country threatening to cut the flow of lending; countries are not under a program (and therefore carefully monitored); they also derive some benefits from compliance (prospect of no longer being under a program, of not facing international sanctions in case of default), whereas for most countries almost 100% of the benefits of good behavior are enjoyed by foreigners.

24. http://data.worldbank.org/indicator/EP.PMP.SGAS.CD/countries/1.

25. For example, the NASA Orbiting Carbon Observatory-2 (OCO-2) is already orbiting the planet. The ESA CarbonSat project is also promising.

26. See Green and Newbery (1992) and Joskow andTirole (2000).

27. Even in a well-designed, long-term-oriented system, such as the acid rain program in the United States, SO_2 prices have been volatile. They were stable in the first 10 years but then exhibited substantial volatility from 2005 through 2009, for instance.

28. The precise implementation of this mechanism has been criticized for being asymmetric and failing to have the desired dampening effect (Trotignon et al., 2015).

29. For instance, suppose that scientists demonstrate that the climate is deteriorating faster than had been thought. Then permits must be withdrawn. The Market Stability Reserve mechanism reacts to an intertemporal use of permits ("is permit use more frontloaded or backloaded than expected?") rather than to the overall target. So it is likely to miss some desirable adjustments.

30. In an asymmetric information framework, Martimort and Sand-Zantman (2016) describe the optimal mechanism that prevents the free-riding problem with local co-benefits when participation is voluntary.

31. Incidentally, we are not convinced that the Onusian framework is optimal either, as bargaining among 195 nations is incredibly complex. A coalition of the current and future high emitters (say the G20) might prove more effective, both to negotiate and then put pressure on other countries, including through the WTO.

References

Armstrong, M., and J. Vickers. 2000. Multiproduct price regulation under asymmetric information. *Journal of Industrial Economics* 48:137–160.

Beccherle, J., and J. Tirole. 2011. Regional initiatives and the cost of delaying binding climate change agreements. *Journal of Public Economics* 95 (11/12): 1339–1348.

Bosetti, V., C. Carraro, E. De Cian, E. Massetti, and M. Tavoni. 2013. Incentives and stability of international climate coalitions: An integrated assessment. *Energy Policy* 55:44–56.

Buhr, K., S. Roth, and P. Stigson. 2014. Climate change politics through a global pledge-and-review regime: Positions among negotiators and stakeholders. *Sustainability* 6:794–811.

Chakravorty, U., B. Magne, and M. Moreaux. 2006. A hotelling model with a ceiling on the stock of pollution. *Journal of Economic Dynamics & Control* 30 (12): 2875–2904.

Cramton, P., A. Ockenfels, and S. Stoft. 2013. How to negotiate ambitious global emissions abatement. Mimeo, carbon-price.com.

Cramton, P., and S. Stoft. (April 2012). How to fix the inefficiency of global cap and trade. *Economists' Voice*: 9.

Cremer, H., F. Gahvari, and N. Ladoux. 2003. Environmental taxes with heterogeneous consumers: An application to energy consumption in France. *Journal of Public Economics* 87 (12): 2791–2815.

De Perthuis, C., and L.-A. Jouvet. 2015. *Routes to an Ambitious Climate Agreement in 2015*. Paris: Institut Louis Bachelier, Opinions et Débats.

Dietz, S., C. Gollier, and L. Kessler. 2015. *The climate beta. Mimeo*. London School of Economics.

Diamond, J. 2005. *How Societies Choose to Fail or Succeed*. New York: Viking Books.

Diewert, W. E. 1993. Index numbers. In *Essays in Index Number Theory*. vol. 1. Ed. W. E. Diewert and A. O. Nakamura. New York: Elsevier Science Publishers.

Ellerman, A. D., P. L. Joskow, R. Schmalensee, J. P. Montero, and E. M. Bailey. 2000. *Markets for Clean Air: The U.S. Acid Rain Program*. Cambridge, UK: Cambridge University Press.

Gollier, C. 2012. *Pricing the Planet's Future: The Economics of Discounting in an Uncertain World*. Princeton, NJ: Princeton University Press.

Gollier, C. 2014. *Evaluation of long-dated investments under uncertain growth trend, volatility and catastrophes. Mimeo*. Toulouse School of Economics.

Green, R., and D. Newbery. 1992. Competition in the British electricity spot market. *Journal of Political Economy* 100 (5): 929–953.

Hardin, G. 1968. The tragedy of commons. *Science* 162 (3859): 1243–1248.

IPCC. 2011. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.)] Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. 2014. *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)] Cambridge, UK; New York: Cambridge University Press.

Joskow, P., and J. Tirole. (Autumn 2000). Transmission rights and market power on electric power. *Rand Journal of Economics* 31 (3): 450–501.

Laffont, J. J., and J. Tirole. 1996a. Pollution permits and compliance strategies. *Journal of Public Economics* 62:85–125.

Laffont, J. J., and J. Tirole. 1996b. Pollution permits and environmental innovation. *Journal of Public Economics* 62:127–140.

Laffont, J. J., and J. Tirole. 1999. *Competition in Telecommunications*. Cambridge, MA: MIT Press.

Martimort, D., and W. Sand-Zantman. 2016. A mechanism design approach to climate-change agreements. *Journal of the European Economic Association* 14 (3): 669–718.

Nordhaus, W. D. 2011, October. Estimates of the social cost of carbon: Background and results of the RICE-2011 model. Cowles Foundation Discussion Paper.

Nordhaus, W. D. 2015. Climate clubs: Overcoming free-riding in international climate policy. *American Economic Review* 105 (4): 1–32.

OECD. 2013. *Climate and Carbon: Aligning Prices and Policies, OECD Environment Policy Paper 1*. Paris: OECD Publishing.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge University Press.

Posner, E., and D. Weisbach. 2010. *Climate Change Justice*. Princeton, NJ: Princeton University Press.

Quinet, A. 2009. *La valeur tutélaire du carbone*. Paris: La Documentation Française, Rapports et Documents 16.

Trotignon, R., P. A. Jouvet, B. Soliera, S. Quemina, and J. Elbezea. 2015. *European carbon market: Lessons on the impact of a "market stability reserve" using the Zephyr Model*. Mimeo. Chaire Economie du Climat, University Paris Dauphine.

US Interagency Working Group. 2013. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 128666.

Weitzman, M. L. 1974. Prices vs. quantities. *Review of Economic Studies* 41 (4): 477–491.

Weitzman, M. L. 1998. Why the far-distant future should be discounted at its lowest possible rate? *Journal of Environmental Economics and Management* 36:201–208.

Weitzman, M. L. 2001. Gamma discounting. *American Economic Review* 91:260–271.

Weitzman, M. L. 2013. Can negotiating a uniform carbon price help to internalize the global warming externality? *Journal of the Association of Environmental and Resource Economists* 1 (1/2): 29–49.