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FLEXIBLE GLOBAL CARBON PRICING: A BACKWARD-COMPATIBLE UPGRADE FOR THE KYOTO PROTOCOL

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Abstract

The Kyoto Protocol's approach of assigning emission targets, or "caps," promises certainty that it cannot deliver, because it exacerbates problems with international cooperation and commitment. Global carbon pricing addresses these problems and, with less risk and more reward, can generate and sustain stronger policies.

This paper proposes a system, "flexible global carbon pricing," designed to replace the Kyoto Protocol. It provides backward-compatibility with the Kyoto Protocol by allowing un-modified cap and trade as one form of national carbon pricing. Instead of many national "caps," the proposal sets a global target price for carbon and specifies a pair of incentives.

A Pricing Incentive rewards nations that set their carbon price higher than the global target and penalizes nations that underachieve. These rewards and penalties sum to zero by design. The strength of the Pricing Incentive is adjusted automatically so that the global average carbon price converges to the global target price.

A Clean Development Incentive (CDI), free from the gaming problems that plague the U.N.'s Clean Development Mechanism, encourages full participation by low-emission countries. An example, based on a $20 price target, causes transfers from the United States of only seven cents per capita per day. Nevertheless, India's CDI receipts cover its compliance costs. The example shows that low costs can be guaranteed.

Keywords

Kyoto protocol ; cap and trade ; flexible global carbon pricing ; international cooperation

Preface

This paper presents a carbon-pricing alternative to the Kyoto Protocol's cap-and-trade approach. To motivate such a proposal, I point out several advantages of global carbon pricing over the Kyoto approach, but these are not intended to be a rigorous comparison of the two systems. The purpose of this paper is to present an alternative system in enough detail that comparisons can be discussed concretely, and to explain the motivations behind various design features and how the features work.

Since technical criticisms of cap and trade can easily be misinterpreted as assigning blame, I would like to point out two significant benefits of having 39 nations adopt emission caps under the Kyoto Protocol. First, this has shown that even with most of the world free-riding, and under a mechanism that provides little incentive for cooperation, many nations are willing to make significant sacrifices for the public good. Second, this has established a carbon price of roughly $30 per ton as a non-trivial starting benchmark. In short, those who accepted caps under the Protocol have put us far ahead of where we would have been under the alternative scenario of no policy.

The source of the current troubles is not those who have adopted caps or implemented cap and trade. Instead, the trouble was caused by the displacement of the carbon-tax paradigm by the cap-and-trade paradigm at the Kyoto conference. The driving force behind the idea of caps was the faulty analogy, originating in the United States, between coal-fired power plants and nations, and between the Kyoto conference and the U.S. government. This proved to be an exceptionally poor guide to the attitudes of developing countries and to the limited ability of the Kyoto conference to enforce its program. Unfortunately, that analogy remains dominant in the United States, which has only just now recognized that China is serious in its rejection of a meaningful cap.

It is also important to recognize that the developing countries are not to blame for the failure of Kyoto's national capping approach. Such caps would necessarily cap the developing countries at per-capita levels far below the U.S. level of emissions in spite of the fact that they have contributed little to the problem of climate change. Also, caps are dangerous for a country like China. For example, its emissions grew 27% between 1990 and 2000. What if it had committed in 2000 to cap itself in 2010 at 27 percent above its 2000 level—a seemingly modest goal? It would have found itself, by current predictions, having to reduce its emissions in ten years by 40 percent relative to business as usual. This would have been exceptionally costly and exceedingly unfair.

1. Introduction*

The Kyoto Protocol has been troubled from the start. Eleven years after its adoption, with the Copenhagen renegotiation conference fast approaching, no clear remedies have been found for the problems caused by the Protocol's emission targets, or "caps." These problems include outright rejection by most countries, a Russian cap so loose it could only increase total emissions, and failures to comply with accepted caps. Moreover, the developing countries, which have rejected caps for 15 years, continue to reject them, and even the United States now admits that China will not accept a cap.

The failure of the Protocol to cap half of all emissions—and by far the faster-growing half—leaves only one small hope for the Kyoto approach. The carbon credits issued under the Protocol's Clean Development Mechanism could be used to pay developing countries to control their emissions. Such an inverted market design, which pays emitters for not doing harm instead of for supplying goods, is prone to corruption (see Appendix A.1). Also it is inefficient because U.N. approval cannot reach

* The author would like to thank Jurgen Weiss, Marcelo Saguan, Douglas Hale, and especially Daniel Kirshner for helpful comments and suggestions. An almost identical proposal is explained in a more elementary fashion in Part 4 of Carbonomics: How to Fix the Climate and Charge It to OPEC, by Steven Stoft, Diamond Press, 2008.

moderate-to-small-scale efforts. Clearly the developed countries are not about to finance such an in appropriate and expensive method of reining in the larger part of the world's emissions. The Kyoto approach has reached a dead end, and a new approach is necessary.

A number of leading U.S. economists have believed this for some time; see Richard N. Cooper (2008, 2007, 2000, 1998), N. Gregory Mankiw (2008), William D. Nordhaus (2008, 2007a, 2005), and Joseph E. Stiglitz (2007). James E. Hansen (2009), the climate scientist most respected by environmentalists, shares this view. Under the circumstances, it seems prudent to explore the alternative approach suggested by these and other experts.

The alternative approach calls for a global target price for carbon emissions, or preferably a target price for greenhouse gases. This single target price would replace all national caps and would apply as well to nations currently without caps. Such an approach aims at achieving international cooperation, unlike the carbon-cap approach, which seeks instead to gain certainty of emissions. But aiming for certainty is no guarantee of achieving it. Industrialized (OECD) countries will increase emissions more than 20 percent by 2012, the end of the Kyoto commitment period, rather than reduce emissions by 5 percent, the goal set in 1997. During that same period, the rate of world emissions will increase by 50 percent.

The real-world uncertainty of caps contrasts starkly with their theoretical certainty. The explanation is that the attempt to lock in quantities with a cap undermines perceived fairness, financial predictability, and enforceability—all qualities needed for effective cooperation and commitment.[1] Moreover, caps reproduce the exact externality problem they are intended to solve. They do this by requiring encouraging every nation to negotiate for a higher cap and against the common interest of climate stability. But requiring nations to agree on a single carbon price target, applicable to all, comes close to internalizing the climate externality. Appendix A.1 explains this point and other uncertainties caused by caps.

Flexible Global Carbon Pricing

Global carbon pricing has been proposed many times. Nordhaus (2008) makes an exceptionally good case for what he calls a system of "internationally harmonized carbon taxes," but he provides few details. Cooper (2008), who proposes to "levy a common charge on all emissions of greenhouse gases, worldwide," provides considerably more detail and makes an equally strong case for global carbon pricing in general and his approach in particular.

Flexible global carbon pricing, presented here, is a third variant of global carbon pricing. Cooper takes a step toward flexibility by stating that his common charge can coexist with cap and trade, provided limits are placed on the variability of permit prices. But he does not provide for the compliance flexibility now offered by international permit trading, which allows nations to miss their target and instead pay other nations for help with compliance. Flexible carbon pricing accommodates such an option. It also provides national discretion in targeting different fuels just as the Protocol's national emission targets provide.

Preview

Flexible global carbon pricing comprises: a definition of national carbon price, the Pricing Incentive, its adjustment rule, and a Clean Development Incentive. Both incentives require transfers of funds, or perhaps of clean-technology shopping credits. These will flow from some nations to others through a central agency. The transfer payment rules guarantee that both incentives will pay for themselves.

[1] China, India and Brazil have expressed their perception of unfairness for the last 15 years. The volatility of permit prices under a cap is well known. Canada provides a prime example of the difficulty of enforcing caps.

Those wishing to see a simple mathematical summary of the basic design should look ahead to Table 2.

- **The definition of the national carbon price**

  To be backward-compatible, carbon pricing must accommodate existing cap-and-trade policies. As will be explained, carbon revenues can be associated with permit retirements under a cap. Revenues from caps and taxes are then used to define a national carbon price.

- **The Pricing Incentive**

  Nations are not required to set their national carbon price equal to the target. Instead the Pricing Incentive, based on national carbon revenues, rewards nations for collecting extra carbon revenue and penalizes them for under-collecting.

- **The Pricing Incentive adjustment rule**

  A reward/penalty percentage Z, for over- and under-collections, is increased annually until the global average carbon price equals the global target price.

- **The Clean Development Incentive (CDI)**

  The CDI encourages low-emission nations to participate fully. It also helps pay their compliance costs, and it encourages all nations to achieve additional emission reductions through non-price policies such as efficiency standards.

Carbon Prices under Emission Targets and under a Target Price

Using a carbon price instead of a cap raises a concern over effectiveness for who favor caps. One simple reminder may allay some fears. A carbon tax of $X per ton should be somewhat more effective than a carbon cap with an average permit price of $X per ton. This is because the volatility of the permit price makes investing more risky. This risk increases the cost of investing, which causes delays and also increases the option value of waiting to invest. And, of course, it must be remembered that the cap itself has no direct effect on business decisions—only the price of carbon permits matters.

From the start of the European Emissions Trading scheme on April 22, 2005 until April 27, 2009, permit prices were 2.9 times more volatile than the U.S. stock market during that same period.[2] Of course a carbon tax can be changed by law, and this creates some risk, but this is mirrored by an equivalent risk of the cap, or one of its safety valves, being changed. So there is no reason to think a tax suffers from greater regulatory risk.

Hence, in order for emission targets to be more effective than a price target, the emission targets will need to generate a higher average carbon price. This could happen if nations vote to lock in emissions targets that produce higher prices than they expect and then comply with those targets. While such a miscalculation seems possible, it seems at least as possible that the unpredictable nature of prices under a cap will cause nations to adopt weak caps to avoid unpleasant surprises.

One advantage of a pricing target is that it is not locked in, as the Kyoto targets have been for 15 years. Since the evidence for climate change is expected to become more dramatic over time, the acceptable cost of carbon policy should be expected to increase over time. As this happens, a price target can easily be increased.

In any case, the price target will be decided politically, based on perceived risks—both climatic and financial. Although the quantity-based approach presumes only science will influence the target quantity, both approaches will face the same political tradeoffs. Because a price-based approach minimizes risks and perceived unfairness, and, as will be discussed, maximizes national benefits and flexibility, the balance of risks may well be struck at a higher carbon price under global pricing.

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[2] Monthly changes in ETS futures with a settlement date of December 2012 were compared with the S&P 500.

The Four Challenges of a Pricing Design

The design of flexible global carbon pricing addresses four major challenges.

1. **Flexibility:** Avoid disrupting existing cap-and-trade systems and allow maximum workable flexibility, guided by incentives, in setting national carbon prices.
2. **Enforcement:** Guarantee that the global carbon-price target is achieved on average.
3. **Clean Development:** Encourage full participation by developing countries.
4. **Non-price policies:** Encourage non-price policies to reduce emissions.

The first challenge is self-explanatory. The second, enforcement, has not been met by the Kyoto Protocol so it remains essential. The third challenge, clean development, is identified by Nordhaus (2008, p. 150.), who suggests that "poor countries might receive transfers to encourage early and complete participation."

The fourth challenge is addressed well by a system of caps, but not at all by simply setting a uniform international price for carbon. Under a cap, energy research and fuel-efficiency standards help to meet a cap. But since these do not tax carbon, they do nothing to help a country comply with a carbon-pricing requirement.

The next four sections present the basic design of this proposal and address the four challenges. Appendix A.2 through A.5 addresses more subtle questions in each of these four design areas. Appendix B presents a more complete design.

2. Flexibility and the Definition of "National Carbon Price"

Accommodation of the European Union's cap and trade system is crucial to the success of any international climate agreement. To accomplish this within a price-based system, define a single *national price,* p , as total national carbon revenue divided by *total carbon emissions,* e_T .

National carbon-price definition: $$p = \frac{total\ national\ carbon\ revenue}{e_T} \qquad (1)$$

The next step is to associate a revenue stream with carbon permits.[3] Carbon permits must be retired periodically to cover emissions. For example, if retirement happens annually, define annual carbon revenue as the number of permits retired times the average price of permits during the year.[4] This rule works whether permits are given out for free or auctioned. Revenues from carbon taxes can simply be added to the revenues associated with carbon permits. Revenues from carbon subsidies must be subtracted. (Because of this, even a carbon price target of zero would have a significant effect if it caused the elimination of fossil-fuel subsidies.)

While cap and trade prices are unpredictable, the enforcement mechanism described in the next section allows for any magnitude of deviation from the global target price. There are rewards and penalties for price deviations, but they should nearly cancel out if permit prices are right on average. Appendix A.2 explains how international offsets could be accommodated.

The flexibility resulting from the total-revenue approach to defining price means a country could tax, for example, only oil or only coal. A carbon tax focused only on oil is of particular concern. However, the Clean Development Incentive (CDI) will be seen to reward any reduction in emissions,

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3 Cap and trade is just a carbon tax set by the permit market. Free permits just give those who receive them a right to some of the tax revenue. Equation (1) is a way of measuring this tax revenue.

4 For the EU's Emission Trading Scheme the price could be the daily average over the emissions year of the price of the ECX EUA Futures contract that settles at the end of the emissions year.

which will encourage a higher carbon price for coal. This and other factors discussed in Appendix A.2 make a serious distortion of carbon prices unlikely. If necessary, the design could easily be adjusted to require some level of emphasis on coal. Flexibility in pricing will encourage participation and the acceptance of a higher target carbon price.

One concern with flexible pricing will need to be addressed from the start: carbon pricing for energy-intensive exports, such as aluminum. Kyoto's caps allow a similar flexibility in carbon pricing, so this concern must be addressed in any case. Energy-intensive exports will need closer international alignment than other sectors, but such details are not discussed in this study.

3. Enforcement: The Pricing Incentive and Adjustment Rule

Global carbon pricing sets a single target price of carbon for the world. A nation can be sure of achieving the target simply by taxing all emissions at the target price. Similarly, a nation can meet a quantity target by capping all emissions. However, as with caps, a more complex policy can introduce some uncertainty as to what emissions level or carbon price will be achieved. Also, under either system, a country can deliberately miss its target. Under the Protocol, a nation can purchase international offsets or allowance from other countries to compensate for underachievement.

As with the Kyoto Protocol, individual nations should be allowed to underachieve the global pricing target. Under flexible global carbon pricing, an underachieving nation can make a payment to a fund supervised, for example, by the U.N. This fund is used only to pay other countries for overachieving their target price.

In effect, this creates a market in which underachieving nations pay other nations to overachieve. On the surface, however, this mechanism functions simply as a monetary incentive that penalizes nations with low carbon prices and rewards those with high carbon prices. But, just as with caps, a nation could underachieve and then refuse to pay, so the payment requirement must be backed by something stronger. As Stiglitz (2007) and Cooper (2008) argue, the World Trade Organization has established a precedent for using trade penalties to enforce environmental concerns. This topic is discussed further in Appendix A.3. The present section discusses how the Pricing Incentive is used to induce nations to set their carbon prices so that the *average global price of carbon* P , will closely track the *global target price*, P^* .

The Pricing Incentive

Because nations vary in size, the Pricing Incentive must be proportional to national carbon price, p , scaled by the nation's level of total emissions, e_T . The result, $e_T \cdot p$, is carbon revenue. The incentive payment is proportional to the amount by which a nation's carbon revenue exceeds its target revenue, $e_T \cdot P^*$. It will prove convenient to express incentive payments on a per-capita basis, so we convert total emissions, e_T , to emissions per capita, e , by dividing by population. The Pricing Incentive is then expressed as follows:

Pricing Incentive payment per capita: $$w = Z \cdot (p - P^*) \cdot e \quad (2)$$

The *incentive strength*, Z , might be, for example, 10 percent.

With P^* = \$20/ton and e = 5 tons per capita, if a country increases its carbon price, p , from \$18 to \$21/ton, its incentive payment, w , will rise from 10%·(\$18−\$20)·5, or −\$1.00, to +\$0.50 for a gain of \$1.50 per person per year.[5] Thus equation (2) provides an incentive for nations at every price level

[5] The cases in which all nations, or none, set $p < P^*$ are handled by the revenue-neutral version of this incentive in Appendix C. In the case without penalties, no rewards are needed, since all nations are over-achieving.

to raise their price. The equation uses annual values, and, as explained in Appendix A.3, payments can be made promptly by using an estimate and true-up.

The Pricing-Incentive Adjustment Rule

The next question must be how to set Z, which is used to control the global average price of carbon. The basic strategy is to raise Z when the average global price, P, is below the target price, P^*, and to lower Z when P is greater than P^*. Increasing Z increases the incentive of every country to set a higher price whether it is under- or over-achieving. A simple rule would be to increase Z in proportion to how far P is below P^*. Algebraically, this would mean:

Pricing-Incentive adjustment rule:
$$Z_{y+1} = Z_y \cdot \frac{P_y^*}{P_y} \qquad (3)$$

where Z_{y+1} is Z in the year following year y.

Although the global average price will fluctuate, this rule prevents it from remaining either above or below P^*, so it will fluctuate around P^*. Generally this should keep the average price quite near the target. Since Z determines penalties as well as rewards, without doubt, some penalized countries will complain that it is set too high. But, remember, any country can avoid the consequences of Z simply by setting its national price to the global target price.

Can the Pricing-Incentive-Rate Z be Estimated?

Even when a nation achieves the target price, and its Price-Incentive payment is zero, incentive strength, Z, is still in control. Its value is the reason the nation did not choose a higher or lower carbon price and miss the target. Because nations always feel pressure from Z, it will be best if Z is small so that enforcement does not seem heavy-handed and does not involve large sums of money when nations deviate from the target price. But we cannot choose Z, since it is determined automatically by equation (3) and by the way nations behave. But to check on whether the design is likely to function satisfactorily, we need to estimate Z.

Most countries would likely prefer to collect and keep \$10 in carbon taxes rather than pay \$1 to other countries. With a Z of 10 percent, they must pay \$1 out of every \$10 not collected, or they must achieve the target price. This suggests that a Z of 10 percent or less might be adequate. But what would a country do if it used cost-benefit analysis? That would mean trading off domestic abatement costs against international payments. Appendix A.3 (Result 1) shows that for such a countries Z would equal their price elasticity of demand for carbon emissions when Z is set for compliance with the target price.

As Appendix A.3 argues, this elasticity is less than the elasticity of fossil fuel with respect to its price. The appropriate time frame for measuring the elasticity is the political time horizon, and energy-demand elasticities are quite low in the short run. Hence Z is likely to have a low value whether determined by political psychology or cost-benefit analysis over a political time horizon. The CDI, which is discussed next provides a reason for Z to be even lower.

4. The Clean Development Incentive

Developing countries have contributed little to the climate problem, but their help is needed to solve it. Low-emission countries have less to tax and a proportionally smaller tax burden. But full participation is still too much to ask of very-low-emission nations without some type of reciprocity transfers. These are provided by the Clean Development Incentive (CDI), which also serves to encourage full participation by low-emission countries.

The CDI relates to both a country's income and its emissions. But for two reasons, emissions per capita should be used to calculate the CDI. First, the purchasing-power-parity problem makes international income comparisons difficult. Second, linking the incentive to emissions encourages emission reductions. In any case, emissions are well correlated with income.

Besides emissions per capita, the CDI will involve a parameter, Q , that determines the incentive's strength. Although Q must be negotiated, we will find an indicator that may serve as a starting point, or perhaps a focal point, for negotiations. The choice of Q will be difficult, but not as difficult as the choices that must be made under the Kyoto Protocol. Under the Protocol's Clean Development Mechanism (CDM), the tightness or looseness of each country's emissions cap will determine its cost of, or income from, offsets. CDM offset payments serve the same functions as CDI payments but are made by the private sector under pressure from governments. The individual national caps used under CDM are like using different CDI parameters—different Q s—for every country.

The CDI design, together with Q , determines transfer payments from high-emission countries to low-emission countries. The transfers could be monetary or could be, for example, shopping credits, good for agreed-upon clean-energy technologies. If the transfers are monetary, the use of the funds could be restricted in some way and overseen by an agreed-upon arbiter. All of these will be matters for negotiation, and are not discussed in this paper.

Designing the CDI

The design of the CDM focuses on transferring funds instead of on incentives. The result is problematic incentives, high expenses, and low emission reductions. The CDI design process focuses on incentives. Fortunately, three different approaches lead to a particularly simple formula for a CDI with good incentive properties. Two approaches suggest the same reasonable value for Q .

The first line of approach considers the classic solution to the problem of global warming when it is viewed as a "tragedy of the commons." In this view the atmosphere is viewed as a global commons which is being over used by an excess of carbon emissions. The classic, market-based, solution to the problem of over-use is to issue equal atmospheric rights to each person and allow them to trade. Total rights are capped at the socially optimal level.

Although this solution is completely impractical, its financial outcome is easily simulated at the national level. National transfers under equal rights are given by $(E-e)\cdot P^*$, where E is the global average level of per-capita emissions, and P^* is the market price of rights. This is the CDI payment formula suggested by the first of our three approaches.

Notice that an average-emissions country, one with $e = E$, will receive enough rights to cover its emissions. So it will neither buy nor sell rights, and the formula shows zero transfer payments. High-emission countries must buy rights, and the formula assigns them a negative payment. Payments to low-emission countries help them cover their cost of compliance. Using this formula, CDI payments would also encourage countries to reduce emissions. So this "equal-rights CDI" has some good incentive properties, and we will soon add to it an incentive for compliance with the global target price of carbon.

Unfortunately, as Appendix A.4 shows, the equal-rights CDI is too strong and too costly. In fact it is so strong that a sensible country would implement a national carbon price equal to P^* just to achieve a lower emissions rate and better CDI transfers. As Appendix A.4 explains, the equal-rights CDI could completely replace the Pricing Incentive except for the fact that its cost to high-emission countries would be politically unacceptable. We need a CDI that is similar but weaker.

The second design approach is cost-based, and so requires a relevant cost to use as a basis its basis. Appendix A.4 shows that the cost $Z\cdot E\cdot P^*$ is an upper limit on the average, per-capita compliance cost experienced by low-emission countries when implementing flexible global carbon pricing. So this cost will be used as a benchmark for payments under a CDI.

The next step is to decide which countries should receive transfers. The most natural dividing line would seem to be the average level of emissions per capita. This means that only those nations with $e < E$ would receive CDI transfers, while those with $e > E$ would pay. A country on the dividing line (with $e = E$) should neither pay nor receive. And countries with emission-per-capita levels near E should pay and receive very little. Only the lowest-emission nations should receive a payment close in value to the full benchmark cost.

This suggests that a country with $e = 0$ would receive $Z \cdot E \cdot P^*$, while one with $e = E$ would receive nothing, and those in between would receive a linearly interpolated value. This gives our second possible Clean-Development Incentive formula:

Possible Clean Development Incentive: $$d = Q \cdot (E - e) \cdot P^*, \qquad (Q \approx Z) \qquad (4)$$

Notice that this is the same formula as found with the equal-rights approach but multiplied by Q. If Q is set to Z, the formula gives a payment of zero for $e = E$, as intended, and a payment of $Z \cdot E \cdot P^*$ when $e = 0$, also as intended. The incentive-strength parameter, Q, has been introduced because the selected cost is only a benchmark—a plausible value, but not one dictated by economic theory or by fully convincing design considerations.

As argued above, Z will likely be much less than one. Hence this formula determines payments that are smaller than the equal-rights payments, perhaps by a factor of ten. Nonetheless, very low-emission countries will undoubtedly have compliance costs well below average cost of all low-emission nations (well below $Z \cdot E \cdot P^*$), so the CDI will more than cover their costs.

Table 1. Annual CDI Payments per Person with Q = 10% and P^* = \$20/ton

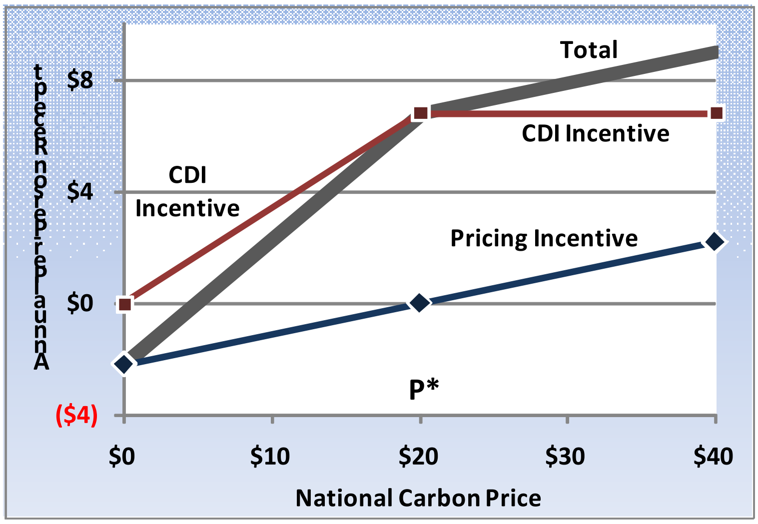
	Emissions per Capita (e)	CDI Incentive per Capita (d)	Total CDI Transfers (billions)
Low-Emitter Nation	1 ton	\$8	\$9
Average Country	5 tons (E)	\$0	\$0
High-Emitter Nation	20 tons	−\$30	−\$9

Payments are per-person and annual.

The basic CDI formula can better be understood with the help of the example shown in Table 1, which is roughly realistic. It assumes Q, in equation (4), has a value of 10 percent, global average emissions is 5 tons per person per year, and P^* is \$20/ton. The values in the third column (d) are calculated from the values in column (e) by using equation (4). Finding the total CDI transfers requires data on total emissions. Note that, as shown in Appendix A.4, and shown in the fourth column of Table 1, equation (4) is revenue neutral.

We would probably not want to make CDI transfers to a country that did not implement carbon pricing at all (that is, a country that set P = 0). Otherwise the CDI would overwhelm the Pricing Incentive for low emission countries and they would be paid for doing nothing. It seems natural to scale back the transfers in proportion to any reduction in compliance with P^*.

Figure 1. Incentive payments for India under Pricing Incentive and CDI, with $Q = Z = 10\%$



So for countries receiving development payments we adjust d, the CDI payment from equation (4), as follows:

$$\text{If } p < P^* \text{ and } e < E, \qquad \text{multiply } d \text{ by } \frac{p}{P^*} \tag{5}$$

The result of applying equation (5) is shown in Figure 1. The graph assumes that $Q = Z = 10\%$ and applies to India which has an estimated emission rate of 1.1 tons/person in 2010, compared with a world average of 4.5 tons. Notice how the CDI transfer increases the incentive for India to achieve the target price, P^*, when $p < P^*$. This effect diminishes for countries as their emissions approach the average, but it encourages low-emission nations to set p near P^*.

Equations (4) and (5) give the flexible-global-carbon-pricing recommendation for the Clean Development Incentive. But the value, Z, should only be interpreted as a recommendation for a starting point, or focal point, for negotiations to determine the CDI strength parameter, Q.

Ultra-Low-Emission Countries

Under the CDI, an extremely poor country, with ultra-low emissions, would receive the largest CDI payment per capita. This will strike some as peculiar. So, let us review what considerations led to this aspect of the design.

First, under the classic solution to the tragedy of the commons, which gives everyone equal atmospheric rights, the lowest-emission countries need the fewest rights. So they sell the most rights and obtain the most revenue. The CDI scales this back, but the result is similar.

The second approach argued directly that low-emission nations should receive CDI payments, and high-emission nations should pay. Extending this trend means the lowest-emission nations will receive the highest CDI payments.

The next section argues for the CDI because it directly encourages lower emissions. Such an incentive naturally rewards the lowest emitters the most.

5. Non-Price Policies

Non-price government programs are still needed even with ideal carbon pricing. These include clean-energy research, siting of transmission lines, mass transit projects, energy efficiency standards, public information programs, and many more. To see how these are treated by the Pricing Incentive alone, consider an example in which a country has set a uniform carbon tax, with tax rate p , on all carbon emissions. When a non-price policy reduces emissions, it will reduce carbon revenue proportionally and the national carbon price will, of course, remain constant at p . As a consequence, the Pricing Incentive payment, $w = Z \cdot (p - P^*) \cdot e$, will remain zero if $p = P^*$. And it will, unfortunately, decrease if $p > P^*$, as the non-price policy reduces emissions, e . So the Pricing Incentive can actually discourage non-price programs that reduce emissions.

Fortunately, as will be seen shortly, the CDI encourages non-price policies by rewarding lower emissions per capita. But if there were no CDI, we would need to invent an incentive for non-price policies. What would it be? Such an incentive would reward emission reductions directly. We would also want it to be simple and revenue neutral. That is best accomplished by the payment formula $Q \cdot (E - e) \cdot P^*$, but what value should be chosen for Q ? As just seen, the Pricing Incentive alone encourages any country with $p > P^*$ to *increase* emissions. Since P^* is the average national carbon price, roughly half of all nations will fall into this category. However, if the CDI is used and Q set equal to Z , all countries with $p < 2P^*$ will have an incentive to reduce emissions. This is demonstrated in Appendix A.5. This should cover all but the countries with the most ambitious climate programs, which should be sufficient. Note that we have arrived back at equation (4).

The CDI solves another, related problem besides the problem with standard non-price policies. It motivates countries to put a higher price on coal carbon because this will almost always cause a greater reduction of emissions than pricing oil or natural gas.

Although, in theory, it should not be necessary, the CDI will almost certainly encourage efficiency standards that should be implemented simply to save consumers money, but which are often overlooked. But it may be wise to explicitly reward standards as well as implementing the CDI. If this is desired, fuel-efficiency standards and the like can be re-designed as feebates. The feebates can be counted as carbon revenue.[6] However, a number of important efficiency standards, such as building codes, cannot be converted to feebates, so CDI is needed for them.[7]

6. Summary of Flexible Global Carbon Pricing Formulas

Table 2 summarizes the basic version of flexible global pricing, while Appendix B presents a more complete version. Implementation requires two fundamental choices: the global target carbon price, P^*, and the strength of the Clean Development Incentive, Q . The value of the Pricing-Incentive-strength, Z , which results from automatically adjusting Z to keep the global average carbon price at the target, is suggested as a reasonable value for Q . This assures that both Z and Q will be reasonably low, perhaps near 10 percent.

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6 A \$1-per-gallon-saved feebate applied to all new cars would count the same as a gasoline tax of \$1 per gallon applied to all the gasoline used by those cars.

7 Subsidies for renewable technology are generally inefficient. Some, such as subsides for residential photovoltaic solar power, are extremely inefficient. For this reason it might be best if they were discouraged by providing them no credit toward carbon revenues. But it would be fair to credit them with revenue equal to the amount of carbon they save times the global target price of carbon.

Table 2. Flexible Global Carbon Pricing with Global Carbon Price Target P^*

National price, p : Carbon-tax plus carbon-permit revenue divided by total national emissions.	$p = \frac{national\ revenue}{e_T}$	(1)
Pricing-Incentive reward or penalty, w : fraction Z of over- or under-collection of carbon revenue per capita (e = national emissions per capita)	$w = Z \cdot (p - P^*) \cdot e$	(2)
Pricing-Incentive-strength adjustment rule: Adjust Z yearly to keep average carbon price, P , very near P^*	$Z_{y+1} = Z_y \cdot \frac{P_y^*}{P_y}$	(3)
Clean Development Incentive: Payments to low-emission countries (d >0) from high-emission countries (d <0). (E = global emissions per capita)	$d = Q \cdot (E - e) \cdot P^*$, $(Q \approx Z)$	(4)
Compliance adjustment when $p < P^*$ and $e < E$	$d \rightarrow d \cdot \frac{p}{P^*}$	(5)

CDI strength, Q , and price target, P^*, are negotiated values, with $Z = Q$ suggested as a starting point for negotiations. All variables are annual; w and d are measured per capita. This is the basic design. The revenue-neutral and stabilized design is given in Appendix B.

7. A Realistic Example of the Design in Operation

Having completed the design, it's informative to see how it might function in the real world. Table 3 illustrates one plausible possibility, but its values cannot be considered predictive. The table is based on the U.S. Department of Energy's estimates of population and carbon emissions in 2010.

The basic result shown in Table 3 is that a moderately strong and effective carbon-pricing policy is inexpensive—about 1/7 of one percent of GDP for the United States in this example. Understanding this requires understanding the true cost of compliance with carbon pricing. This is not related to carbon revenues, but rather to costs that society incurs while adapting to lower carbon emissions. These costs are proportional to the amount of abatement that takes place and to the costs of abatement. The cost per ton of any given abatement can vary from zero to the price of carbon. Few people will spend more than $20 to avoid emitting a ton of carbon when a $20 tax can be paid instead. These considerations suggest the formula commonly used to approximate societal abatement costs:[8]

$$\text{Cost of Abatement} = ½\ (\text{carbon price})\ (\text{emissions reduction}) = p \cdot \frac{\Delta e}{2} \qquad (6)$$

This is the formula used to compute the "Cost of Abatement" in Table 3.

The policy described by Table 3 is a $20 carbon price target that happens to result in a 20 percent reduction in emissions in all nations.[9] This is similar to what is being proposed in the United States in

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8 Emissions reductions becomes scarcer as price increases, so more reductions are available near zero. The formula in equation (6) is used by the U.S. Environmental Protection Agency.

9 For simplicity a 20% carbon reduction is assumed for all regions even though they implement different carbon prices. Also the reduction is not used to alter the emission levels reported by the U.S. DOE for 2010.

early 2009 for the year 2020.[10] However, in this example, the United States participates in a global-carbon-pricing system. The United States, with more than double the emissions per capita of the next highest region, makes the largest CDI payments. Its total cost of abatement, including its share of CDI payments, comes to 17 cents per person per day.

Table 3. Flexible Global Carbon Pricing, a Plausible Example

with target P^* = $20, and Pricing-Incentive, Z , and CDI rate, Q , equal to 10%.

		Non-OECD Countries			OECD Countries			Units
		India	Other	China	E.U.+	U.S.	World	
Inputs	Emissions / Person (e)	1.1	2.9	5.1	8.8	19.3	4.5	tons
	Carbon Price (p)	$20	$14	$20	$30	$20	$21	$ / ton
	Population	1220	3127	1352	893	311	6903	millions
Outputs	Carbon Revenue	$22	$40	$102	$263	$387	$94	$/capita-year
	Pricing Incentive (w^*)	$0	–$2	$0	$6	$0	$0	$/capita-year
	Clean Dev. Incentive (d^*)	$7	$2	–$1	–$7	–$25	$0	$/capita-year
	Transfers ($w^* + d^*$)	$7	$1	–$1	–$1	–$25	$0	$/capita-year
	Cost of Adaptation	–$2	–$4	–$10	–$26	–$39	-$9	$/capita-year
	Transfers + Cost	1.3¢	–1.0¢	–3.1¢	–7.5¢	–17.4¢	–2.6¢	**¢/capita-day**

That 17 cents is comprised of less than 7 cents for CDI payments and less than 11 cents for society's cost of emission abatement. To check the abatement cost, note that U.S. citizens will reduce their carbon emissions by 20 percent or 3.86 tons per person per year. Under the assumed carbon price of $20/ton, equation (6) gives a total abatement cost of $\$20 \cdot \frac{3.86}{2} = \$39$ per person per year, a bit less than 11 cents per day.

Could there be some significant underestimate of cost? To check equation (6), note that an MIT study (Paltsev *et al.*, 2007) of cap-and-trade policies in the United States modeled a carbon tax and found values that show equation (6) overestimated costs in every case, especially in the early years. Could the Pricing Incentive strength, Z , be underestimated? It could be, but since the United States sets its carbon price, p , equal to the target price, P^* , in this example, Z has no effect.

Could the CDI strength, Q , be underestimated? If a policy of setting $Q = Z$ has been adopted, then an underestimate of Z would mean an underestimate of Q . But as noted, $Q = Z$ is only an initial bargaining point, and this example assumes that Q has been set to 10 percent. Hence Q = 10 percent should simply be viewed as the chosen value of Q .

A separate concern from the total cost to U.S. citizens will be the amount of money spent on CDI payments. This comes to about $8 billion per year (not shown) or 1/18 of one percent of GDP. For comparison, $20 billion per year would be allowed in this example under the initial Waxman-Markey proposal (March 31, 2009) for the purchase of international offsets. That proposal specifies that one billion tons of foreign offsets may be purchased, and these could cost nearly $20 per ton.

[10] The draft Waxman-Markey bill of March 31, 2009 includes a cap and trade program designed to reduce emissions 20% by 2020 and the EPA estimates the price of permits at about $20/ton at that time.

In contrast with the United States, very poor countries, such as India, come out a little ahead on the transfer payments, $7 per person per year in this case. But if emissions reductions are 20 percent, the social abatement cost of the carbon tax will be $2 per person. So the net gain to India's citizens will be a little over one cent per person per day.

Everything in the example is under policy control except for the amount of emissions reduction. But if they were half as much, it would cut in half the cost of abatement, making it cheaper than shown to set the target carbon price to $20 per ton. If this is seen to be occurring, the low cost will encourage an increase in the target carbon price. If the reduction were double, it would mean that a dramatic, 40 percent, carbon reduction would be achieved for only twice the cost shown—$130 billion per year, instead of $65 billion. That is less than one quarter of one percent of world GDP.

8. Energy Security Benefits

Saving on Oil

Global carbon pricing will reduce carbon emissions globally. In part, that means reducing oil use, which will reduce the world price of oil. A $4-per-barrel reduction would save oil-importing nations $65 billion per year, an amount equal to the world's cost of carbon pricing shown in Table 3.

Countries will likely focus their carbon pricing more on oil than on coal, and those that now subsidize gasoline will instead tax it.[11] A calculation in *Carbonomics* (Stoft, 2008, p. 252) confirms that large oil-import cost savings are likely.[12]

The likely focus on oil could save enough money to make significantly higher carbon prices acceptable. Lower oil prices in five years are a more immediate and tangible reward than improved climate in forty years. This motivation for carbon pricing should not be ignored.

In contrast to flexible global carbon pricing, a broad cap-and-trade approach keeps the price of oil-carbon equal to the price of coal-carbon. This is theoretically incorrect, because it ignores the financial and security benefits of reducing oil imports.

India, China and the United States

China and the United States alone account for roughly 40 percent of all carbon emissions, and with India included, these three countries span nearly the full range of emissions. The views of these countries regarding global carbon pricing will be key to its chances for acceptance.

India strongly opposes accepting any cap that might limit its economic growth. Global carbon pricing allows India to make a verifiable commitment as a full and equal participant without accepting a cap. Moreover, the Clean Development Incentive could assure a net economic gain for India for a number of years to come. Like China and the United States, India also has a strong interest in reducing oil prices. Flexible global carbon pricing will do more to limit world oil prices than any other strategy India could undertake.

China's per-capita emissions are four times greater than India's, and by 2010 its emissions should be above the world average. As a consequence, China would actually pay a small amount under global pricing's CDI, unless it sets its carbon price above the target or works hard to reduce its emissions. So why should China consider such a plan? First, note that its CDI payment in 2010 would be 25 time

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[11] Also with a CDI, and especially if feebates are credited as carbon pricing (see footnote in Non-Price Policies), global carbon pricing will stimulate fuel-efficiency standards or efficiency incentives for cars and light trucks.

[12] This is based on a conservative estimate of oil-price sensitivity from the International Energy Agency.

less per person than the U.S. payment. Second, in the example of Table 3, its total cost, CDI plus the cost of adapting to lower emissions, comes to only $11 per person per year, or about 1/10 of 1% of GDP. That cost is the same as if China gave up one week of economic growth—not one-week-per-year, just a single one-time delay.

But China will gain an overlooked advantage—savings on imported oil. China is predicted to find itself importing 80 percent of its oil by 2030, leaving it highly vulnerable to oil-price spikes. And by 2030, without a strong international effort, such price spikes will likely be frequent and worse than the spike in 2008. Because global carbon pricing causes all participating nations to reduce oil use, China would benefit from the efforts of every other nation. But that will happen only if carbon pricing succeeds. And that will happen only if China joins the effort.

The United States emits nearly four times as much carbon per person as does China. Consequently its CDI payments are significant, though still tiny as a percent of GDP. But compare global pricing to a system in which the developing countries do not make any binding commitments. The United States might meet its own cap through the purchase of one billion tons per year of foreign offsets—as under the Waxman-Markey (2009) proposal. But this would cost more than the CDI payments in Table 3 and would have far less impact on emissions from the developing countries than would their commitment to carbon pricing. The United States would also benefit substantially from reduced oil prices, perhaps enough to pay the cost of carbon pricing.

9. Summary and Conclusion

Stopping climate change requires global cooperation. The Kyoto approach assumes cooperation and focuses on controlling the quantity of emissions.[13] That focus undermines fairness, financial predictability, and enforceability—qualities needed for effective cooperation and commitment.

In contrast, global carbon pricing is designed to encourage cooperation and commitment. It assumes that, in the long run, caps cannot trick the world into spending more on emission reductions than it would spend under a system with clear and predictable cost commitments.

Global carbon pricing eliminates the probability of unpleasant cost surprises. It allows developing countries to commit without committing to the caps they have rejected as inequitable. The requirement of a carbon price can be met quickly and surely, and there is no need for corruption-prone carbon offsets.

Flexible global carbon pricing is designed to overcome four design challenges. First, flexible pricing fully accommodates cap-and-trade policies.

Second, carbon pricing is enforced by a Pricing Incentive, but only on average. Nations can underachieve and effectively pay others to overachieve. Since the global average is all that matters for the climate, this is sufficient. Incentive penalties are backed by trade sanctions.

Third, the Clean Development Incentive (CDI) encourages low-emission countries to participate fully. Under it, high-emission nations contribute funds, and low-emission nations are paid in proportion to how well they achieve the global pricing target. The CDI approach is far cheaper than paying for clean development one project at a time through the Kyoto Protocol's corruption-prone CDM.

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[13] For a decade, Kyoto proponents have assumed the developing countries were bluffing with their logical and vehement objections to caps. So they have felt no need to address their concerns. This was most recently expressed by Al Gore, "If the United States leads, China will follow." (Guardian, 2009.)

The forth challenge of carbon pricing is to reward nations that reduce their emissions-per-capita using policies other than carbon pricing, such as energy research and energy-efficiency standards. The CDI, serving double duty, addresses this problem as well.

Two aspects of the climate problem are unusual and dangerous. First, action is needed now to protect against damage that will occur in the distant future, and that means action must be based on uncertainty. Second, the climate externality means every nation has a strong incentive to avoid contributing its fair share to the solution. These problems make cooperation difficult.

The emissions-cap approach denies uncertainty to focus on locking in emission quantities. And it reproduces the externality problem with individual national emission targets monetized by permit trading.

In contrast, flexible global carbon pricing focuses on facilitating cooperation and commitment. It respects the requests of developing countries not to restrict their growth, and it targets a single carbon price for all—inducing some commonality of interest. If the world is to address global warming successfully it must learn to cooperate. And cooperation is best learned by building trust, not by attempting to lock each nation into an individually-negotiated 15-year commitment of unknown cost.

Appendix A

Appendix A provides a more detailed discussion of points made in the introduction and in each of the four major design sections: flexibility, enforcement, clean development, and non-price policies. The numbering and headings in Appendix A match those in the paper's body.

A.1. Introduction

International Cooperation and Commitment

Cap-and-trade advocates promise "high certainty because emission guarantees are built into the policy." But this fails to account for what might go wrong as the world attempts to negotiate, implement, and enforce these built-in guarantees. And, as Nordhaus (2008) says, "Quantity-type systems are much more susceptible to corruption than price-type regimes." Here are some of the problems that make quantity targets uncertain.

Capping Low-Emission Countries. Any cap that causes India, for example, to reduce its emissions before 2020 must cap India at a per-capita level 10 times lower than any level Americans would accept. The objections of developing countries will likely continue, resulting in an absence of any firm commitment. This dramatically increases emission uncertainty.

Compliance-Cost Uncertainty. Cost uncertainty gives opponents their most effective argument against a climate policy and causes its supporters most concern. This blocks commitment, and, depending on the cost outcome, will cause some committed nations to renege.

Negotiations and Delays. Permit trading monetizes the value of a caps, and increases the difficulty of negotiating individual caps. If caps are accepted, nations will need to design and test complex cap-and-trade systems.

The Clean Development Mechanism. As discussed below, this backward market for *not* supplying "bads" will face growing opportunities for gaming. This makes the effect of caps on developed countries uncertain, and emission reductions more uncertain.

Achieving Targets and Enforcement. The Kyoto Protocol set targets 15 years in advance. But China's emissions grew 27% in ten years from 1990, and will grow an estimated 127% in the ten years from 2000. No one guessed this in 2000. Because long-range targets are known to be inaccurate, they provide a ready excuse for underachievers when they miss their targets. This makes enforcement of quantity targets nearly impossible.

Cap and Trade. As caps bind tighter, say in the 2020s, permit prices will become substantial. Already these prices are understood to be taxes passed on to consumers. Someday, their normal volatility will result in an unfortunately large and rapid price increase. Then a voter backlash against tax rates set by speculators will become almost inevitable.

International Unraveling. When national caps fail because of enforcement problems or a cap-and-trade backlash, it undermines the stability of the international agreement.

Incentive Problems with the U.N.'s Clean Development Mechanism

Incentive problems with the Kyoto Protocol's Clean Development Mechanism stem from two sources. First, although CDM poses as a market mechanism, it lacks the crucial character of a market—consumers who care about the quality of what they purchase. In the CDM market consumers only care about price, so the quality of CER offsets would fall to zero if the U.N. were not enforcing quality.

Unfortunately, quality must be defined by the "additionality" of the emissions, but the baseline for this determination becomes increasingly murky over the years. Already the vast majority of project applications must be rejected as fraudulent and the U.N. has had to suspend Det Norske Veritas, its original and most trusted verifier of CDM projects. Along with flaws in its auditing process, DNV had signed off on five projects it had not reviewed. (AccountancyAge, Dec. 1, 2008.)

The root problem is that the incentives in a market for ***not*** supplying "bads," as opposed to a market for "goods," are hopelessly misaligned at all levels. This is why the only private markets that pay people not to do bad things are known as "protection rackets" and blackmail. A market for "bads" is not a new idea in need of improvement, it is simply a bad, and very old, idea. There will be times when it is necessary, but for the most part, the CDM market is entirely unnecessary. A carbon price would work far better.

Can a global carbon price internalize the climate externality?

National caps reproduce the externality problem that caps are intended to solve. A nation that manages to raise its cap, as Russia did, gains the full benefit of increased emissions but incurs only the same small fraction of the climate costs normally incurred when increasing national emissions. When nations are forced to vote on a single global carbon price, this does not exactly force each nation to internalize the external cost of its emissions. Rather, when a given nation votes for higher emissions, it finds it must accept the effects on itself of more emissions from all other countries. The effect is similar to internalization of the external effects and it dramatically improves cooperation.

Internalizing externalities would cause a nation that is immune to climate change to vote for lower emissions. Implementing a single global cap or carbon price, unfortunately, does not accomplish this. No policy set by a vote of nations seems capable of true internalization, but voting on a single global cap or a single global price comes close.

A.2 Flexibility and the Definition of "National Carbon Price"

How problematic is uneven carbon pricing within a nation?

In theory, under flexible pricing, a nation could choose only the least effective fossil-fuel tax. In fact, economic theory predicts a tilt in this direction, because the cost of adapting to a tax is proportional to its effect.[14] However, the CDI rewards every decrease in emissions per capita, which provides one reason to raise the price on any fuel, say coal, that responds more to price. This tilts carbon pricing back in the right direction. However, if a nation is strictly minimizing the total economic cost of compliance, the CDI will not have a strong-enough effect to equalize prices across fuels. While the political process of price-setting is unlikely to pay much attention to such economic calculations, it's worth checking them a bit more closely.

Suppose one fuel, oil, is five times less responsive to carbon pricing than another fuel, coal. Because the social abatement cost due to carbon pricing is given by $p \cdot \frac{\Delta e}{2}$ (equation (6)), oil will have a five times lower abatement cost if exposed to the same carbon price as coal. A government could take this into account and minimize social cost by imposing a five times higher carbon price on oil. This is called Ramsey-Boiteux pricing, and it is an efficient way to tax, though unpopular for other reasons.

[14] If a tax did not reduce emission, it would impose no adjustment costs; it would simply transfer revenues from one group to another. So a tax that did not reduce emissions would be the cheapest form of compliance.

But for a Pigouvian tax (used to reduce pollution, not to raise revenue) this type of pricing is not efficient. Instead, a uniform carbon price is efficient. In the present example, Ramsey-Boiteux pricing would result in a 45% loss of emission reduction compared with efficient uniform pricing. But this does not take account of the fact that oil has energy-security externalities and should be taxed more for that reason. It also does not take the CDI into account. Moreover, governments have almost never engaged in Ramsey-Boiteux pricing, even when it was recommended. In any case, if pricing unevenness proved to be a serious problem, the system could be amended to limit the extent of unevenness.

It should be remembered that even Europe, which has adopted permit trading to equalize prices, has missed the mark of uniform prices by a wide margin. Carbon taxes on gasoline are vastly higher than those on coal. In fact, nations have legitimate reasons for some internal unevenness in carbon pricing, such as health and energy security. So insisting on completely equal carbon prices may not improve efficiency.

Can flexible carbon pricing accommodate international cap-and-trade offsets?

Currently, the EU's Emission Trading Scheme relies partly on purchases of carbon offsets ("Certified Emission Reductions," or CERs) under the U.N.'s Clean Development Mechanism. This system could continue and be integrated into flexible global carbon pricing. For example consider a purchase of Chinese CERs by the France. The payments from French companies would be counted as carbon revenue collected by France and the emission reduction would, of course, reduce China's emissions per capita. As an alternative approach, it might work to credit both the EU and China with a transfer payment that would be counted against their incentive payments.

A.3 Enforcement

Enforcing Incentive Payments with Trade Sanctions?

An international climate agreement is a lot like a cartel—the member nations agree to follow the rules for mutual benefit. But following the rules is against their self interest, even though having the organization succeed is very much in their interest. As a result, cartel members usually cheat and cartels usually fall apart. Almost certainly, a successful climate agreement will require some method of enforcing its rules.

As Joseph E. Stiglitz (2006) explains in his recent book, *Making Globalization Work*, "There is already a framework for doing this: international trade sanctions. The Montreal Protocol on ozone-depleting gases employed the threat of trade sanctions-though they never had to be used." But as he also notes, this approach has been tested in a judicial proceeding of the World Trade Organization (WTO).

The United States passed a law forbidding importation of shrimp caught in nets without U.S.-style turtle excluder devices. The World Trade Organization (WTO) at first ruled against the United States because it had not applied its regulation fairly, but in this ruling it stated unequivocally, "We have not decided that sovereign states should not act together bilaterally, plurilaterally or multilaterally, either within the WTO or in other international fora, to protect endangered species or to otherwise protect the environment. Clearly, they should and do." Eventually, the U.S. corrected the unfairness and the WTO ruled in its favor.

Clearly, if the United States can enforce its view of global turtle endangerment with trade sanctions, the U.N. could enforce a climate agreement with trade sanctions. Since the poorest countries profit from compliance and most wealthy countries will likely cooperate voluntarily, such enforcement should rarely be needed. Moreover the possibility of trade sanctions will induce most countries to play it safe and comply, even if not so inclined.

Won't payments be delayed too long by the need to estimate emissions?

Most nations will know what price of carbon they set and how much revenue they collected. This will provide a good estimate of emissions. Other indicators, such as past trends and GDP, can be used as well. Incentive payments are not based on year-to-year changes, but on aggregate values that change slowly from year to year, so accuracy is not difficult.

The simplest quick estimation procedure is to ask each country to estimate their own emissions, and then charge them a slightly high rate of interest on funds they over-collect and must return when the final accounting is made. A risk-free interest rate would be paid on over-payments.

Can the Pricing-Incentive-Rate Z be Estimated?

This section in the body of the paper mentioned Result 1, which concerns how a nation would respond to the Pricing Incentive if it used cost-benefit analysis. Assuming that nations minimize the social cost of adapting to carbon pricing, we have Result 1, which is not intuitive, but is demonstrated in Appendix D.

Result 1: If η is a nation's short- and long-run price elasticity of the demand for carbon, then, when Z is set so that a nation chooses to set p equal to p^*, $Z = \eta$.

This gives us several reasons to believe that Z will be small. First, the long-run price elasticity of energy is generally thought to be fairly low. Nordhaus (2007b) reports a 10-year elasticity for oil of only 0.24. Second, the price of carbon is only part of the cost of energy, and at first it will be a small part.[15] Third, the short-run price elasticity is much smaller than the long-run elasticity and should have a strong influence since politics generally takes a short-run view.

How Much Will Carbon Prices Vary from Country to Country?

Equalizing carbon prices across nations tends to reduce the overall cost of climate stabilization.[16] Global carbon pricing contains incentives that encourage some uniformity of national prices. The first of these is the result of the social costs of compliance—the cost of reducing emissions to adapt to a higher price of carbon. As the carbon price increases, abatement costs increase slowly at first and then more rapidly. So at first, the Pricing Incentive more than compensates for abatement costs, but eventually the costs rise faster than incentive payments. To the extent abatement-cost curves have a similar shape in different countries, the countries should set similar carbon prices. To understand this better, consider equation (6), reproduced here for convenience.

$$\text{Abatement cost} = \tfrac{1}{2}\,(\text{carbon price})\,(\text{emissions reduction}) = p \cdot \frac{\Delta e}{2} \tag{6}$$

[15] This means the elasticity of fuel with respect to the price of carbon is less than it is with respect to the fuel's price. For low carbon prices, it will be much lower.

[16] Suppose the only benefit of carbon pricing is a more stable climate. Then, if one country had a lower price for carbon, it would be failing to take advantage of carbon saving opportunities that were cheaper than opportunities in countries with higher prices. This is not efficient. In reality there are many other reasons, such as local environmental concerns and energy security, for pricing carbon. So unequal prices can be efficient.

Since there is already a considerable cost to emissions when p is zero, $\Delta e \approx a \cdot p$ for small values of p . The means that Δe is approximately $a \cdot p^2$. So cost starts out slowly as just noted.

The second effect comes from the Clean Development Incentive (CDI) and is illustrated in Figure 1 above. There will also likely be domestic and international pressures for countries to meet the global target price. These pressures, and CDI for low-emission countries, will be stronger below the target price than above it. If the divergence of carbon prices between nations is felt to be too great, the Pricing-Incentive function can be redesigned slightly to be stronger below P^* than above P^* .

A.4 The Clean Development Incentive (CDI)

This section examines the value-based approach and the cost-based approach to designing the CDI. The value-based approach is the market-based, equal-rights approach. The next section examines an approach based on the need for a direct incentive to reduce emissions.

The Market-Based, Value-Based Approach to the CDI Design

Surprisingly, a slight modification of the most basic cap-and-trade approach gives us the basic form of the CDI. Imagine placing a cap on global emissions and auctioning off the permits. This will raise hundreds of billions of dollars per year, which must be returned to the nations of the world. Return it in proportion to emissions, and the cap has no effect. But return it in proportion to population, and the cap functions as intended.

Returning auction revenues in this way is equivalent to distributing free emission permits to nations in proportion to their populations. And this is equivalent, at the national level, to the classic solution to the tragedy of the commons, which is to distribute tradable rights to the commons on an equal-per-person basis. But how can this cap-and-trade approach be used as a CDI that accompanies a pricing approach?

The result of returning auction revenues on a per-person basis is that any specific country will receive $\left({pop}/{POP}\right) \cdot E_T \cdot P^*$ in revenue, where pop is the country's population, POP is the global population, E_T is total global emissions, and P^* is the price that results from auctioning the permits. However each country will spend $e_T \cdot P^*$ buying permits, where e_T is the country's emissions. The result is a net payment to the country of

$$\text{Net auction payment} = \left({pop}/{POP}\right) \cdot E_T \cdot P^* - e_T \cdot P^* .$$

Dividing by the country's population gives

$$\text{Net per-capita auction payment} = (E - e) \cdot P^* ,$$

Where E and e are global and national emissions per capita, respectively.

This shows the payments that would result from an equal-per-capita cap-and-trade program. But consider such a payment policy on its own, without permits or an auction. First, since the auction process is revenue neutral, such payments would also be revenue neutral and pay for themselves. Second, high emission countries, with $e > E$, would make large payments. The United States, which emits about 5.5 billion tons of greenhouse gases more than average could easily pay over $100 billion per year to low-emission countries. Third, sensible countries would realize that reducing emissions saves them money. As a consequence, countries would implement some system, either a cap or a tax, that resulted in a national price for carbon of $p = P^*$.

This means that adopting a CPI payment of $(E - e) \cdot P^*$ is like adopting a duplicate incentive system equivalent to global carbon pricing with a target price of P^* . This is clearly too strong a measure to add to basic global carbon pricing, but it does have excellent incentive properties and it does transfer funds to low-emission countries. It also solves the problem of non-price policies discussed in the next section. So it makes sense to use a scaled-down version of the formula as the basic CPI formula:

$$\text{Per-capita CPI payment} = Q \cdot (E - e) \cdot P^*$$

The factor Q would need to be set to some value such as 10 percent to scale back the strength of the incentive and the magnitude of the transfer payments.

Selecting Clean Development Incentive Parameter, Q

The classic approach of giving each person the same tradable rights to the atmosphere provides little guidance as to the proper value for *Q*, the strength of the incentive. So a cost-based approach is considered next.

The first approach is based on rewarding value, while this cost-based approach is based on compensating the cost of participation in global carbon pricing. To understand the difference, consider the case of two countries, with the same population, and with initial emission levels of 1.1 tons and 9.9 tons per capita respectively. Both set a global carbon price of $10 per ton, which results in emission levels of 1 ton and 9 tons. By equation (6), the cost of compliance ($p \cdot \frac{\Delta e}{2}$) is roughly $0.50 and $4.50 per capita, respectively. However if the same reductions were achieved by issuing equal rights of five tons per capita under a cap-and-trade system, the low emitters would each sell four tons of rights to the high emitters, and those rights would have a value of $40. So this market-based approach results in a payment to low emitters of $40 per person when the cost of complying with that market-based policy is only $0.50 per person.

The source of this discrepancy is the fact that adapting to the global-carbon-pricing policy did not bring about the low emission level, so there was no cost to producing the value of that low emission level. This example does not show that all people do not have an equal right to the atmosphere; it simply explains the difference between value and cost.

To base the CDI on cost, we need a benchmark for cost. Fortunately, the Pricing Incentive and the value of Z provide some cost information. If a country sets its carbon price to zero, it loses any positive Price-Incentive payment and is charged a penalty. The extent of this net loss puts an upper limit on the country's cost of compliance.

The cost we are looking for should apply specifically to low-emission countries, and it should be valid with the CDI in operation. This may seem circular since we are going to design the CDI on the basis of this cost, but there is a simple and useful result that anticipates the CDI, equations (4) and (5), and is demonstrated in Appendix C.

Result 2: Under the proposed Pricing Incentive and CDI for countries with $e < E$, average compliance cost per capita is less than $Z \cdot E \cdot P^*$, provided these countries' weighted-average carbon price is P^*.

Notice that Result 2 does not give an estimate, but only an upper limit on average compliance costs of below-average-emission countries.[17] Compliance cost for very low-emission countries will, of course, be much less than average and approaches zero as emissions-per-person approaches zero.

[17] Because p is not guaranteed to equal P^*, $C = Z \cdot E \cdot P^*$ is not guaranteed to be an upper limit on costs. However, Because of equation (5), low-emission countries will have a stronger incentive than high-emission countries to achieve P^*. Also, the reasons for C to overstate compliance costs are quite strong, unless the distribution of emissions-per-capita is narrowly distributed around E, and this will not likely be the case for many years to come. Hence C can safely be taken as an upper bound.

A.5 Non-Price Policies

Why the CDI Is Needed to Encourage Non-Price Policies

The fourth and final design problem is to include an incentive for emissions policies other than carbon pricing. To see that the Pricing Incentive does not provide adequate motivation for such policies and why this is a problem, consider the following example. A country taxes all carbon with a tax rate of P^*, exactly as required. Suppose this country can reduce the use of gasoline by improving the design of highway intersections. Also suppose that, without the carbon tax, all investments of this type that save more than they cost have been made.

Because the carbon price reflects a true external cost, this cost should be taken into account by government decisions. Taking this carbon cost into account will make more highway efficiency improvements cost effective. From a global perspective, these should be undertaken. But does the carbon Pricing Incentive motivate a national government to take such action?

If the government did improve efficiency, it would reduce emissions and carbon revenue proportionally. So, of course, the price of carbon would remain unchanged, and there would be no direct reward from a Pricing Incentive payment. But the country would pay fewer carbon taxes. Would this motivate the government to make the efficiency improvement? It would not, because the carbon taxes are not a national cost. When a consumer pays $1 of carbon taxes this simply transfers money from the consumer to the government. The government can use the revenue to reduce some other tax or to provide some service. Since paying the tax is not a cost to the nation, stopping that payment is not a net gain. Hence the Pricing Incentive provides the government with no reason to implement such non-price carbon-reducing policies, even though they are cost effective from a global perspective.

This example shows a gap in the Pricing Incentive, which needs to be filled by an incentive that directly rewards lower emissions. The CDI does that. While there may be examples of non-price programs that are properly motivated by the Pricing Incentive, these appear to be difficult to discover. There are however many examples of non-price policies which would benefit from the CDI. These include appropriate government-funded energy-research programs and appropriate efficiency standards.

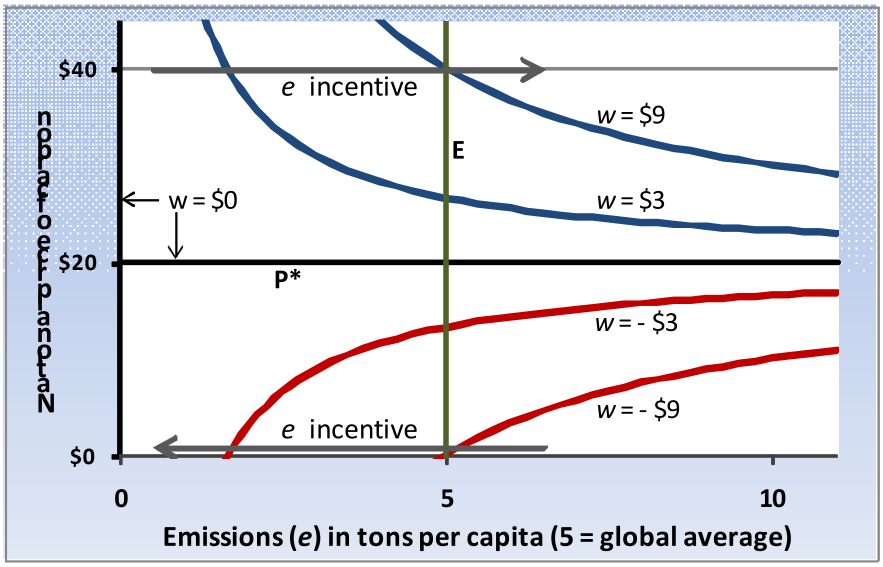
It should be remembered that such non-price programs are properly motivated by normal cost saving up to a level determined by the pre-carbon-tax cost of fossil fuels. It is only the cost of the carbon tax that will not be properly taken into account if governments are rational. However, there may be a good argument that a CDI incentive will remind governments to implement ordinary energy efficiency programs, which are often overlooked.

Analysis of $Q = Z$

Checking the Pricing Incentive, $Z \cdot (p - P^*) \cdot e$, shows that when $p > P^*$, the Pricing Incentive rewards increases in emissions, e , which is the opposite of what we want. Appendix C (Result 3) shows that, for countries with $p < 2P^*$, picking $Q = Z$ gives them a positive incentive to reduce emissions. This is not ideal, but it seems adequate. In fact only $Q = 1$ gives the optimal incentive for correcting consumer myopia with regard to carbon pricing.

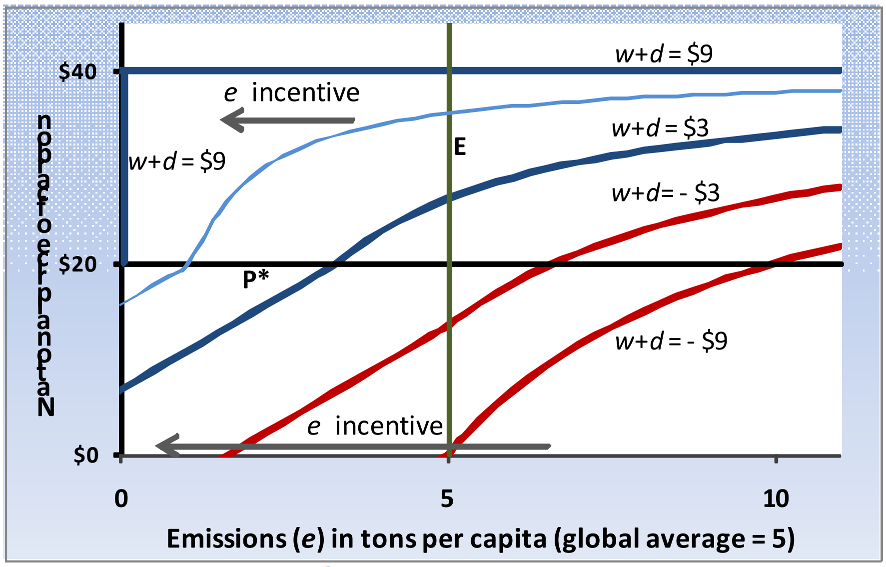
Mapping the Pricing Incentive and the CDI

Figure 2. Pricing Incentive Payments with P^* = \$20 and Z = 9%



A contour map of w constructed from equation (2).

Figure 3. Pricing Incentive Payments Plus CDI Payments with P^* = \$20 and Z = 9%



A contour map of $w + d$ constructed from equations (2), (4) and (5).

Figures 2 shows the incentive to reduce emissions (or raise them) without CDI, and Figure 3 shows the total incentive with CDI added. The CDI is assumed to use incentive-strength factor $Q = Z$. As can be seen, without CDI, any country that sets $p > P^*$ will experience an incentive to increase emissions per capita. But after the CDI is added any country with $p < 2P^*$ will have an incentive to reduce emissions per capita. Of course if Q were larger, the incentive to reduce emissions would be more far reaching. This should be kept in mind when selecting Q .

Although Figure 3 appears radically changed by the addition of the CDI, note that the incentive to raise the price of carbon remains unchanged except in the lower-left quadrant, where it is increased by equation (5). The vertical spacing of the contours, which is perfectly even along any vertical line, remains the same as in Figure 2, except for the lower-left quadrant. Next note that moving to the left, toward lower emissions, reduces the total incentive payment, $w + d$, in all cases where p is less than \$40, which is twice P^* .

Appendix B

A Revenue-Neutral and Stabilized Design

The basic design, shown in Table 2, has three main shortcomings. Neither the pricing nor the development incentive is revenue neutral, and the adjustment formula for Z needs to be limited to prevent unexpected dynamics. The necessary modifications of the basic design are presented below.

Revenue-Neutral Pricing Incentive

The classic approach to revenue neutrality for the Pricing Incentive would be to base the rewards on the actual average global price, P , instead of the target price P^*, but this creates the following fairness issue. If $P > P^*$ then the classic solution will penalize some nations that fall short of P but exceed P^*. This will reasonably be viewed as unfair—if a country meets the target, P^*, it should not be penalized.

The approach recommended here works as follows:

1. Penalize countries with $e < E$ exactly as specified in Table 2.
2. If penalties plus banked funds are sufficient, reward countries with $e > E$ exactly as specified in Table 2.
3. If funds remain after steps 1 and 2, bank them for future rewards.
4. If penalties plus banked funds are not sufficient in step 2, calculate rewards as specified in Table 2 and then reduce them all proportionally just to the point where all funds from current penalties and all banked funds are used.

Revenue-Neutral Clean Development Incentive

The basic Clean Development Incentive, $Q \cdot (E - e) \cdot P^*$, is automatically revenue neutral. But when payments are discounted to low-emission countries with $p < P^*$, CDI collections from countries with $e > E$ need to be scaled down to compensate. Again, the payment for countries with $e > E$ are calculated per Table 2, and then all are reduced proportionally.

Stabilized Automatic Pricing-Incentive Adjustment Rule

The following are suggested additions to the adjustment rule designed to avoid large swings in Z . It should be remembered countries that set $p = P^*$ will not be affected be Z in any case.

Initial incentive strength: $Z_0 = 5\%$

Incentive adjustment rule: $Z_{y+1} = Z_y \cdot \frac{P_y^*}{P_y}$

Incentive change limits: $0.7 < Z_{y+1}/Z_y < 1.5$

Incentive limits: $2\% < Z < 40\%$

Appendix C

Explanations of Results

Result 1 assumes the nation in question is maximizing net benefit.

Result 1: If n is a nation's short- and long-run price elasticity of the demand for carbon, then, when Z is set so that a nation chooses to set p equal to P^*, $Z = n$.

Although price elasticities are often stated as positive, as in Result 1, this proof uses the technical definition, which makes n negative, in which case Result 1 concludes $Z = -n.$

We begin with the basic Price-Incentive formula:

$$w = Z \cdot (p - P^*) \cdot e$$

The marginal incentive to raise p is:

$$\frac{dw}{dp} = Z \cdot \left[e + p \cdot \frac{de}{dp} - \left(\frac{de}{dp}\right) P^* \right]$$

Now define $p(e)$ to be the inverse of the emissions function, $e(p)$.

Social adjustment cost, c , is given by:

$$c = \int_{e(p)}^{e(0)} p(e) de$$

Differentiating:

$$dc/dp = [-(de(p))/dp](p(e(p)) = -de/dp\ p$$

Now equate the marginal incentive to raise p with the marginal cost of raising p .

$$\frac{dw}{dp} = \frac{dc}{dp} \Rightarrow \qquad Z \cdot \left[e + p\frac{de}{dp} - \left(\frac{de}{dp}\right) P^* \right] = -\frac{de}{dp} p$$

Setting $p = P^*$ gives

$$Z = -\frac{de}{dp}\frac{p}{e} = -n$$,

where n is the elasticity of emissions with respect to the price of carbon.

This result assumes short- and long-run elasticities are equal. In reality, short- and long-run elasticities are different and there is likely an appropriate intermediate value for n that can be calculated as an appropriately weighted average of the spectrum of elasticities. The formula for the appropriate weighted average is conjectured to be the annual elasticities (1-year, 2-year, 3-year…) averaged using weights that decline at the nation's political discount rate (e.g., 1, 0.9, 0.81…).

Result 2: Under the proposed Pricing Incentive and CDI for countries with $e < E$, average compliance cost per capita is less than $Z \cdot E \cdot P^*$, provided these countries' weighted-average carbon price is P^* .

Explanation of Result 2:

1. According to equation (2), (4) and (5), the total transfer, T , to countries with $e < E$ will satisfy:

$$T < Z \cdot (p - P^*) \cdot e + Z \cdot (E - e) \cdot p$$

Because the actual CDI is only $Z \cdot (E - e) \cdot P^*$ when $p > P^*$.

2. However, if these countries set p=0, their transfers would fall to:

$$T_0 = Z \cdot (0 - e \cdot P^*)$$

3. Hence their net reward for their actual level of participation is the difference, or:

Net reward for compliance $= T - T_0 < Z \cdot E \cdot p$

4. If the cost of compliance were greater than their net reward, they would not comply.
5. If the weighted average carbon price of these countries is P^*, then the weighted average cost of compliance is at most $Z \cdot E \cdot P^*$.

Result 3: Adding $Z \cdot (E - e) \cdot P^*$ to the Pricing Incentive provides a positive incentive to reduce emissions whenever $p < 2P^*$.

Explanation of Result 3:

1. The Pricing Incentive is $Z \cdot (p - P^*) \cdot e$, so adding the new term gives:
2. $Z \cdot (E - e) \cdot P^* + Z \cdot (p - P^*) \cdot e$
3. Which equals $x = Z \cdot (E \cdot P^* - 2e \cdot P^* + e \cdot p)$.
4. Differentiating with respect to e gives $dx/de = p - 2P^*$.
5. This is negative, indicating an incentive to reduce e , if and only if $p < 2P^*$.

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