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Public Interest Comment[1] on
The Environmental Protection Agency's Proposed Rule:

Carbon Pollution Emission Guidelines for Existing Stationary Sources – Electric Utility Generating Units

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The George Washington University Regulatory Studies Center works to improve regulatory policy through research, education, and outreach. As part of its mission, the Center conducts careful and independent analyses to assess rulemaking proposals from the perspective of the public interest. This comment on the Environmental Protection Agency's proposed rule setting carbon emissions guidelines for electric generating units (EGUs) does not represent the views of any particular affected party or special interest, but is designed to evaluate the efficiency consequences of EPA's choice of an intensity constraint for carbon emissions, and to give guidance to states on the relative advantages and disadvantages of this type of constraint.

[1] This comment reflects the views of the author, and does not represent an official position of the GW Regulatory Studies Center or the George Washington University. The Center's policy on research integrity is available at http://regulatorystudies.columbian.gwu.edu/policy-research-integrity.

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Introduction

EPA's proposed rule sets state-by-state carbon intensity targets for the production of electricity. States are expected to adopt some form of economic incentive regulatory system to achieve these targets, but there has been a great deal of confusion about how, exactly, such a system should work. Several states have asked EPA how to translate these "rate-based" intensity targets into equivalent "mass-based" targets that could form the basis of a cap-and-trade or similar system; EPA recently responded to these questions with a supplementary notice.[3]

This comment will argue that it would be a serious mistake for states to convert intensity goals to mass-based goals. Economic theory suggests that the costs of achieving emissions reduction using a mass-based control system will be an order of magnitude more expensive than achieving the same reduction with a rate-based system, when the costs of rent-seeking (which a rate-based system can better resist) are taken into account. Moreover, states that adopt a mass-based system place themselves at a severe competitive disadvantage, not only with respect to other states, but also with respect to foreign jurisdictions that adopt a rate-based target or no target at all. Finally, a mass-based system of emissions control would have regressive distributional effects that can easily be avoided with a rate-based system of control.

Historically, emissions trading has been most successful when designed to achieve an intensity goal. For example, between 1982 and 1987 EPA used an emissions trading system to phase out the use of tetraethyl lead as an octane booster in gasoline.[4] Other countries followed, and the United Nations Environment Program recently estimated that the global benefit of removing lead from gasoline now amounts to at $2.4 trillion per year.[5] A key factor leading to the success of this effort was EPA's deliberate use of an intensity target, rather than a mass-based target.

The economic literature on emissions trading contains confusing and contradictory discussions about the relationship between *constraints on the intensive margin* (intensity constraints) and *constraints on the extensive margin* (mass-based constraints). This comment, which will be most accessible to economists, is intended to provide a structure for thinking about these options and their advantages and disadvantages.

This comment will *not* address many other important questions raised by EPA's proposal: e.g., climate science, the estimation of the Social Cost of Carbon, EPA's legal authority for the proposed rule, or the calculation of state-by-state targets. Regardless of the disposition of this particular rulemaking, any attempt to regulate carbon emissions – particularly at the state level – will require that policy makers understand the dynamics of emissions trading and the implications of working under a constraint on the intensive or extensive margin.

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[3] Notice; Additional Information Regarding The Translation Of Emission Rate Based Co2 Goals To Mass Based Equivalents, https://www.federalregister.gov/articles/2014/11/13/2014-26900/carbon-pollution-emission-guidelines-for-existing-stationary-sources-electric-utility-generating.

[4] The lead trading system was developed by the author at the Office and Management and Budget in 1981-82, and implemented by EPA at OMB's request.

[5] http://www.unep.org/newscentre/default.aspx?DocumentID=2656&ArticleID=8917

Options for Reducing Emissions:

In order to illuminate the critical policy choices in designing regulatory instruments for reducing carbon emissions, and to explore their economic implications, this section will review six distinct control options:

1. A Carbon Tax
2. An Auctioned Cap-and-Trade System
3. A Rebated Carbon Tax
4. A Rebated Cap-and-Trade System
5. An Output-Compensated Carbon Tax
6. An Output-Compensated Emissions Trading System

Economic theory tells us that the first two options, which at some level are equivalent ("dual"[6]) to each other, will raise the effective price of carbon emissions and will thereby reduce the level of emissions, which will follow an ordinary "Marshallian" demand curve. The second pair of options are also mutually dual, but will reduce emissions by following an income-compensated demand curve. The final pair of options are mutually dual and follow an output-compensated demand curve.

Option 6 is simply emissions trading with an intensity constraint, and it has multiple advantages over other options. To understand both its advantages and disadvantages, however, we will first have to explain where those different demand curves come from and what they mean.

1. A Carbon Tax

There is an extensive literature regarding the efficiency advantages of using a price instrument – a Pigovian emissions tax – to "internalize" the externalities associated with air pollution. In many ways CO_2 emissions, if they are indeed harmful, would be an ideal candidate for an emissions tax set equal to the external "Social Cost of Carbon" (SCC). As the author has argued elsewhere: "The SCC may appear to be a gross oversimplification of a complex underlying reality; but, in fact, it is the right simplification to undertake. This is because any damage that greenhouse gas emissions may inflict on global climate systems is independent of the source of the emissions. To the climate, all CO2 molecules look the same. . . [A]ny cost-effective portfolio of climate policies will have a single implicit marginal cost of carbon."[7]

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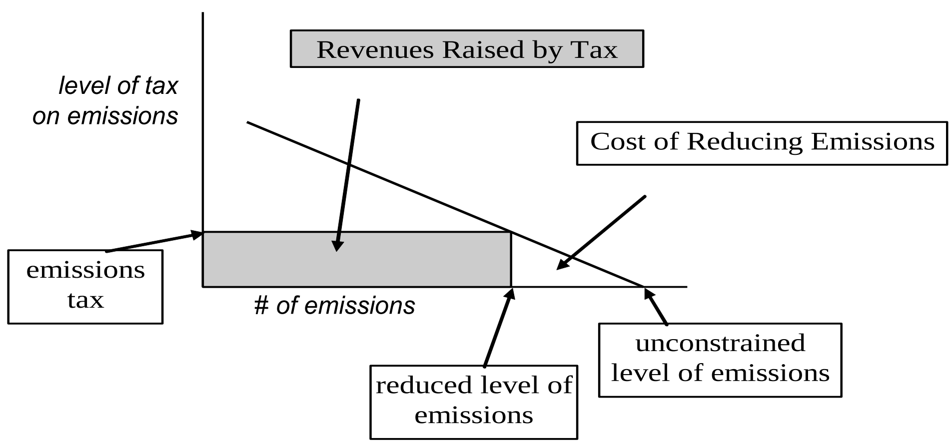
[6] http://en.wikipedia.org/wiki/Duality_%28optimization%29

[7] Brian Mannix and Susan Dudley, *Public Interest Comment on The Interagency Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order No. 12866*., 26 February 2014.

https://regulatorystudies.columbian.gwu.edu/sites/regulatorystudies.columbian.gwu.edu/files/downloads/OMB_2013-0007_SCC.pdf

In addition to its theoretical advantages, however, a carbon tax has some major drawbacks. As illustrated in the drawing below, a carbon tax would impose two distinct costs on consumers[8] of electricity: the real resource costs of eliminating some fraction of emissions, plus the cost of paying the tax on those emissions that are *not* eliminated. Typically, the cost of paying the tax – that is, the tax revenues – will be several times larger than the cost of reducing emissions. Economists will usually treat this tax as a "transfer payment" to the government rather than a real resource cost to the economy. Nonetheless, from consumers' perspective, both of these costs will cause an increase in the price of electricity. A tax on carbon emissions from EGUs will effectively translate into a tax on electricity, which is likely to be very unpopular, in part because it is regressive compared to other sources of state revenue. Such a tax would also render a state much less competitive in attracting businesses that use electricity. Moreover, to the extent that an EGU carbon tax drove electricity-using businesses to other jurisdictions, the purpose of the tax will have been defeated. Carbon emissions can effectively flee the tax, causing a rebound effect. Thus a carbon tax is particularly ill-suited for use at the state level, because states have few options for avoiding that counterproductive outcome. In Figure 1, below, the downward sloping line is an ordinary Marshallian demand curve that shows how the level of carbon emissions will respond to a price, or Pigovian tax.

Fig. 1: Effect of a Tax on Emissions

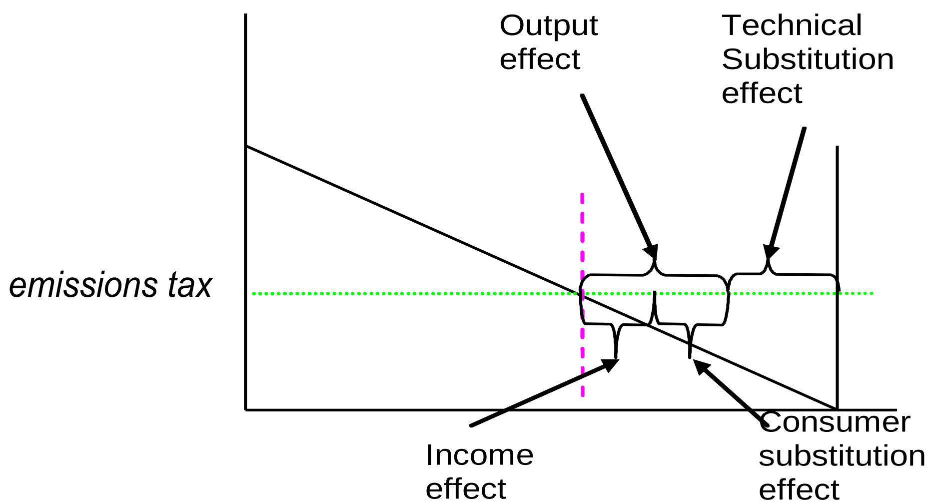


Before leaving the carbon tax, we need to make note of three distinct ways that it will cause emissions to be reduced below the level of unconstrained (untaxed) emissions. First, it causes a *technical substitution effect*, as electricity producers substitute lower carbon-intensity technologies for higher ones. Second, it causes a *consumer substitution effect* by raising the price of electricity, thereby inducing consumers to buy more of other goods and less of electricity.

[8] A carbon tax, or almost any other method of controlling carbon emissions, will impose costs whose incidence will be felt both downstream of the EGUs (by residential and commercial electricity consumers) and upstream (by owners of carbon-intensive infrastructure and fossil fuel deposits, especially coal-fired EGUs and coal mines). The majority of the costs, in the long run, are likely to fall downstream; hence our focus here will be on consumer impacts. This will help simplify the diagrams, which will show various demand curves for emissions allowances, but policy makers should understand that the actual incidence of costs is more complex.

Third, it causes a *consumer income effect*, as consumers find that higher electricity prices have left them less able to afford everything, including electricity. The latter two effects are sometimes referred to in combination as the *output effect*, since both of them result in lower output of electricity. In the illustration below, both components of the output effect are exaggerated for clarity. In practice, the technical substitution effect will dominate, and the income effect will likely be very small, in terms of its effect on carbon emissions. Of course, the effect of a carbon tax on consumer incomes is likely to be quite large, in terms of political acceptability, but that is another matter. The downward sloping line in Figure 2 is an ordinary factor-market demand curve (because carbon emissions are a factor of production for electricity), and these three effects are standard features of any such demand curve.

Figure 2: Three mechanisms by which a tax will reduce emissions

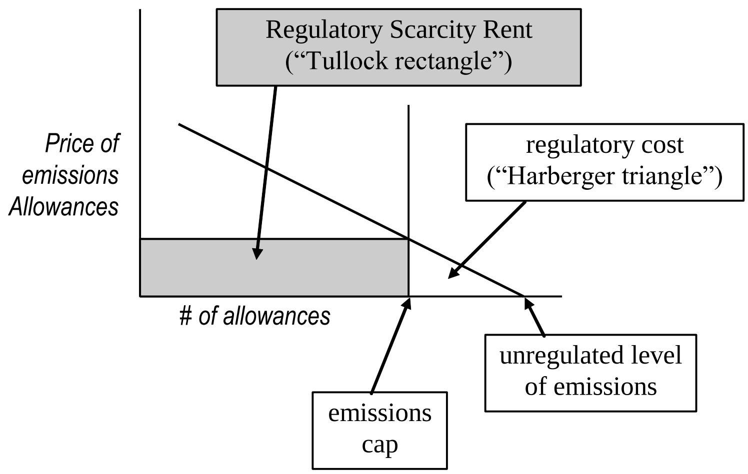


2. A Cap-and-Trade System

A cap-and-trade system, with the allowances auctioned by the government, is the dual equivalent of a Pigovian emissions tax. As such, its effect on emissions can be described by the same factor-market demand curve we saw above. In the diagram below, the shaded rectangle, which had represented the revenue raised by a carbon tax, now has been relabeled a "regulatory scarcity rent," and it represents the market value of the outstanding emissions allowances. This is sometimes called a "Tullock rectangle," named for Gordon Tullock, who died on November 4, 2014. Tullock pointed out that the creation, by regulation, of a scarcity rent, will inevitably touch off a rent-seeking contest to capture that value. It will take place in political, administrative, and judicial arenas, and – to a first approximation – will likely continue up to the point where the entire scarcity rent has been consumed. Thus in practice the Tullock rectangle represents, not a transfer that can be ignored, but a real resource cost that substantially reduces the efficiency of the regulatory system. Of course, taxes are not immune from rent-seeking, so a carbon tax would also likely induce some of these same costs. But, with a tax, there is some expectation that at least a portion of the revenue will accrue to the treasury. With a cap-and-trade system there may be no such expectation, making them particularly susceptible to rent-seeking.

Apart from that, a cap-and-trade system will suffer from many of the same drawbacks as a carbon tax: it will impose an unnecessarily large burden on consumers, and it will substantially impair the competitiveness of any jurisdiction that adopts it.

Figure 3: Demand for Emissions Allowances under Cap-and-Trade

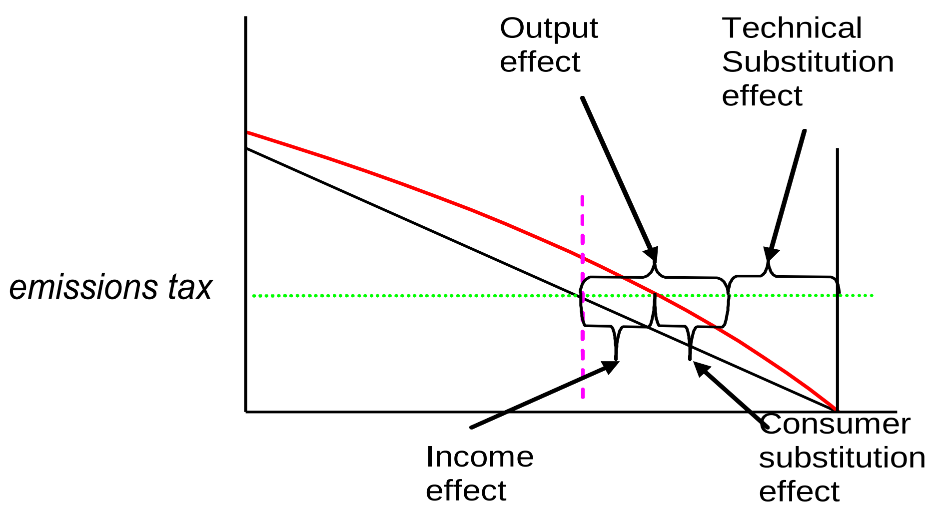


3: A Rebated Carbon Tax

In order to ameliorate the consumer impact of a carbon tax, some have proposed a rebated carbon tax, also known as an "income-compensated" or a "revenue-neutral" carbon tax. The rectangle of revenue that was collected by the tax would be returned to the public in the form of a cut in the income tax or sales tax, so that the net change in the public tax burden would be zero. One difficulty is that the rebate cannot easily be targeted on the same consumers who are bearing the incidence of the carbon tax. Another is that dramatic changes in tax policy have uncertain outcomes.

Note that, if successfully adopted, the effect of an income-compensated carbon tax would be to eliminate the (very small) consumer income effect on carbon emissions, so that emissions would be slightly higher than they would be under an uncompensated carbon tax. In effect, the level of carbon emissions would not follow the black line – what economists call an ordinary or "Marshallian" demand curve. Instead, it would follow the slightly higher red line – what economists call an income-compensated demand curve. It reflects the technical substitution effect and the consumer substitution effect, but the consumer income effect (on carbon emissions) has been eliminated.

Figure 4: Deriving an Income-Compensated Demand Curve



4: A Rebated Cap-and-Trade

We can imagine doing something similar with a cap-and-trade system. The emissions allowances would be auctioned, and the resulting revenues returned to consumers by cutting other taxes. In practice, it would not likely work out that way. Various interests would stake a claim on the revenues, or would lobby for a set-aside of free allowances to be allocated by some political or administrative process. Again, by creating a scarcity rent, cap-and-trade systems tend to stimulate costly rent-seeking. But, assuming that could be avoided, a rebated cap-and-trade system would work very much like a rebated carbon tax, and would follow the same income-compensated demand curve.

5: An Output-Compensated Carbon Tax

There is an alternative means of returning the revenues from a carbon tax to the consumers who paid it. The revenues can be placed in a fund which is used to subsidize electricity production. Every EGU would pay a tax on carbon emissions, and receive a subsidy on electricity output. Those with relatively high carbon emissions would be net payers into the fund; those with relatively low carbon emissions would be net recipients. Overall, the net revenues to the fund – and the net tax burden passed on to consumers in the price of electricity – would be zero.

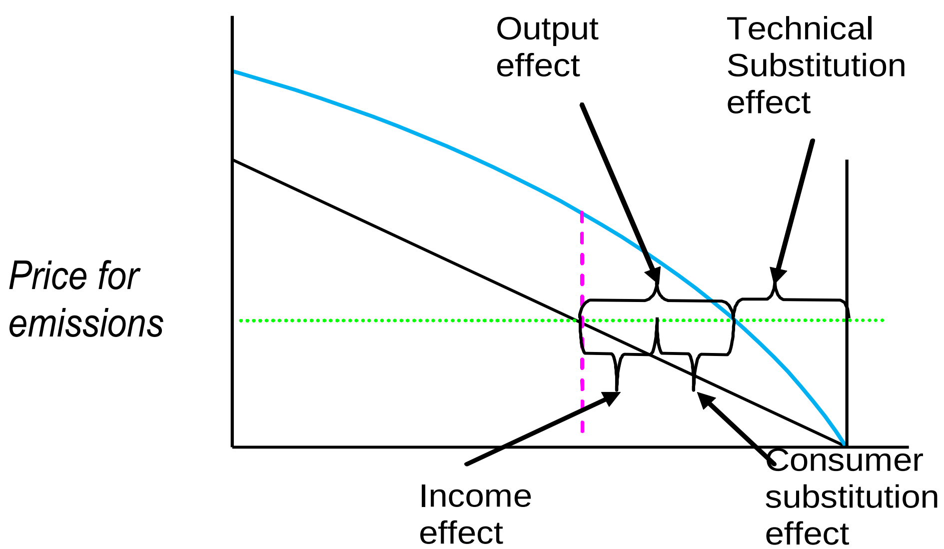
This tax/subsidy system has been used to manage conventional NOx emissions from EGUs and other large point sources in Sweden. It has the virtue of targeting the benefit of the subsidy on exactly the same consumers who bear the burden of the tax.[9] In enacting its system of refunded emissions payments, Sweden was conscious of the fact that output compensation would

[9] Note that, in order to work as described, the tax must be on current carbon emissions and the subsidy must be on current electricity production. Various proposals to use "historical" emissions as the basis of allocating emissions allowances will not work the same way, since historical emissions are completely inelastic.

substantially mitigate the damage to the nation's competitiveness that otherwise would have been incurred as a result of an emissions tax. Sweden was also deliberately seeking to create incentives to produce a technical substitution effect, rather than a change in consumers' lifestyles or market baskets.[10]

As seen in Figure 5, the effect of an output-compensated carbon tax is limited to the technical substitution effect. It will not produce either a consumer income effect nor a consumer substitution effect. Emissions under an output-compensated carbon tax will follow the blue line – an output-compensated demand curve. Note that, because it uses only the technical substitution effect, an output compensated carbon tax will produce slightly fewer emissions reductions than an uncompensated tax at the same price per ton of carbon. Still, from the consumer's perspective, the costs of a compensated tax will be dramatically lower.

Figure 5: Deriving an Output-Compensated Demand Curve



6. An Output-Compensated Emissions Trading System

With this last option, things get simpler rather than more complicated. It turns out that an output-compensated emissions trading system is simply emissions trading combined with an intensity constraint. States can simply require that all covered sources comply with the same carbon intensity constraint, denominated in tons per megawatt-hour, and can allow trading of carbon allowances among them. This is sometimes called an "offset market." More carbon-intensive sources will need to buy allowances from sources that are less carbon-intensive. As long as no one cheats, the overall system will meet the intensity goal, and trading will allow participants to

[10] For an excellent discussion of how this system works, see Thomas Sterner and Bruno Turnheim, "Innovation and Diffusion of Environmental Technology: Industrial NOx Abatement in Sweden under Refunded Emission Payments," http://www.rff.org/Documents/RFF-DP-08-02.pdf

find the least-cost means of doing so. There is no fixed pool of allowances to be allocated, and no central authority need collect any tax or pay any subsidy; as a result this system is very resistant to rent-seeking.

So, for example, when EPA set the intensity constraint on lead in gasoline at 1.1 grams of lead per gallon of leaded gasoline in 1982, refiners began trading lead allowances at a price that fluctuated around 2 cents per gram. This automatically translated into a subsidy on leaded gasoline of around 2.2 cents per gallon, because each gallon produced would earn 1.1 grams of lead allowances. The price at the pump incorporated both the effect of the lead "tax" and the effect of the gasoline "subsidy," which exactly offset each other. Other than enforcing the intensity constraint and monitoring the trading, there was little that EPA needed to do. There was no pool of allowances to be allocated, and no fund to collect revenues. Rent seeking in the lead phasedown program, which had been rampant prior to 1982, virtually vanished. Within five years, with little resistance, EPA was able to phase out lead use almost entirely.

Of course, emissions trading under an intensity constraint will produce only a technical substitution effect. It will not, for example, do much to encourage electricity conservation by consumers.[11] But its advantages, in terms of economic competitiveness, distributional effects, and especially resistance to rent-seeking, are substantial.

Putting it All Together

The chart below summarizes the relationships among the six options we have been discussing.

Constraint is applied to . . .	Extensive margin w/ No Compensation	Extensive Margin w/ Income Compensation	Intensive Margin w/ Output Compensation
Price instrument:	1. Carbon Tax	3. Income-compensated carbon tax	5. Output-compensated carbon tax (like Sweden)
Quantity instrument:	2. Cap & Trade	4. Cap & Trade w/ rebate	6. carbon trading under an intensity constraint (like lead phasedown)
Reduces emissions by . . .	Technical substitution effect; consumer substitution effect; income effect	Technical substitution effect; consumer substitution effect	Technical substitution effect only
Carbon emissions follow a . . .	Marshallian demand curve	Income-compensated demand curve	Output-compensated demand curve
Revenue/scarcity rents accrue to . . .	Revenue to the treasury or the distributees	Revenue may be returned to consumers via tax cuts or coupons	Revenue is retained by consumers

[11] There is an argument that, by producing only a technical substitution effect, an intensity based standard is more compatible with EPA's legal authority under Section 111(d). There is little evidence that Congress intended this section of the Clean Air Act to go beyond the use of technology to reduce emissions, to be used to penalize consumers, or to induce changes in consumer lifestyle. Such legal arguments are beyond the scope of this paper, however.

The one disadvantage of Option 6 (emissions trading under an intensity constraint) is that it is limited to the technical substitution effect, and therefore will not achieve emission reductions associated with reductions in electricity demand – reductions that theoretically could be achieved by a simple unrebated carbon tax and that might be economically justified. On the other hand, it has substantial advantages in that it achieves substantial emission reductions while simultaneously minimizing the increase in the price of electricity by avoiding any net tax burden. This avoids undesirable consumer impacts, and also minimizes the damage to the economic competitiveness of any jurisdiction using this system.

Finally, trading under a uniform intensity constraint has the advantage of providing a very small attack surface for rent-seekers. It is awkward for any government agency's economic analysis to provide a frank discussion of the costs of rent seeking, but they are very real and very large. Consumer advocates, especially, ought to be alert to the danger. If a state converts an intensity target into a mass-based target, with the resulting pool of carbon allowances subject to allocation via some political/administrative process, the effect on consumers will be dramatic. The costs to consumers will rise by an order of magnitude, generating revenues that will fund a massive redistribution of income to the various groups that will attempt to claim some share of the allocation.

Commercial consumers of electricity, too, should recognize that a state moving from an intensity-based constraint to a mass-based constraint will be unlikely to stay competitive with states (or with foreign jurisdictions) that choose not to embed a carbon tax in their electricity prices.

One other complication needs to be addressed. We know that an efficient Pigovian tax on carbon would be set equal to the Social Cost of Carbon, assuming the latter is correctly calculated. If a state is instead using emissions trading under an intensity constraint, how can it know the efficient level of the constraint? The short answer is, it cannot know, and neither can the EPA. Even if EPA has done a creditable job of calculating reasonable targets for the short term, they will quickly become obsolete as circumstances evolve. It is not possible to calculate the "right" targets for the states, regardless of whether the targets are expressed in terms of intensity or total emissions. The same is true in international negotiations for a global system of carbon controls.

What is possible, both for states and for nations, is to come to some agreement about the target price for carbon allowances, and to manage their emission control systems to converge on that target price. For states that use an intensity constraint, that means observing the price at which carbon allowances trade, and intervening in the market if it rises above a target level (the Social Cost of Carbon, properly calculated). There are various mechanisms to do this. A "safety valve" mechanism can, in the short term, sell additional carbon allowances into the market to prevent a price spike. In the longer term the state can adjust its intensity constraint so that the market price for carbon settles at an appropriate level, without excessive reliance on the safety valve mechanism. As markets evolve, states can compare the price of carbon across different jurisdictions, and seek adjustments in their targets as needed. Ultimately, a national (or international) system of emission control needs to coordinated around a common price for carbon, rather than on any central authority doling out quantitative targets.

Appendix for Economists[12]

For those who are interested, this Appendix gives a little more formal detail on the arguments outlined above, and on the nature of the duality between Options 5 and 6.

The Slutsky equation, & three income-compensated demand curves

Ordinarily we use the Slutsky equation to decompose the price elasticity of demand for a consumer good ($\varepsilon_{electricity}$) into a consumer substitution effect and a consumer income effect.

$$\varepsilon_{electricity} = \varepsilon_{cons\text{-}substitution} + (PQ/I)\ \varepsilon_{income}$$

ε_{income} is the income elasticity of demand for electricity, and the weighting factor (PQ/I) is simply the fraction of income (I) devoted to purchasing Q of this good at price P.

The ordinary (Marshallian) demand curve shows the relationship between quantity and price, and reflects both effects. In contrast, an "income compensated" demand curve is one that reflects only the substitution effect. Conceptually, this involves removing the income effect by compensating the consumer for the income loss that is implicit in a price increase – or, in our case, a tax increase.

But there is an ambiguity in defining how much the consumer should be compensated. Hicks proposed compensation that would exactly preserve the consumer's welfare – giving what is known as the Hicks compensated demand curve, which (for the diagrams in this paper, showing the effect of tax increases) lies above the Marshallian demand curve. Consumer welfare is not observable, however; so Slutsky instead proposed compensating the consumer to the point where the initial market basket could still have been purchased. This is compensation using a Laspeyre index of price changes, and it generates the Slutsky compensated demand curve, which lies above the Hicks compensated demand curve. An alternative (and less generous) measure of compensation uses a Paasche index of price changes, producing a compensated demand curve that lies below the Hicks compensated demand, but still above the Marshallian. The Laspeyre indexed and the Paasche indexed compensated demand curves effectively give an upper and lower bound on the locus of the Hicks curve; the region in between corresponds to Samuelson's "zone of darkness" in which we cannot really be certain of the sign of the consumer welfare effect.

When dealing with infinitesimal price changes (e.g., in the Slutsky equation above) it makes little difference which flavor of compensated demand curve we choose, since they converge for small price changes. When designing policies to reduce pollutants, however, we are not really interested in infinitesimal changes. Hence it is important to identify which curve we are dealing with. For reasons that will become clear in the next section, we are interested in the third type –

[12] For simplicity, throughout this Appendix I will continue to ignore supply side effects, and will assume that consumers bear the incidence of upstream taxes.

the Paasche indexed compensated demand curve, despite the fact that it is far more obscure in the literature than the more familiar Hicks and Slutsky variants.

The *extended* Slutsky equation, & three output-compensated demand curves

When a price increase or a tax applies to a factor of production, such as carbon, rather than a consumer good, we can use the factor-market Slutsky equation (analogous to the consumer-good Slutsky equation) to decompose the price elasticity of demand (ε_{carbon}) into a technical substitution effect and an output effect.

$$\varepsilon_{carbon} = \varepsilon_{tech\text{-}substitution} + (TE/PQ)\, \varepsilon_{electricity}$$

Here the weighting factor (TE/PQ) is simply the fraction of the firm's revenue (PQ) consumed by the tax T on emissions E. But we already know from the section above that $\varepsilon_{electricity}$ can be expanded further. Combining the two equations, we get:

$$\varepsilon_{carbon} = \varepsilon_{tech\text{-}substitution} + (TE/PQ)\, \varepsilon_{cons\text{-}substitution} + (TE/I)\, \varepsilon_{income}$$

This extended form of the Slutsky equation shows how the price elasticity of demand for a factor of production (in this case, carbon allowances) can be decomposed into a relatively large technical substitution effect, a smaller consumer substitution effect (weighted by tax revenues as a fraction of industry revenue), and a still smaller consumer income effect (weighted by tax revenues as a fraction of consumer income).

The Marshallian demand curve for carbon emissions will be a function of all three effects. The output-compensated demand curve will reflect only the technical substitution effect. Again, when we move away from infinitesimals, we can distinguish three different flavors of output-compensated demand curve, depending on which type of index we use for determining the level of compensation. The uppermost of the three output-compensated demand curves uses Laspeyre index compensation. The middle one, corresponding to the Hicks compensated demand curve, holds electricity output (rather than consumer welfare) constant. Note that electricity output is perfectly observable, so there is no reason to disparage the Hicks flavor of compensated demand curve in factor markets. Nonetheless, our interest lies with the third variant: the Paasche-indexed output-compensated demand curve. The reason is that this is the only one of the three curves which is revenue neutral. That is, with Paasche indexing, the output compensation (in the form of a subsidy for electricity output) is exactly equal to the revenues collected from the carbon tax.

We are interested in revenue neutrality, not because it sounds like an appealing political slogan, but because it is an inherent property of emissions trading with a constraint on the intensive margin. Just as there is a mathematical duality between the two instruments that operate on the extensive margin (an emissions tax, and a cap-and-trade system), there is a similar mathematical duality between the two instruments that operate on the intensive margin. A tax on emissions which is exactly offset by a subsidy on output, is dually equivalent to a system of emissions trading with an intensity constraint. Both of these instruments will cause the price and quantity of carbon emissions to trace a revenue-neutral (i.e., Paasche indexed) output-compensated demand curve.

The key to demonstrating this duality is to decompose the shadow price of the intensity constraint by adding one extra variable, and one extra constraint, to the maximization problem. If the intensity constraint is expressed in tons of carbon per megawatt-hour, then the shadow price of that constraint should be expressed in dollar-megawatt-hours per ton – an unfathomable dimension. That vector can be resolved into two components, however: a shadow price, or shadow tax, on carbon that is expressed in $/ton, and a negative shadow price, or shadow subsidy, on output that is expressed in $/megawatt-hour. Replacing one shadow price with two, however, adds an extra degree of freedom to the maximization problem. We need to add one more equation to remove that degree of freedom: the revenue from the carbon tax must exactly offset the cost of the electricity subsidy. This is the revenue-neutrality constraint.

We know that an offset trading market is revenue neutral, because there is no mechanism for any central authority either to collect revenue or to make payments. Every trade in the market has a buyer and a seller. Such offset trading – trading under a constraint on the intensive margin – is naturally revenue neutral, which is what causes it to follow a Paasche-indexed output compensated demand curve, just like the output-compensated tax that Sweden used in the illustration above.

This framework of different demand curves may appear excessively abstract, but it has important real-world consequences. Only by understanding the relationship between embedded shadow taxes and shadow subsidies, their incidence, and their incentive effects, can we hope to design emissions control systems that are effective, fair, and efficient.