Some Economics of Global Warming

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This paper reflects on the economics and politics of an international climate policy agreement. The international community has so far failed to design institutions and a compensation scheme that would lead to an abatement effort commensurate with the IPCC recommendations that it attempts to follow. The paper first lays out what could be a proper institutional design, minimizing the impact of abatement on the world consumer's income, and thereby making the fight against climate change more credible. It then sketches a governance mechanism as well as an approach to compensation. Finally, it concludes with a roadmap for the negotiation. [JEL classification: D62, F51, H23, Q54]

Keywords: climate change, command and control, cap and trade, international agreement.

In 1824, French mathematician Joseph Fourier developed a theory predicting that gases in the atmosphere are instrumental in keeping our planet warm; he was in effect discovering the greenhouse effect. This effect was later documented and by the mid 1980s scientists had become increasingly concerned about the impact of human emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs)[2] on climate change. They envisioned

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[1] This paper is the written version of the «Angelo Costa» Lecture, delivered in Rome on April 16th, 2009 at LUISS "Guido Carli" University. A more complete analysis can be found (in French) in my report to the French Council of Economic Advisors (CAE).

[2] Among other anthropogenic GHGs, the most abundant are methane, nitrous oxides, and chlorofluorocarbons (CFCs).

dire consequences of this anthropogenic greenhouse effect: sea level rise (with disastrous consequences for populations, such as those in Asian deltas living at sea level), water shortages in Africa and other parts of the world, changes in weather patterns, *etc.*[3].

The Intergovernmental Panel on Climate Change (IPCC) issued its first report in 1990, leading to the 1992 United Nations convention on climate change. This convention, ratified by 192 countries, stated the joint, but differentiated responsibility of countries in this "tragedy of the commons", but it did not take any concrete step. The Kyoto agreement in 1997 was the first agreement in which some countries (those in "Annex I", by and large the industrialized countries) committed to emission control targets. Its impact has however been very limited, due in part to the lack of commitments by rapidly growing emerging countries such as China[4], India and Brazil, and to the United States' non-ratification. Other heavy emitters of GHGs either did not abide by their commitments (*e.g.* Canada) or took advantage of credits obtained elsewhere (*e.g.* Europe).

Global warming is in essence an economic and political problem. It has long been recognized that the atmosphere is a (global) public good. When a European emits 10 tons of CO^2 per year, he does not internalize the impact of these emissions on the welfare of other citizens of the world, including future generations. He free rides and counts on others to reduce their own emissions, which they of course have no incentive to do.

In order to stabilize at a concentration of 550 parts per million (ppm) in 2050 (from about 445 CO_2 equivalent today)[5], it is

[3] Discussions and measurement of the costs of global warming can be found for example in the *Stern Review on the Economics of Climate Change* (2006), NORDHAUS W. and BOYER J. (2000) and NORDHAUS W. (2008).

[4] For example, the ratio of China's emissions relative to those of the United States was 0.55 in 1997, and 1.13 ten years later.

[5] Estimates as to what is desirable of course vary with estimates of the actual impact of global warming, with the choice of discount rate, etc. The *Stern Review* (2006) recommends a 500-550 ppm target (more recently, Stern has emphasized that even this is risky); the European Council on March 8th and 9th, 2007 has called for a 450 ppm of CO_2 equivalent, and set an own target of a 20% reduction by 2020, with an extra 10% reduction in case of a satisfactory agreement.

Gollier has made a number of contributions to our understanding of social rates of discount: see *e.g.* GOLLIER C. (2008) for a recent contribution.

estimated that each inhabitant of the planet will need to emit 2.5 tons of CO_2 equivalent. Comparing this number to the current 23.5 tons in the US, 14 tons in Russia and 10 tons in Europe[6], and considering the likely (and desirable) growth of emerging countries, one may wonder how this will come about.

The obvious answer is that we need to reduce our carbon emissions through a mix of policies. Energy savings is in some instances a simple way to reduce emissions. Alternatively, we can opt for less carbon-intensive technologies and consumptions: carbon-light power (renewables, nuclear, carbon capture, storage and sequestration, *etc.*), cleaner transportation, building insulation, cleaner agriculture[7], less deforestation, and so forth.

It is however unwise to approach this problem from a command-and-control perspective by picking an "appropriate" mix and setting percentage reductions in specific areas. We just do not have the information. What we need to do instead is to put a price on carbon and provide households, firms and the public sector with incentives to keep their emissions low.

With this background, the Copenhagen negotiation in December 2009 will be determinant for the future of climate change policy. While voluntarism serves some purpose, ambitious abatement target announcements by governments and supranational organizations serve mainly to placate public opinion and avoid international pressure, and do little to promote the stated objectives. Unfortunately, and the aftermath of the Kyoto protocol is a cruel reminder, national interests are better predictors in international matters than loose promises.

To move forward, an agreement in Copenhagen must address three key issues:

• the design of institutions built around the use of economic instruments, allowing a much needed abatement cost minimization. Limiting the damage to output and welfare is not the only argument for keeping abatement costs down. For, the containment of emissions has little credibility if it is later perceived as too expensive.

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[6] These numbers are drawn from DE PERTHUIS C. (2009).

[7] Ruminants, rice production, and fertilizers are among the high emitters of GHGs in agriculture.

• an agreement that creates a reasonable chance that nations will abide by their commitments in the future; as we will later explain, their temptation to renege will be high.

• an agreement on a compensation scheme that induces everyone to get on board. The international community's reluctance to address the compensation problem explicitly makes it unlikely that the agreement will include ambitious actions.

These three issues – economic instruments, commitment and compensation – will hopefully take the center stage in Copenhagen. But they should by no means be the only topics on the agenda. Chances unfortunately are that no comprehensive agreement will emerge. It is therefore important to reflect on the measures that could foster the probability of a future agreement.

This lecture accordingly discusses what economics can bring to the debate on the two key issues: the design of an efficient and sustainable mechanism, and the transition to such a mechanism. Needless to say, it focuses on a subset of issues; we will return to a few neglected issues in our conclusion.

The lecture makes two main points:

First, economics offers some simple messages relative to target design. Some (price coherency and the principle of compensation) are well-known, and yet frequently ignored in the policy debate.

A ton of carbon is a ton of carbon and so the price of carbon should not be allowed to vary widely depending on the emitter. A uniform price cuts down on the abatement cost substantially. For example, a well-known MIT study[8] estimates that the creation of a market for sulfur dioxide in the US reduced the cost of achieving the reduction target by half compared to traditional command-and-control approaches, amounting to an annual cost savings of $1 billion. Many studies of incentives-based environmental programs suggest cost savings in excess of this factor 2.[9]

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[8] JOSKOW P. *et* AL. (2000).

[9] For reviews, see TIETENBERG T. (1990); HAHN R. and STAVINS R. (1992); HAHN R. (2000).

Alas, powerful lobbies repeatedly call for subsidies and exemptions, creating a wide array of carbon prices in the economy. Similarly, a basic principle of economics – the optimality of maximizing a pie and then sharing it, unless one has a good reason to believe that value destruction facilitate the reaching of an agreement – suggests that Copenhagen negotiations should first define an emission target and a governance framework, and then discuss how winners can compensate losers through, say, the allocation of tradable permits.

The second message is that game theory should guide us in thinking about the transition. The optimism of experts who think that countries will spontaneously take their responsibilities through unilateral actions seems unwarranted in view of the extensive evidence (in environmental and other matters) on the defense of national interests. In the absence of sanctions for countries that sign an agreement but do not abide by it, and for those that stay outside, promises will be what they really are: cheap talk.

1. - The Agreement

As we already noted, an inefficient agreement, besides being costly by definition, lacks credibility. On both grounds, much attention should be paid to design.

[*Warning*: In what follows I will use the concept of "carbon price" to refer either to the level of the carbon tax under a tax system, or to the market price under a cap-and-trade system; as is well known, the two approaches are equivalent under demanding conditions – in particular a predictable environment –, but may differ in their cost efficiency otherwise.]

1.1 *Price Coherency/Uniqueness*

Ideally, the price of carbon should not depend on the source, country, or industry that emits it. The underlying reasoning behind this "single price" or "price coherency" principle is straightforward. If for example emitting a ton of CO_2 involves a payment of a tax of, or the purchase of a permit for 50 Euros in country A and 100 Euros in country B, some emitters will prefer to pollute in country A when it would have cost them 51 Euros to engage in pollution abatement, while some other actors in country B will spend up to 99 Euros in abatement in order to avoid polluting. In this extreme example[10], 48 Euros could have been economized while keeping total abatement the same. A single price guarantees that, regardless of the global abatement target, least-cost abatement obtains.

The price-coherency principle has many implications, some of which will be envisioned later. Here are a few first ones:

• In the target agreement, there is no clear reason why some sectors should receive a special treatment. Under sectoral discrimination, low-carbon-price sectors forego cheap opportunities for abatement while high-carbon-price sectors may well overspend on abatement.

• In particular, and contrary to common wisdom, there is no justification for exempting sectors with limited substitution/ pollution abatement technologies in the short run (and therefore high impact of green taxes on cost), or sectors with high elasticity of demand on the grounds that such sectors will suffer from green policies. This reasoning confuses efficiency – which requires that all sectors face the social cost of their emissions and are thereby encouraged to take all reasonable steps to fight global warming – and compensation – which conceivably could be awarded to such sectors. Incentives are key to a proper treatment of global warming.

• When non-price instruments, such as standards, are used, economic instruments should still be introduced whenever possible so as to introduce rationality into the design of these standards. This can be accomplished in two ways. First, public policies should state the implicit price of carbon implied by the standard: what would be the level of tax or the price of permits

[10] On the other hand, our societies sometimes spend 1,000 Euros to economize a ton of carbon when 10-Euros-per-ton actions are not undertaken.

that would give rise to an equivalent abatement? The comparison for instance with the market price may be instructive. Second, a standard imposes at the margin high costs on some emitters and low costs on others. It is therefore desirable to set up a market in which those who under-comply can purchase credits from those who (are then induced to) over-comply[11].

• The common setting of targets for renewable energy (wind power, solar power, etc.) may not facilitate cost minimization. The popularity of such policies results from different considerations. The first is that renewable energies may be subject to substantial learning by doing and that learning is a public good that the firm generating knowledge cannot appropriate. This argument is of course not specific to renewable energies, as it can be made (at least as a matter of theory) for any nascent technology. Its application requires answering the following questions: First, what are the relative impacts of innovation and learning by doing in the reduction of production costs or the improvement of efficiency? If innovation is the primary driver of technological progress, then price uniqueness together with R&D subsidies (to address the fact that knowledge spills over) is called for, not a differentiation of carbon prices[12]. Second, how appropriable is learning-by-doing (if it is, there is no strong case for subsidizing the technology)?

The second argument is in a sense an admission of weakness: setting renewable targets is justified if we expect that tomorrow authorities will not be strong enough to sustain high carbon prices that, today, would lead to the innovation in renewable energies. This of course is a roundabout way of promoting renewable energy. We will return to the commitment problem later on.

The third possibility, clearly less favorable to the case for renewables, is that governments pander to an ill-informed opinion or to a lobby. One of the worst illustrations of this is the American

[11] STAVINS R. (2003) estimates that leaded gasoline tradable permits markets created savings of $250 million per year compared to traditional approaches.

[12] On the need for two instruments (carbon price, R&D subsidy) in the context of endogenous growth, see ACEMOGLU D. *et* AL. (2009) and GRIMAUD A. - ROUGE L. (2008).

policy with respect to bio-fuels under the Bush administration. First-generation biofuels in the US, which stem from soy and (mainly) corn, have been heavily subsidized (51 cents per gallon of ethanol blended into gasoline), apparently with a very limited impact on net GHG emissions.

As in the case of standards, two measures should be appended to the setting of renewable targets. The first is the inclusion of the estimates of cost per ton of avoided GHG emissions (as this cost varies widely across renewable energies and across countries); this approach would allow a comparison with other policies, including the subsidization of R&D concerning future generations of renewables. Second, market mechanisms should be introduced so to minimize the cost of this approach. Consider for example the European Union's target of 20% of renewable energy in 2010. Clearly, countries differ in their natural cost effectiveness in the generation of wind and solar power. A system of tradable credits and debits would ensure that renewable energies be deployed primarily by those countries with a comparative advantage in doing so[13].

1.2 *A Well-Designed Cap-and-Trade Mechanism*

Between the two mechanisms generating price coherency, carbon tax (price mechanism) and cap-and-trade (quantity mechanism), the most likely contender seems to be the latter, if only for political economy reasons. Carbon taxes suffer from multiple flaws on the political economy front. First, for legal reasons, it is harder to impose uniform taxes than a single allowance system (this is one reason why the European Union ETS system was created: any uniform tax scheme requires unanimity while a tradable allowance system only a qualified majority). Second, taxes don't bring a long term visibility as they are set every year. Third, the initial allocation of free permits is a

[13] The European Union has put in place a flexibility system, though. But one wonders why it did not go all the way and adopt a simple and efficient tradable credit mechanism.

more opaque form of compensation than a fiscal transfer, and historically has been the key to the reaching of environmental agreements. The public hardly realized that the 1990 Clean Air Act Amendment operates a sizable transfer of resources in favor of (heavily polluting) mid-western states. Similarly, very few voters in developed countries are aware of transfers implied by the CDM mechanism set up by the Kyoto Protocol[14].

This section discusses what it takes to design an efficient cap-and-trade system.

1.2.1 A Long Horizon

In the matter of greenhouse gas (GHG) emissions, investment decisions (power generators, building insulation, transportation, forestry) often have long-term implications. The deployment of green technology therefore hinges on expectations of the carbon price 10, 20 or 50 years ahead. High carbon prices today *per se* will do little to encourage such deployment.

Similarly, innovators are incentivized to work on carbon storage and sequestration, fuel cells, electricity storage, solar-or wind-power, or any GHG-economizing technology, only if they are confident that in the future they will be able to sell licenses to their technologies at a decent price. The licensing price in turn will be determined by the opportunity cost of not having access to green technologies, that is by the carbon price when and after these technologies become operational.

To invest in green equipments and technologies, economic actors therefore need a long-term visibility. The European ETS system with its very short horizons (2005-2007, 2008-2012, 2013-2020) offers much less visibility than its US counterpart for SO_2 and NO_x as set up by the Clean Air Act Amendment of 1990. That year, the US Congress opted for a cap-and-trade mechanism reducing emissions by half by 2000. Tradable permits exist at all

[14] We will return to this mechanism. The transfers have so far been limited, but they are growing fast; furthermore, many experts, anticipating a failure of the Copenhagen negotiations to take substantial action, propose to expand the use of this mechanism.

horizons up to 30 years[15], offering price signals for economic actors to make their choices in this matter and allowing actors to hedge against carbon price risk.

The setting of long-term targets and the allocation of futures allowances have another benefit: while pollution-intensive companies, sectors or countries have an incentive to demand compensation at the onset (which they obtained in the US and in most similar experiences, in the form of free allowances/grandfathering), they know that they will not return to the bargaining table to negotiate compensation later on. By contrast, when the system is renegotiated every few years, not engaging in pollution abatement actually puts a firm, sector or country (depending on the context) in a stronger bargaining position in future negotiations, as it makes its non-participation more credible and increases the need for compensating it.

1.2.2 A Credible Commitment

Much of the debate on cap-and-trade mechanisms has focused on the notion of safety valve or price cap. Polluting industries are concerned about the impact of high carbon prices on economic activity. In part, this concern stems from the absence of carbon taxation in competing countries. We will come back to this issue. For the moment, we keep assuming that a global agreement has been reached and the level-playing field across competitors in the same industry has been maintained.

I believe that the main concern should then be that the price will be too low in the future. As noted earlier, low-carbon equipments will be deployed and green technologies will be invented only if actors anticipate a reasonable price for carbon in the future. For example, a recent McKinsey study of carbon

[15] Each year new permits are issued for 30 years ahead. These permits are allocated (except for a very small fraction put up for auction) to the initial issuers (regardless of whether they have shut down the plant or not, as it should be in order to avoid providing incentives for keeping inefficient plants just for the sake of earning permits).

capture and storage estimates that the first equipments may add 60 to 90 Euros per avoided ton, and perhaps 30 to 45 Euros when the technology becomes mature. Clearly price expectations at 10 or 30 Euros for tradable emission permits will never stimulate any research in this area if the McKinsey estimates are correct.

Yet, the countries' commitment to a non-negligible carbon price raises some concern. Assume that, say, a worldwide tradable permit system with a long horizon (30 to 40 years) is set up, as I think would be desirable. Once the permits are sold or distributed (in either case in private hands), it may be tempting for the international community to renege on its commitment and to flood the market with new permits, thereby lowering their price. There are several grounds for this concern:

• First, the sovereigns may be short of money (a hypothesis that is strengthened by the current financial crisis, which is likely to have long term effects on public finances). Auctioning off new permits may turn out to be very tempting.

• Second, the states may give in to the industries' (in particular those which have failed or not attempted to convert to green technologies) request to issue new permits.

• Third, the states may want to use low carbon prices in order to exert price pressure on green innovators and force them to widely diffuse the new technologies at low licensing prices.

Either way, the international community may face a "time consistency" problem: it may today want to commit to high carbon prices (ambitious GHG reduction objectives), and, later, be tempted to renege on its promise once green equipments and innovations are in place.

Solving this time inconsistency problem is apparently simple: the authorities can commit to a price floor (for example, "a ton of CO_2 will cost at least 100 Euros in 2030"), and agree to penalties in case of violation. This penalty can be structured in various ways: the countries may commit to repurchase permits if the price falls below the stated level; or they can issue contingent Treasury bonds or put options, that pay off the difference between the stated price and the market price if this difference is positive.

This fix has an obvious flaw: it is hard to predict with certainty the optimal policy in the matter of global warming in 20 or 30 years ahead. Uncertainty relates to scientific knowledge (what is the exact impact of GHG on climate?), technology (how costly will it be to develop green technologies?), social (how acceptable will adaptation be?) and geopolitical (who will join international agreements and under which conditions?). These uncertainties call for some flexibility, in that the price of carbon should in the future adjust upward or downward relative to targets in reaction to the resolution of uncertainty.

Jean-Jacques Laffont and I analyzed the theoretical trade-off between flexibility and commitment.[16] One optimal approach to address this trade-off is to issue tradable permits that have varying redemption rights. For example some permits would be returned at a redemption price of 100 Euros. Others still would be returned at price 95 Euros, and so forth. This ensures that the lower the price of carbon tomorrow, the larger the increase in public debt. But if the schedule is gradual, the authorities are induced to adjust the number of permits flexibly as good news about the abatement cost or global warming accrue. The cost of redemptions however provides commitment and makes authorities think twice before flooding the market with new permits or granting exemptions that reduce the demand for permits.

1.2.3 A Better-Designed Trading System

The European Union's Emissions Trading System (ETS) for CO_2[17] has the merit of existing. It also led to the collection of plant-level data, a necessary condition for effective emission control. Finally, even a low carbon price provides incentives to harvest "low-hanging fruits".

Yet the EU ETS design was flawed in several important

[16] LAFFONT J.J. - TIROLE J. (1996*a,b*).

[17] The ETS was made particularly binding for the power industry, deemed to face no or little competition from outside the European Union and viewed as a good candidate for abatement even in the short run. Other ETS-concerned industries were generously endowed with allowances.

respects[18]. A subset of those flaws comes from the fact that the price coherency principle was abandoned under intense political lobbying. This is a pity, in view of both known theoretical principles and the fact that a more efficient design had been put in place in the US for SO_2 and NO_x. The ETS' initial design "mistakes"[19] include:

• *Allocation of free permits for new entrants or projects*. The allocation of free permits for entrants, besides a windfall profit, creates a multiplicity of prices: 0 for new projects, market price for the others. For example new plants may be installed while otherwise similar existing ones close down simply because of the difference in carbon price treatment.

• *Loss of permits in case of closure*. Some European countries[20] have withheld permits from firms when a plant was closed. This rule again violates the price coherency principle as a firm that contemplates shutting down a plant faces a carbon price equal to 0 (it will lose the permit anyway if it shuts down). This policy inefficiently discourages the closure of dirty plants.

• *Lack of bankability*. By and large, permits for year t cannot be used later on in year t' of another phase. This prevents price smoothing. Consider for example Graph 1. This graph depicts the price of CO_2 in 2007. The spot price in May 2007 was effectively 0 due to small errors in demand forecasts and especially an overly generous distribution of permits by member states. By contrast, the futures price in May 2007 for a 2008 tradable right was around 23 Euros. Yet, there is almost no difference between a ton of CO_2 emitted in 2007 and one released in 2008! Again the principle of price coherency is violated. Bankability by contrast would have allowed more stable prices as well as some convergence toward price coherency.

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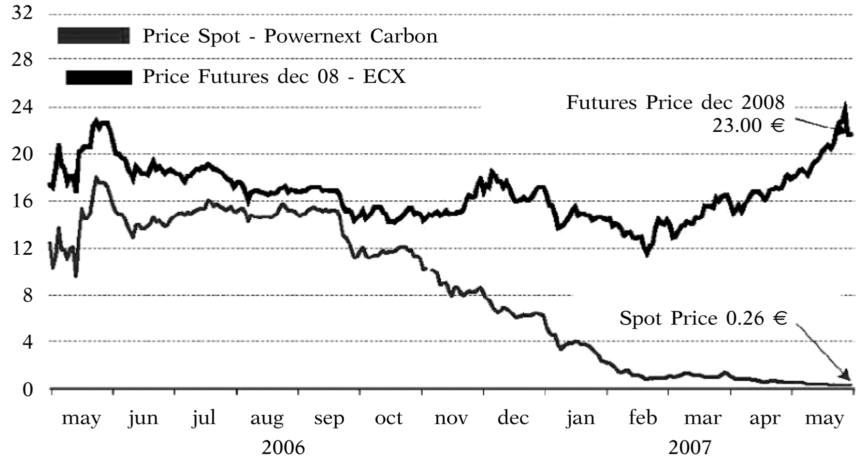
[18] For more details on these flaws, see ELLERMAN D. - BUCHNER B. (2007); see also CONVERY F. - REDMOND L. (2007).

[19] Many of those mistakes have been eliminated since, but it is worth going through them as history has taught us that lobbies often have their say in such matters.

[20] As in the case of permits for entrants, policies were not uniform across Europe.

• *Lack of sanctions*. The Kyoto Protocol (or rather a 2001 extension of it) basically embodied no penalties for breaching the agreement. In principle, not abiding by one's abatement promise leads to an increase in the next target for the country. Unfortunately, such a "sanction" has no bite to the extent that the country is under no obligation to enter future agreements and so will renegotiate the waiving of the sanctions at the same time as it negotiates the new agreement ("bygones are bygones").

GRAPH 1



Source: Powernext Carbon, ECX, Point Carbon in Tendances Carbone, 2007. BOUTTES J.P. - DASSA F. - TROCHET J.M. (2007).

1.2.4 Auctions

In the two systems (CO_2 in Europe, SO_2 and NO_x in the US), very little was auctioned off (under 3% in the US, even less in Europe[21]). The permits were more or less distributed for free to former emitters according to their shares of emissions within the sector (*i.e.* by grandfathering). By and large, no benchmarking

[21] Even the very modest objectives of the EU Emissions Trading Directive (a fraction auctioned off equal to up to 5% of allowances in the first phase and up to 10% in the second) were not met. Indeed in the first phase, 0.13% was auctioned on average in the EU ETS. See ELLERMAN D. - BUCHNER B. (2007).

(that is, an allocation based on a uniform, rather than actual, emission rate per unit of capacity) was adopted.

The European Union has announced that permits would be auctioned off after 2013, first for the power industry and then for other industries. The political statements of the European political establishment however make it likely that numerous sectors will be exempt from auctions on various "grounds" (such as high-carbon-energy content, high-fossil-fuel portfolios, being exposed to leakage, and so forth). Similarly, in the US, President Obama has officially endorsed a cap-and-trade bill featuring a 100 percent auction; the current number under the Waxman-Markey bill (which passed the House, but still has to be adopted by the Senate) is 15 percent! As in Europe it remains to be seen whether the administration will have the political clout to impose an auction for a sizable fraction of the permits.

What are the costs and benefits of having economic agents pay for the permits they acquire in the primary market (all cap-and-trade systems imply that actors pay for the permits they acquire in the secondary market)? In terms of the *compensation* objective, the choice of whether to auction off permits is in principle irrelevant. In the absence of an auction, grandfathering and other methods of free distribution allows compensation and thereby offers scope for bringing on board politically powerful actors that might prevent the enactment of a tradable permit system. Similarly, the proceeds of an auction can be redistributed to participants in rather arbitrary ways and bring out the compensation that is needed in order to reach an agreement. To see this, consider an agreement that brings overall pollution from level n^0 to level n. The net payment to actor k (country, firm) can be written as (where n_k^0 denotes the initial pollution of actor k):

$$p\left(n_k - n_k^0 \frac{n}{n^0}\right)$$

ratio of pollution cap over historical level ($n = \Sigma n_k$ and $n^0 = \Sigma n_k^0$)

equlibrium price of permits

number of permits purchased

initial pollution level

Three distinct goals are illustrated in this simple formula:

• emissions are controlled by the overall target n,

• cost minimization is obtained under a tradable permits system,

• compensation, and thereby political feasibility, is achieved through the initial allocation of permits $\frac{n_k^0}{n^0}$.

In terms of *cost minimization or efficiency*, auctions dominate the free allocation of permits unless the agreement is a credible long-term one, in which case they are equivalent. For, the perspective of receiving free permits tomorrow in the renegotiation of the current agreement provides firms, industries and countries (depending on the context) with strong incentives to maintain or even build dirty equipments. At the very least, auctions should be phased in over time as a matter of principle, if one is to adopt short-term grandfathering policies. But even that is hazardous, as it creates a precedent for a free allocation, and therefore a potential expectation that the free lunch will continue in the future.

Another argument in favor of auctions is that the industry may not need much compensation. Consider the case of an inelastic total industry demand, and full cost pass-through: the cost of pollution permits is then paid by final consumers, and industry profits are unchanged when carbon is priced. Any distribution of permits then amounts to a windfall profit. Of course, firms may not be able to pass through the price of carbon. Regulation for example may prevent them from doing so. And final demand contraction also bites into their profit. So some compensation may be called for. But the general point remains that the free distribution of permits is likely to generate windfall profits for the industry, especially when pass-through is sizeable.

1.3 *"Non-Market" Mechanisms*

1.3.1 Standards

In Europe, less than half of the emissions are subject to the allowance-holding requirement under the ETS. Buildings, agriculture, transportation, waste or small industrial plants are not covered. Rather, several key industries, including buildings and transportation, are regulated by standards rather than by explicit prices.

The use of standards of course does not mean that there is no price, but rather that this price is implicit or hidden: for example, one can define the implicit price as the ETS price that should prevail in a standard-free industry in order to generate the same amount of abatement. When compared to explicit carbon prices, this statistics provides a useful measure of the extent of price coherency (cross-industry comparison), but it may not be exhaustive as it says nothing about the extent of inefficiency relative to a tradable permits system (within-industry inefficiency).

On this latter point, and as we already noted, market mechanisms should be employed so as to minimize the cost of implementing a standard. When a leaded gasoline standard was set by the US Environmental Protection Agency in 1982, it accounted for the fact that refineries did not all face the same cost of reaching the standard. The standard accordingly was set up as an *average* standard, and a market was created in which over-compliant refineries could sell credits and receive money from refineries that were unable to meet the standard at a reasonable cost. One can only regret that the European Commission did not set up a similar scheme when it designed its carbon standards for automobiles in 2007[22].

Standards have costs and benefits:

• One argument sometimes invoked in favour of standards is motivated by a "principal-agent problem". In the case of emissions by buildings, the efficient way to proceed would seem to be to levy a carbon tax on domestic fuel or gas (or to subject refineries and gas importers to the ETS system). The sale price of a house or apartment would then reflect the expected present discounted value of such taxes. Households, in particular tenants, may however be very poorly informed about the characteristics of the

[22] Again there is some flexibility mechanism, but one might just as well have used a simple trading scheme.

house or apartment, and about how these will impact their consumption and therefore emissions. A standard, while a very imperfect instrument, may then be a way of ensuring a minimum quality for insulation.

• Standards may reflect worries about the government's future ability or willingness to tax emissions. Consider for instance the case of gasoline in Europe: any reasonable carbon tax can be easily offset by a reduction in the tax on gasoline[23]. More generally, any tax can be undone provided that the state has another instrument, for example another tax, which it can adjust independently. Similarly, exemptions may be implicitly granted to some sectors that could benefit from a reduced-rate VAT.

• A familiar critique of standards is that they mostly concern equipments, but not the use of these equipments, which is exactly what environmental policies should try to influence. The buyer of a green car may pay a high purchase cost, but he faces a marginal cost of carbon emissions equal to 0, unless gasoline embodies a carbon tax. Incentives to control emissions are therefore not as strong as they would be under a usage taxation of carbon.

• Another criticism of standards is that they tend to generate widely divergent prices for carbon. Relatedly, because standards are industry specific, industrial lobbies have a strong incentive to mobilize in order to obtain a lenient standard. Some succeed in obtaining what they want, and others don't; but in either case, the implicit carbon price need not have any connection with the explicit carbon price that emerges from an ETS. Those who doubt that political negotiations may favor lobbies over the economics of the environment should consider, as an illustration, the formula set in Europe for the automobile carbon standards: the carbon standard (in grams per kilometres) is: 130+ 0.0457(car mass – 1372), as if a bigger mass were beneficial to the environment!

Standards are therefore only a second best. To limit both lobbying and price incoherency, it is advisable to measure implicit

[23] According to the report of the working group chaired by Landau J.P. (2007), a 100 euros per ton of CO_2 would increase the price of gasoline by 0.25 euros, while it would increase the cost of heating fuel for households by 50%.

prices created by any given standard. And, as we have already noted, it is advisable to append tradable permits markets to standards whenever possible.

1.3.2 Projects and Public R&D

Countries and local governments engage in all sorts of projects aimed at curbing carbon emissions: use of biofuels in public transportation, heat pumps, insulation of housing projects, *etc.* The climate impact of such projects can be assessed by looking at the avoided GHG emissions and at the market price for emissions. Of course, there is an issue as to how to measure avoided GHG emissions: what is the counterfactual? The definition of the counterfactual is also a classic issue for the (related) problem of computing credits earned under the Clean Development Mechanism (CDM), a question which we will later return to.

Another matter concerns public R&D: either medium term (for instance, the European Union will subsidize 12 pilot coal fired plants in order to experiment with carbon capture and sequestration technologies) or long term (*e.g.*, fourth generation nuclear power). Measuring the impact of such projects, even *ex post*, is no easy problem, especially if they are aimed at a wide diffusion and do not embody intellectual property rights, or if they create substantial knowledge spillovers. One measure could be the expenses incurred in those projects, converted into emission permits at the market rate. This approach is however not without problems; first, strict accounting supervision is required; second, this scheme is akin to a "reimbursed-cost rule" and may not be the best recipe for efficiency as it provides incentives for cost overruns (this problem can be alleviated through performance based schemes); and, third, countries may engage in low-value projects either because they do not want to outsource research abroad despite poor national capabilities, or because they are captured by a lobby, or because they anticipate strong spillovers on another, commercial activity, or finally because they think they know how to pick winners.

1.4 *Enforcing the Agreement*

Needless to say, an international treaty requires setting up an inventory, as well as a monitoring body, that will oversee compliance. This inventory must be at the country level if countries themselves are made accountable for their emissions. But countries' control over domestic emissions is clearly much facilitated by plant-level/source-level data, as this enables the use of economic instruments instead of a command-and-control approach.

International agreements can be reneged upon; in the case of GHG emissions, countries may issue more permits, exempt sectors, enforce regulations in a lax way, not have enough permits to cover the past year's emissions, and so forth. Consequently, sanctions must be designed into the agreement, which will deter opportunistic behaviour.

In a sense, this problem is even more complex than for free trade. Countries derive benefits from free trade, and so protectionism can be punished by denying these benefits for/imposing tariffs on the deviators. In the case of global warming, one cannot reduce the world effort against global warming in order to punish a specific country without imposing a significant cost on the entire world.

The put options described above make it costlier for the collectivity to flood the market with pollution permits, but they do little to deter deviations by individual countries. We need to find alternative ways of providing sanctions, such as the temporary deprivation of the benefits of free trade or the posting of bonds (for example permits that would otherwise be allocated to the country) that are forfeited in case of reneging (where "reneging" is defined by a dispute resolution body).

Finally, one will have to monitor indebtedness. Some countries will lag behind in their emissions allowances position (after selling allowances forward or entering into *ex post* unprofitable speculative contracts in the allowance futures market) and may at some point choose not to honour their liabilities. Some thought need to be given to how to limit this form of reneging. Private actors may be subject to margin calls on an exchange. For governments, this problem is more broadly that of reneging on sovereign debt. The IMF might be a natural intervener here. The proper design of monitoring of indebtedness will probably have to be thought about together with that of the monitoring structure more generally.

2. - The Political Economy of an Agreement

2.1 *The Compensation Principle*

Countries, industries and firms that are, or anticipate being, large emitters will strive either to keep carbon prices low or to be exempted from carbon taxation. For instance, emerging countries are concerned that high carbon prices will hinder their growth and point out that developed countries were able to build theirs in a free-carbon context. Countries with high coal content power generation (90% for Poland, 80% for China and Australia, 70% for India, 50% for the US and Germany) may not naturally welcome a stringent control of emissions. The OPEC won't approve of a tax that will crowd out its oil rent. Airlines would prefer to avoid an Aviation Trading System (ATS) and its integration of the ATS within the ETS.

On the impact side, global warming also affects countries differently. In particular, the fight against global warming impacts world inequality. Global warming losers include some very poor countries such as those in Sub-Saharan Africa, in the Asian deltas, in the Pacific islands or on the Mediterranean coast. By contrast, beneficiaries of global warming have little incentive to participate in a fight that both proves costly and deprives them from benefits.

Obviously, reaching an agreement requires some kind of transfers. This is indeed true of any negotiated environmental reform. As we already noted, a classical instrument for achieving compensation and getting everyone on board in a cap-and-trade system is the allocation of allowances. Typically, allowances are "grandfathered": they go to previous issuers in proportion of previous emissions. A case in point is provided by the 1990 Clean Air Act Amendment in the US, which allocated future permits on the basis of 1987 pollution levels. Grandfathering was the only way to induce mid-western states to accept the new cap-and-trade system to regulate SO_2 and NO_x[24]. The mid-western power companies' increase in cost associated with either abating pollution or paying for permits was in part offset by the value of the free permits they received. That way, compensation was achieved without sacrificing efficiency, since at the margin all emitters face the market price for their pollution regardless of whether they received permits for free or not.

Needless to say, grandfathering is way too simplistic in the case of global warming. It would amount to a free distribution of permits to current emitters and would in particular benefit the US and other developed countries. Even if one ignored fairness issues, this is a problem: under "Business As Usual", emerging countries will increase their emissions much more than developed ones as their income catches up with the OECD ones. Furthermore and as we have noted, countries that are particularly threatened by global warming have more to gain from an international agreement than others. See Tirole (2009) for more on the principles that might guide compensation.

Compensation through the initial allocation of permits is preferable to other ways of bringing countries on board. For example, a popular proposal is to exempt developing countries from the need to set an emission target until 2020. This approach is highly inefficient as it amounts to setting a 0 price for carbon in the next decade for developing countries[25]. Let us remind ourselves that China alone is building one coal-fired plant per week. Provided one can develop registries and keep track of emissions in these countries, both developing and developed countries have to gain from subjecting developing countries to a

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[24] See JOSKOW P. *et* AL. (2000) for a fascinating account of the politics of the Clean Air Act Amendment.

[25] Some studies have indeed shown that the cost of mitigation would increase substantially if emerging economies delayed their participation. See *e.g.*, BOSETTI V. - CARRARO C. - MASSETTI E. - SGOBBI A. - TAVONI M. (2009).

global cap-and-trade system, and from compensating them through a distribution of permits.

To be sure, actions are and will be undertaken even in the absence of binding constraints. A variety of motivations explain this: collateral damages (coal plants give rise to SO_2 emissions as well to CO_2 emissions; as the former have a more local impact, even selfish behavior commands some effort to increase energy effectiveness of coal-fired plants); direct internalization of some of the global impact of CO_2 emissions for very large countries (China, India); and desire to placate domestic public opinion and to avoid international pressure. But we have no way to judge whether these actions will be sufficient, and both history and theory make us pessimistic in this respect. The refusal to enter binding agreements is telling too.

2.2 *Free Riding and Leakage*

As is well-known, the Kyoto protocol, while important symbolically, has had a limited effect. This was all the more predictable that Kyoto members with commitments faced loose sanctions for reneging, that the US failed to ratify and that large emerging countries that signed the protocol (such as Brazil, China, and India) made no commitment.

In the absence of binding agreement on climate control (an "International Environmental Agreement", or IEA), national interests are likely to defeat the search for the common good:

• *Free riding*. Each country would like other countries to incur the abatement costs. Free riding (the celebrated problem of the commons) exists even in the absence of international trade. Simply, individual countries do not internalize the impact of their own emissions on the rest of humankind.

• *Leakage*. The free riding problem is exacerbated by the presence of trade. A country that sets a domestic price for carbon may just handicap its own industry and actually do little for the environment, as production and investment move to environmentally more lenient countries.

The consequences of a lack of agreement are clear: too much pollution, and for a given overall level of pollution, an inefficient allocation of abatement costs. Negotiators of the Kyoto protocol realized this, and tried to respond to the inefficient-location-of-abatement-effort problem through the Clean Development Mechanism (CDM), which allows investors in Kyoto Annex I countries (industrialized countries) to undertake carbon-reducing projects in less-developed signatories and obtain credits for these projects in the form of certified emissions reductions (CERs). We return to CDMs shortly.

2.3 *Pre-Agreement Arrangements and Incentives to Join an IEA*

If one sets aside international opprobrium (necessarily short lasting), a country's bliss point corresponds to its staying out of a global agreement that severely constraints the other nations. A country will join an agreement only if its welfare when joining exceeds that from staying out. The former depends, *inter alia*, on the allocation of permits among countries (in the context of a cap-and-trade design). The latter hinges both on the signatories' agreement (its abatement target) and on their policy *vis-à-vis* non-signatories. This section discusses how signatories (at least those with commitments) interact with non-signatories or signatories without commitments.

2.3.1 The Costs and Benefits of CDMs

The Kyoto protocol allows the countries in Annex I to obtain credits that count toward fulfilling their commitment, provided they implement certified carbon-reducing projects in LDCs[26]. The

[26] This UN Clean Development Mechanism should not be confused with other forms of offsets, such as those traded under the cap-and-trade scheme set up by the Chicago Climate Exchange, where the criteria for obtaining credits are less strict than under the CDM rules.

For a description of the CDM mechanism and the emergence of a market for CDM credits, see, *e.g.*, LECOCQ F. - AMBROSI P. (2007).

CDM mechanism, whose extension is currently under discussion, has two main benefits:

• It is market-based to the extent that the value of credits obtained under a CDM project is linked to the market price of allowances. For example, the European companies engaged in CDM initiatives may obtain CERs in the form of permits in the European Trading System (even though in practice the price of these credits tends to be smaller than the price of tradable permits). It therefore allows the international community to benefit from cheap-abatement-cost opportunities for reducing GHG emissions.

• It is a form of aid to poor countries[27]. Given the low overall level of international aid to poor countries, this is not to be neglected.

The CDM mechanism raises some issues, though:

• It involves high transaction costs. In order to limit windfall profits and costs for Annex I countries, the protocol insists on the projects being "additional". This requires contemplating a counterfactual, namely what would have happened in the absence of the project: would the country or the firm in question have undertaken an investment in abatement in the absence of the project[28] (a question which is hard to answer without going through the anticipations about future negotiations)? The parties involved have a strong incentive to inflate their estimate of the

[27] This point has been criticized to the extent that China has so far been the beneficiary of almost three fourths of CDM income. Some have also argued that the program is too costly. It is widely reported for example that China received about \$4.3 billion for reducing HFC-23 emissions while spending only about \$100 million in these projects.

[28] A variant of this complexity arises for new projects or replacement investments, which may offer a range of technological choices with different carbon emissions. The CDM supervisor (the CDM Executive Board) must then guess which variant would have been adopted in the absence of a program.

Furthermore, even with full information, projects may be financed, that should not exist in the first place. Take a choice between a clean project, yielding profit $v < 0$, and a project emitting 1 ton of carbon and yielding profit $V > 0$ in the absence of carbon taxation. From a social perspective, none of these projects should be implemented whenever $V - p < 0$, where p is the carbon price. However either the brown project (when $v + p < V$), or the unprofitable green one (if $v + p > V$) will be implemented. The CDM institution provides proper guidance with counterfactual pollution. Furthermore, answering this question properly may require looking beyond the project itself. Consider for example a project that prevents the deforestation of an area[29]. The demand for wood, soy or any other product of deforestation remaining what it is, this reduction in deforestation is likely to be compensated by an increase in deforestation elsewhere in the same country or in a different country. The net effect on CO_2 emissions is then nil. This emphasizes the need for environmental mechanisms that are comprehensive in their scope.

• The very prospect of benefitting from CDM projects tomorrow may discourage LDCs from undertaking abatement projects on their own. In the extreme case, companies located there might want to keep operating old, highly-polluting and uneconomical plants in order to be eligible for CDM money[30].

• Last, the CDM mechanism rewards countries that stay clear of commitments. It is by no means obvious that they thereby provide good incentives to join a (constraining) IEA.

2.3.2 Addressing the Leakage Problem

The leakage problem has until now remained a minor one. Low carbon prices and sectoral exemptions have hardly broken the industrial level playing field between countries that are subject to carbon pricing and the rest of the world. This obviously may change as carbon prices reach more reasonable levels.

To offset the leakage problem, several approaches have been considered (none of these approaches can address the pure free-riding problem: the carbon emitted in the production of goods

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regards to the choice of variant, but encourages projects that would be unviable under carbon taxation, as it embodies a lump-sum subsidy equal to the value of permits corresponding to the pollution in the most profitable alternative under free carbon.

[29] Land Use, Land-Use Change and Forestry (LULUCF) projects have been included in the CDM mechanism in 2003.

[30] This also holds for countries. As De Perthuis C. notes (2009, page 139), in order to qualify on the additionality criterion, the project must not just respond to an existing regulation. This provides countries with an incentive to delay the introduction of environment-friendly regulations.

and services for the internal consumption of non-signatories or signatories without commitments cannot be taxed):

• exempt exposed sectors from carbon taxation. Such a policy would re-establish the level playing field. It however is wrong-headed, as it amounts to exempting these industries from carbon taxation[31]. It further leads to a strong lobbying effort by all industries to "demonstrate" that they are "exposed".

• providing exposed sectors with free permits. The European Commission[32] has advocated that exposed sectors be awarded free permits. This approach shares with the former the drawback that it gives lobbies a strong incentive for rent seeking; this is indeed what we already observe. But unlike the former approach, it does not restore the level-playing field, as the *marginal* cost of permits remains the market price for those firms which receive free permits. So the leakage problem is not resolved, and the policy has just operated a windfall transfer to the beneficiaries.

• taxing imports and subsidizing exports to reflect the difference in carbon taxation across countries. This can be done in multiple ways: first, by requiring that importers, say, acquire tradable emission permits in quantity corresponding to the carbon content of the imports (or some other measure, see below). Second, one can levy a border tax adjustment (BTA) on a similar basis. The two approaches (which we gather loosely under the name of "border tax adjustment") are equivalent if the tax is, as it should be, based on the carbon price in the ETS market.

The latter approach (restoring the level-playing field while maintaining carbon taxation) dominates the former two on a theoretical ground. It further puts pressure on countries without commitment to abatement to join an international agreement[33]. To be certain, and as we already observed, it does nothing to solve the problem of pollution in production for own consumption by

[31] As a matter of principle, carbon taxes should not be differentiated across sectors, provided that the country can use import and export tariffs to prevent leakage: see HOEL M. (1996).

[32] In particular, Industry Commissioner Gunter Verheugen.

[33] In this respect, one could even envision adjustments that use a carbon price in excess of the ETS price so as to add to the pressure to join an agreement.

non-signatories, but this is irrelevant to the problem at hand. The devil is in the details, tough:

• *Measure of carbon content*. The first key obstacle to border tax adjustments is technical. Consider for instance the case of imports from a non-signatory country to a signatory country: how does one measure the direct and indirect CO_2 emissions embodied in imports? A benchmark based on the carbon content in the importing country may well be inadequate, both because countries exogenously have different technologies and energy portfolios, and because they react to differentials in carbon taxation by adopting different technologies. One could alternatively use the average carbon content of the exporting country, assuming this content is measurable. Even this is not satisfactory either. Suppose for example that exports are electricity exports, and that the exporting country's generation portfolio has a fixed supply of hydroelectric power (clean energy) and an unlimited amount of coal (highly carbon intensive). The marginal generator is therefore a coal generator, and its carbon emissions may vastly exceed the average carbon emissions in producing electricity in the exporting country. The same example shows that it may be hard to exempt exporting firms that can demonstrate that their production is "carbon light"; in our example, a hydro producer who is connected through a connector to the importing country could claim that its emissions are very low. But its export creates a substitution toward coal domestically. More generally, if border tax adjustments are computed on the basis of the source's actual emissions, one would expect clean products to be exported and carbon-intensive ones to be kept for domestic consumption. Overall, economically-relevant measures of carbon content are likely to be information intensive and involve substantial administrative costs, while simpler measures may have no connection with the marginal impact of imports on the environment.

• *Protectionism*. Another important critique of border tax adjustments is that countries (especially in the aftermath of the current economic crisis) are likely to use them as an excuse to engage in protectionism. This real concern would be alleviated if the choice of such measures or at least the *ex post* control thereof (based on disputes) were to be made by independent bodies. A model in this respect could be the WTO dispute resolution mechanism.

There is no good solution to the leakage problem. Re-establishing the level-playing field through border tax adjustments is rather unappealing and just a hopefully-temporary *pis-aller* meant to put pressure on countries that do not want to adhere to binding agreements. We should expect significant costs if a BTA is put in place.

2.3.3 Global *vs.* Sectoral Agreements

It is often argued that one would be better off breaking the negotiation into manageable pieces. For example, the Bali Action Plan mentions the possibility of "bottom-up sectoral targets". Under such a mechanism, LDCs would be allowed to earn certified emissions reductions (CERs); and the targets would be "no-lose" (there would be no sanction if they were not attained).

Little analysis has gone into thinking why sectoral agreements would be more appropriate than a global one. Because the industry has a conflict of interest in reaching a sectoral agreement, sectoral agreements must also involve governments. The sectoral approach thus multiplies the number of agreements that countries must negotiate. To be sure, a global agreement cannot do without sectoral considerations, if only because monitoring technologies need to be put in place and because compensation must be calibrated.

But, like in the case of standards, sectoral agreements raise concerns with respect to price coherency and the related issue of lobbying. One may wonder if one will reach a coherent outcome by proceeding piecemeal. My view is that one should stay away from sectoral approaches.

3. - Concluding Remarks and a Roadmap for International Negotiations

This lecture has attempted to shed light on the economics of an international climate agreement. First, it argued that we must not lose track of what design we should aim at. Economics offers a few simple insights concerning price coherency in its various guises, the separation between efficiency and compensation, and the need for a credible commitment. Second, we can expect very inefficient gaming during the transition to an international agreement. It is therefore important to alleviate the incentive to increase emissions and to apply a credible pressure on non-committing countries for them to join, while avoiding self-serving moves by signatories.

Negotiations have stalled. At the date of this writing the Copenhagen Protocol is likely to be an a minima agreement, so that the waiting game that Kyoto was unable to stop will be prolonged until 2020. This would have dramatic consequences.

What could countries do instead? In my view, countries should settle on some early actions and on some broad principles, and a negotiation timetable toward an agreement in 2015-2016:

• they should set a global emissions target for 2050 in conformity with IPCC's consensus view,

• they should agree on the rapid deployment of a satellite system able to measure country-level emissions, and on the allocation of the corresponding cost,

• they should converge on the principle of setting up a long-term, worldwide cap-and-trade type system, leading to a unique carbon price and therefore consistent with the minimization of the abatement cost; this system would make the agreement sustainable and would provide long-term visibility for those who hesitate to deploy green equipments or to engage in green R&D;

• they should design a governance providing incentives to join the agreement (including the eventual demise of the CDM) and to abide by it: for example, by treating countries' resulting environmental debts as sovereign debt (monitored by the IMF), by entering a global trade-environment deal (involving the WTO), by agreeing on a partial withholding of permits awarded to countries, and on a naming & shaming process, and other possibilities;

• they should state a subsidiarity principle, with permits allocated domestically by the countries themselves, on the grounds that *a)* to be on board, governments must be able to build a consensus at home, *b)* it is important to make political leaders receive political benefits rather than backlash from the agreement, and *c)* only a country's global GHG emissions matter to the international community and so domestic policies can be delegated to countries, which will be made accountable for their emissions.

The negotiation for 2015 would then focus on a single dimension: the allocation of free permits to countries so as to get everyone on board; this would involve for example a generous allocation to emerging countries. Complex as it is, the negotiation would still be simpler than the multi-dimensional one that we are engaged in; it would also lower substantially the global cost of abatement. In the current situation, reaffirming and committing to good governance would be a significant step forward.

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