

*Energy Policy*, 30, 333-345, 2002.

Professor Peter Cramton  
Department of Economics  
University of Maryland  
College Park MD 20742-7211  
Cramton@umd.edu

Dr. Suzi Kerr  
Motu Economic Research  
19 Milne Tce., Island Bay  
Wellington, New Zealand  
suzi.kerr@clear.net.nz

---

# Tradeable Carbon Permit Auctions

---

## How and why to auction not grandfather

Peter Cramton (University of Maryland)

and Suzi Kerr (Motu Economic and Public Policy Research)

---

---

# Tradeable Carbon Permit Auctions

---

## How and why to auction not grandfather

### Abstract

An auction of carbon permits is the best way to achieve carbon caps set by international negotiation to limit global climate change. To minimize administrative costs, permits would be required at the level of oil refineries, natural gas pipe lines, liquid sellers, and coal processing plants. To maximize liquidity in secondary markets, permits would be fully tradable and bankable. The government would conduct quarterly auctions. A standard ascending-clock auction in which price is gradually raised until there is no excess demand would provide reliable price discovery. An auction is preferred to grandfathering (giving companies permits based on historical output or emissions), because it allows reduced tax distortions, provides more flexibility in distribution of costs, provides greater incentives for innovation, and reduces the need for politically contentious arguments over the allocation of rents.

---

## Introduction

*"...the U.S. Climate Change Action Plan, ... developed a wide range of voluntary programs and technology strategies to help the United States reduce domestic emissions to 1990 levels. While these remain laudable and important programs, they have not put us on a path toward significantly reducing greenhouse gas emissions. In fact, rather than accomplishing that goal, by the late 1990s, U.S. emissions were at least 11 percent above those 1990 levels. Clearly then, the next global climate change treaty will have to include binding emission limits by industrialized nations,.."* Senator Byrd, US Senate May 04, 2001

Although President Bush recently announced that the US would not ratify the Kyoto Protocol, both scientific evidence and domestic pressure are continuing to move the US toward more aggressive domestic climate policies. Uncertainty still exists but the mainstream scientific consensus, represented by the Intergovernmental Panel on Climate Change, is that "In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." (IPCC, 2001).

The question at hand is how best to achieve domestically the binding emission targets. CO<sub>2</sub> is the major current contributor to climate change.<sup>1</sup> It is released whenever fossil fuels are burned and sequestered in the growth of trees. How can we reduce our consumption of fossil fuels at lowest cost? The major option for the United States, being discussed in Washington, is a tradeable permit program, following in the footsteps of the successful acid rain trading program.

A carbon tax would have similar efficiency properties to a permit market. Taxes make the development of risk sharing options, equivalent to those in a permit futures or options market, less feasible. Taxes are also more transparent and hence generally considered to be less politically feasible. An intermediate option would be to use a trading system but with a price ceiling or 'safety valve' set at a level that is not expected to bind (Pizer 1999). This would have many of the advantages of the permit program while preventing extreme price fluctuations such as those observed in the RECLAIM NO<sub>x</sub> market in California in 2001. It would allow limited non-compliance in situations where the costs were much higher than expected.

Although most researchers now recognize the advantages of a comprehensive auctioned permit system, most policy analysts still predict that, because of the political power and persuasiveness of energy sector interests, the US will choose a system with permits grandfathered to electric utilities and large industrial energy users. Even worse, the choice of policy instrument is not independent of the distribution of rents. The political desire to grandfather may also lead to an administratively cumbersome downstream system with exemptions for some sectors and inefficient command and control type regulation for others. Despite the intense criticism, increased CAFE (car average fuel efficiency) standards are being seriously considered. The potential cost of this inefficient system is tremendous. If auctioned permits were accepted, much of the rationale for choosing these inefficient options would disappear. Presenting a clear theoretical and empirical case for the feasibility, efficiency and equity of an auctioned tradeable permit system is critical.

---

<sup>1</sup> Other greenhouse gases, such as NO<sub>2</sub> and CH<sub>4</sub> could be incorporated into the trading program at a later date. These gases raise complications in monitoring and comparability with carbon.

CO<sub>2</sub> is a uniformly mixed, accumulative pollutant. Neither the source of emissions nor their timing is important from an environmental standpoint. Thus, permits are ideally defined in a homogeneous way over space and time. Ideally permits would be fully tradeable internationally. Although we do not deal with some of the issues of an international permit trading system such as monitoring and enforcement, the conclusions of this paper on auctions are consistent with an domestic system operating within an international trading system.<sup>2</sup> We are considering only allocation of permits within a domestic system, not the international allocation of permits.

We assume that the domestic permit system regulates carbon at the level of oil refineries, natural gas pipe lines, natural-gas liquid sellers, and coal processing plants.<sup>3</sup> This creates a comprehensive, administratively feasible system. Carbon emissions in all sectors of the economy will be indirectly controlled. Permits allow a one-time use of one metric ton of carbon. They can be banked indefinitely for use in later years. Trade in the secondary permit market is completely unrestricted. None of this is contentious.

The debate turns heated on the issue of how to allocate the permits. Not surprisingly, vested interests (electric utilities, coal, and oil companies) are lobbying that the permits be allocated to them in a way related to historical output.

There is a simple and highly efficient alternative to giving these newly defined property rights to energy companies. Let the government sell the permits in periodic auctions – just as the Treasury sells debt. The bonus is that the revenue from the auctions could be refunded through tax cuts to all citizens of the United States. This “revenue recycling” means that polluters are effectively buying the right to pollute from the public. If the target, of a 7% reduction below 1990 annual emissions between 2008 and 2010, is implemented, 1,246 million metric tons of permits will be issued on average each year (EIA 1997 Annual Energy Outlook). Estimates of the carbon prices needed to achieve compliance in Annex 1 (developed countries) vary dramatically. As an indication, however, with no trading the likely marginal costs / taxes range from \$10—\$1,075 per metric ton (1990 US \$; low EU estimate to high Japan estimate).<sup>4</sup> With Annex 1 trading, the tax required will be same in all countries and will probably be between \$20 and \$225.

If the marginal cost, and hence the permit price, is \$100 per metric ton, an efficient auction could raise \$125 billion annually. This is around 10% of federal receipts and around 2% of GNP in 1995. If permits are grandfathered to companies in the energy sector (oil, coal and gas companies, heavy industry or electric utilities), 2% of GNP is given away.

Advocates of grandfathering usually fail to point out that, if the permits are given to energy companies, consumers will still pay the higher energy prices. It is the carbon cap itself that will determine the price increase. Regardless of whether the government auctions permits or gives them away for free, the same energy price should be expected.<sup>5</sup> In either case the cost of producing energy (i.e. the supply curve) will rise by the price of carbon permits times the carbon per unit of energy. The price of carbon permits depends only on the marginal cost of abating carbon, i.e. the demand for permits, and the supply of permits set by the cap. The method of allocation affects neither demand nor supply of permits. The

---

<sup>2</sup> For extensive discussion of design issues in an international permit market see Kerr (2000).

<sup>3</sup> The justification for this is discussed in Hargrave (1997). In brief, this point of regulation achieves near comprehensive coverage of carbon, and minimizes the costs of administering the program. The paper also begins to outline the details of how carbon would be monitored in such a system.

<sup>4</sup> Calculated from Stanford Energy Modeling Forum results, Weyant and Hill (1999).

<sup>5</sup> If, however permits are allocated on the basis of current output the price effect is different and abatement is inefficient. See Fischer (1998).

energy price rise depends only on the carbon permit price and the relative elasticities of energy demand and supply. The only difference between grandfathering and auctioning is that in grandfathering the energy companies, not the taxpayers, pocket the extra revenue.

The experience in cellular communications provides a vivid illustration. In the 1980s, the FCC gave away cellular licenses. The companies did not respond to the gift with lower prices. Rather, prices were high, since only two companies could operate in each market. Now the FCC has auctioned additional licenses, generating billions of dollars for the Treasury. Prices are falling as those who purchased the licenses enter the markets of those who were given licenses. Giving away permits did not lower prices, nor did auctioning permits raise prices. Prices fell because of the increase in competition and hence efficiency.

Researchers are actively estimating the aggregate costs of carbon dioxide policy and the optimal aggregate path for carbon emissions both domestically and globally.<sup>6</sup> The literature on how to achieve those emissions paths is sparse. This paper presents the issues in designing a carbon permit auction. The analysis is relevant for achieving any aggregate emissions target. In previous work on environmental auction design, researchers considered the serious design problems in the SO<sub>2</sub> auction and its effects on the operation of the auction and market (Cason 1995; Cason and Plott 1996; Joskow, Schmalensee and Bailey 1997). We offer the first analysis of the design of a carbon permit auction.

The arguments for auctions have not been comprehensively addressed before, although many of the individual arguments have been discussed elsewhere. In particular, papers address the advantages of revenue recycling (Parry 1995; Parry, Williams and Goulder 1998), and the effects on incentives to innovate (Milliman and Prince 1989; Pizer, Fischer and Parry 1998). In the context of the Acid Rain Program, Van Dyke (1991) argued that fairness required that SO<sub>2</sub> allowances be sold rather than given out for free. No previous work has addressed the full distributional implications of allocating carbon permits through auctions rather than some form of grandfathering.

We begin by describing how carbon permits should be auctioned. Then we consider the alternative, grandfathering, and argue why an auction is better for domestic allocation. We conclude that bankable, identical permits should be auctioned on a quarterly basis using a standard, ascending-clock design. In the case of carbon we conclude that the arguments for auctions rather than grandfathering, on efficiency and distributional grounds, are overwhelming.

## How to auction carbon usage permits

An auction of carbon usage permits answers two questions: who, on efficiency grounds, should get the permits and at what prices? The best answer to these questions depends on the government's goals. Presumably a primary goal is efficiency – to put the permits to the best possible use. A secondary goal is revenue maximization. Indeed, a government concerned with efficiency must put some weight on revenue maximization, since revenues can be used to offset distortionary taxes. Fortunately, these goals are closely aligned. An efficient auction will raise substantial revenues.<sup>7</sup>

---

<sup>6</sup> See Nordhaus (1994), Cline(1992), Jorgenson and Wilcoxon (1992), and Manne and Richels (1990).

<sup>7</sup> Ausubel and Cramton (1998) prove that an efficient auction maximizes revenues if resale markets are efficient.

## What to auction

In any auction, it is crucial to define the items being auctioned. With carbon permits this is a simple matter. Each permit is for one metric ton of carbon usage. To minimize regulatory transaction costs, permits are required by oil refineries, natural gas pipelines, natural-gas liquid sellers, coal processing plants and fuel importers. Such an “upstream” system is comprehensive and minimizes the number of parties that need permits.<sup>8</sup>

A basic fact from Treasury auctions is that the Treasury must pay for illiquidity. The less liquid the issue is, the greater is the transaction cost. Illiquidity not only costs the seller money, but it also reduces auction efficiency. In the FCC spectrum auctions, the primary source of inefficiency stems from the exercise of market power in thin markets. Illiquidity increases the risk that some bidders may have market power in certain circumstances.

To increase liquidity in this market, all permits are the same after their date of issue, and permits are bankable; that is, a permit issued for the year 2000 can be used in any later year. There is no environmental loss in making permits bankable. Current carbon emissions are reduced to the extent that permits are banked. Given the long life time of CO<sub>2</sub> in the atmosphere, short term voluntary banking is unlikely to have significant impacts on CO<sub>2</sub> concentrations. Allowing banking further increases liquidity in secondary markets, since all permits are the same after their date of issue.

Under the Kyoto targets permits can be used any time within a five year commitment period. This essentially allows borrowing of up to five years worth of permits in the first year of the program and reducing amounts in later years. A US program could be more or less restrictive than this.

In addition, permits can and should be auctioned not only for the current years but also for future issue years. Thus, some permits for 2005 could be auctioned in 2000 even though they cannot be used to offset carbon emissions until after January 1, 2005.<sup>9</sup> Early auctions would facilitate the development of an active futures and options market, thus improving risk allocation.<sup>10</sup>

Market power should not be a concern in an auction for carbon permits. Even in an upstream program, there would still be more than 1,700 permit buyers. Most importantly, even the largest buyers would constitute just a tiny fraction of the market, as is seen in Table 1. This should be contrasted with the U.S. Treasury auctions where the top-five primary dealers routinely purchase over one-half of the issue. Despite this concentration, market power is not a serious problem in Treasury auctions.

Table 1 Carbon Permit Needs across Firms - Direct Permit Market Players

<b>Carbon User</b>	<b>Total Carbon produced in 1995 (million metric tons)</b>	<b>% of permit market</b>
<b>Oil Industry<sup>11</sup> (175 refineries)</b>	<b>436</b>	<b>31.1 %</b>
Largest Oil Company (Chevron)	31.1	2.3%
Second largest (Exxon)	28.7	2.0%

<sup>8</sup> Some refinements for non-combustion uses of fossil fuels (eg; plastics) and for exports of fuel would be required.

<sup>9</sup> In the US Acid Rain program, allowances are issued 30 years in advance.

<sup>10</sup> See Fischer et al (1998).

<sup>11</sup> U.S. Department of Energy, Energy Information Administration. (1996)

Largest 10 oil companies	226.7	16.2%
<b>Coal Industry</b> <sup>12</sup> (550 coal preparation plants)	<b>610</b>	<b>43.5 %</b>
Largest Coal Producer (Peabody Holdings)	79.3	5.6%
Largest 3 companies	158.6	11.2%
<b>Natural Gas Industry</b> <sup>13</sup> (250 natural gas pipeline companies and 725 natural gas processing plants)	<b>356</b>	<b>25.4%</b>
<b>Total</b>	<b>1402</b>	<b>100%</b>

It is inconceivable that any party would be successful in exercising substantial market power in the market for carbon permits. Even the largest bidder (Peabody Holdings with 5.6% of the market) can gain little by understating demand. For it to be profitable to understate demand and lower the permit price, one or a small group of buyers must have relatively elastic permit demand and a large share of the market, and other buyers must have relatively inelastic permit demand.<sup>14</sup> None of these conditions are present here. Attempts to corner the market to exclude competitors would be even more fool hardy. It would be impossible for a single firm to prevent competitors from buying permits at auction or in an active secondary market for carbon permits.

## Ways to auction many identical items

There is a great deal of experience in the auctioning of many identical items. In the most basic setting, a seller is offering a fixed supply of identical items. The buyers express their willingness to buy various quantities at various price levels by submitting bids at auction. A permit auction fits the simplest case. The government desires to sell a fixed supply of identical permits.

As in Treasury auctions, carbon permit auctions should be held on a regular basis, perhaps quarterly. This is frequent enough that firms will have a good idea of their likely needs. Quarterly auctions also reduce the cash flow problems associated with less frequent sale.

Many different auction forms are possible. They are best divided into two basic forms: sealed-bid auctions and ascending-bid auctions. Below we discuss the advantages and disadvantages of each.

### Sealed-bid auctions

In sealed-bid auctions, the bidders simultaneously submit demand schedules. The auctioneer adds these demand schedules to form the aggregate demand curve. Typically, demand schedules are required to be step functions, but piecewise linear schedules are permitted in some settings. A sample demand curve appears in Figure 1. The point at which the aggregate demand curve and the supply curve cross determines the clearing

<sup>12</sup> U.S. Department of Energy, Energy Information Administration (1997)

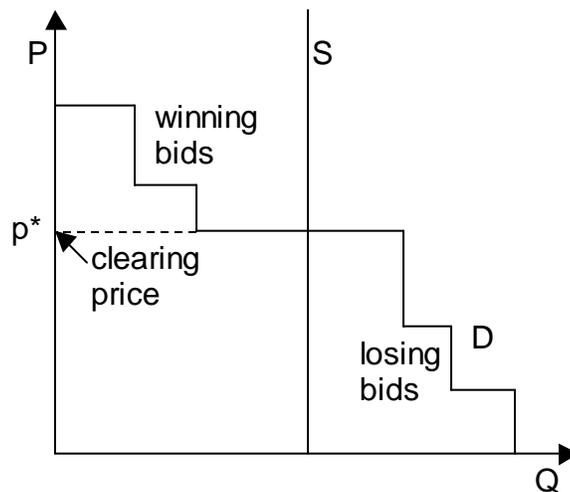
<sup>13</sup> U.S. Department of Energy, Energy Information Administration

<sup>14</sup> For a discussion of market power in permit markets, with some empirical simulations, which show the small effects on efficiency in realistic situations see Tietenberg (1985). Even if some buyers are able to affect the market price it will not be profitable for them to do so.

price. All demands above this clearing price are filled, those at the clearing price are rationed, and those below are rejected. The various sealed-bid auction forms differ in what each bidder pays for the amounts awarded.

The two most common pricing methods are uniform pricing and pay-your-bid pricing. Under uniform pricing, each winner pays the clearing price  $p^*$  for each permit. With pay-your-bid pricing, each winner pays its bid. Of course, bidding behavior is quite different under the two approaches. With pay-your-bid pricing, the bidder attempts to guess where the clearing price is likely to fall and then bids slightly above it. Bids in excess of the clearing price are money left on the table. With uniform pricing, predicting the clearing price is less important, since every winner pays the clearing price regardless of how high it bids. With a uniform price however, bidders may bid below their true value in an attempt to influence the market price. Neither pricing rule is fully efficient. In both, the bidders shade their bids (bid below their true values) in complex ways. This differential shading leads to inefficiency (Ausubel and Cramton 1996).

Figure 1. Sample Demand Curve



A third pricing rule, proposed by Vickrey (1961), does yield efficiency in a private value setting.<sup>15</sup> With Vickrey pricing, each winner pays the opportunity cost of its winnings; that is, the extra value that would be gained if its units went to the most deserving losers. Vickrey pricing eliminates all bid shading: it is a dominant strategy to bid your true demand curve. Vickrey accomplishes truthful revelation by rewarding large bidders for bidding their full demands. Typically, a bidder pays less for each additional unit it wins. It pays the highest rejected bid of the other bidders for its first unit; the second-highest rejected bid for its second unit; and so on.

Comparing the sealed-bid auctions is difficult, even in the setting with private values. Vickrey is best from an efficiency standpoint. The distinction between uniform pricing and Vickrey pricing depends on the extent of market power. When no bidder has significant

<sup>15</sup> It is unclear whether a carbon auction is best thought of as a private value or a common value auction. In a private value auction, each bidder's value does not depend on information held by others, but depends on the bidder's particular situation. In a common value auction, all bidders have the same value for the good, and each has private information about this uncertain value. Common value auctions arise when the good is purchased for resale. A carbon auction would have elements of both.

market power, then the outcomes are close, and uniform pricing is nearly as efficient as Vickrey pricing. Uniform pricing has the added benefit that everyone pays the same price. Uniform pricing also encourages participation by small bidders, since it is strategically simple and the small bidders benefit from the demand reduction (bid shading) by the large bidders. In contrast, pay-your-bid pricing exposes small bidders to strategic risk, since they may be less able to gauge where the clearing price is apt to be. Hence, among the sealed-bid auctions, a uniform-price auction probably is best for the case of carbon usage permits.

### Ascending auctions

Ascending auctions have many advantages over sealed-bid formats. A reliable process of price discovery is a primary advantage. Both price and allocation are determined through a process of open competition. Each bidder has every opportunity to improve (raise) its bids, changing losing bids into winning bids. In the end, those willing to pay the most win the permits. Bidders get to choose exactly how many permits they want based on good information about price. An ascending process is especially desirable when bidders' valuations depend on information held by others. Then the bidding process reveals information, which refines the bidders' valuation estimates, enabling them to bid more aggressively without fear of the winner's curse.

Multiple-unit ascending auctions can be conducted in two basic ways: with demand schedules or with an ascending clock.

The demand schedule approach can be thought of as a multiple-round version of the sealed-bid auctions. In each round, bidders submit a demand schedule. The schedules are aggregated to form the demand curve. The clearing price, where demand intersects supply, defines the tentative split between winning and losing bids. If this were the final round, those bids above the clearing price would be filled, those at the clearing price would be rationed, and those below the clearing price would be rejected. The process repeats until no bidder is willing to improve (raise) its bids.

To promote reliable price discovery an activity rule is needed. The activity rule prevents bidders from holding back initially and then submitting large bids after the other bidders have revealed their information. In most situations, the bidders will have (weakly) downward sloping demand curves. In this case, a simple yet powerful rule can be used without distorting behavior. The rule has three elements:

1. All bids must be entered in the initial round (that is, the total quantity that a bidder bids can only decrease).
2. Any losing bid that is not improved in the next round is permanently rejected.
3. The improved bid must exceed the clearing price by at least the minimum bid increment.

This activity rule is the one-sided variant of a rule proposed by Wilson (1997) for the California Power Exchange's day-ahead electricity auction. The rule is based on the concept of revealed preference in the following sense. A failure to improve a losing bid is taken as presumptive evidence that the bidder's valuation is below the minimum bid (one increment above the prior clearing price). Prices only increase, so the unimproved bid can be permanently rejected. Thus, bidders are required to improve losing bids in the next round or reduce the quantity demanded.

The activity rule forces the bidders to bid in a way that is consistent with a downward sloping demand curve. A competitive process results in which winning bids in the prior round get topped by losing bids in the current round. This process repeats until the clearing price increases to the point where excess demand falls to zero. At this point no bidder is willing to improve a losing bid and the auction ends.

### Ascending-clock auction

The ascending-clock auction offers a simpler approach. The clock indicates the current price. In each round, the bidders submit the quantity they are willing to buy at that price. If the total quantity bid exceeds the quantity available the clock is increased. The bidding continues until the quantity bid is less than the quantity available. The permits are then allocated at the prior price, and are rationed for those that reduced their quantity in the last round. The activity rule in this case is simply that each bidder cannot increase its quantity as prices rise.

This design shares all the advantages of the ascending auction with demand schedules, and has several additional advantages:

1. It is easier to implement for both seller and buyers, since a buyer only bids a single quantity in each round, rather than a schedule.
2. There is no possibility of undesirable bid signaling, since only the total quantity bid is reported.
3. Rapid convergence is guaranteed, since the price increases by one bid increment with each round of bidding.

Like the uniform-price auction, a difficulty with the ascending-bid approaches described above is that they are inefficient. In each case, bidders shade their bids (bid below their true demand curves) in order to keep the price down. Large bidders tend to shade more than small bidders, since a particular price effect has a bigger impact on profits for a large bidder. This differential shading leads to an inefficient outcome. Large bidders tend to win too little and small bidders tend to win too much.

Ausubel (1997) proposes an alternative ascending-clock auction that achieves full efficiency. The auction implements Vickrey pricing in an ascending format. Efficiency is restored without losing the advantages of an ascending-bid format.

However, in this setting where market power is apt to be slight, the inefficiencies from a standard ascending-clock auction are likely to be insignificant. Hence, the equity and simplicity of having everyone pay the same price may be worth a modest inefficiency.

In years past, conducting an ascending auction for carbon permits would have been difficult, because of the costs of getting all the bidders together at the same time and place. However, communication advances have now made it easy to implement an ascending auction of this scale over the Internet.

### Desirable auction form for carbon permits

We conclude that bankable and identical carbon permits should be auctioned on a quarterly basis using a standard ascending-clock design. If it is viewed that an ascending

auction is infeasible, then we prefer a sealed-bid uniform-price auction. Both the auction market and the secondary market should be open to all.

The auction setting for carbon permits is especially simple. The items are identical and there is an absence of market power. Bankable permits will further increase the liquidity of the permits. As such, we see no impediments to creating a fully efficient carbon permit auction. Indeed, auctions in much more complex and challenging settings have worked extremely well. Examples include spectrum auctions and electricity auctions.

Secondary markets for permits are likely to be highly efficient as well. These markets will complement an efficient auction, allowing firms to make adjustments to their permit inventory on an as-needed basis.

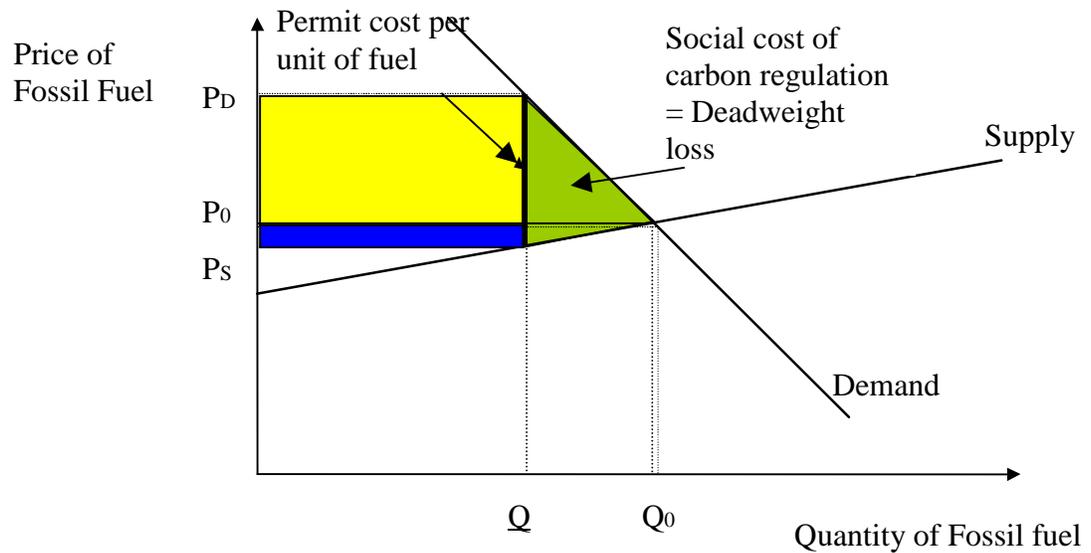
## Why auction rather than grandfathering?

Instead of auctioning, the government could give the permits away to specific groups. This alternative is known as “grandfathering.” The government could allocate permits on the basis of past usage, on some measure of output, or to politically favored groups. The traditional view is that grandfathering, while inefficient, is chosen because it provides greater political control over the distributional effects of regulation (Stavins 1997). We argue that auctioning is superior to any of these methods, because it allows reduced tax distortions, provides greater incentives for innovation, provides more flexibility in distribution of costs, and reduces the need for politically contentious arguments over the allocation of rents. We recognize that this does not mean auctions will be chosen. We argue however that these arguments may be more compelling in the case of carbon than they have been in SO<sub>2</sub> and other programs, and therefore may outweigh the political economy problems.

### Efficient revenue raising

Auction revenue can replace distortionary taxes. Distortionary taxation creates a deadweight loss by inserting a wedge between marginal cost and price. Any efficient form of carbon regulation must make carbon scarce, thereby raising the marginal cost of using carbon. The rise in marginal cost implies a real cost of carbon regulation equivalent to the deadweight loss from distortionary taxation. In Figure 2, the simple graph shows how carbon regulation raises the price of fossil fuel by the permit cost per unit, and reduces the quantity from  $Q_0$  to  $Q$ . This figure assumes only one fossil fuel, and that it is sold directly from producers to the ultimate consumers.  $P_0$  is the original unregulated price,  $P_D$  is the price consumers pay after regulation and  $P_S$  is the price sellers receive. The difference is the permit cost. The social cost is equal to the deadweight loss of an equivalent tax. This real welfare cost corresponds to loss of output estimated to be on the order of 0.8% of GDP which would have been \$60 billion in 1995 (Repetto and Austin 1997). At the same time, the regulation of carbon creates scarcity rents on the order of \$125 billion (1246 metric tons at \$100 per ton). In a grandfathered system, these rents go to those who receive the permits. In an auction system, the rents are collected as revenue by the government. This revenue could be used to cut labor, payroll, capital, or consumption taxes or to reduce the deficit, all of which would create efficiency gains. Some could be used to further equity goals as discussed below.

Figure 2 Cost of carbon regulation – equal to deadweight loss from equivalent tax.



Ballard, Shoven and Whalley (1985) estimate that each additional \$1.00 of government revenue, raised through distortionary taxation, costs society \$1.30. If we can gain revenue with no additional distortion, by auctioning rather than grandfathering, we can achieve significant efficiency gains. The revenue raised in the auction could be used to cut taxes and reduce the deficit. One concern commonly expressed by private sector actors is that government will not use the revenue well.<sup>16</sup> While this may be true, with revenue of around \$125 billion annually Congress will be pressured to use the revenue in transparent and hence probably more socially beneficial ways. If the auction raises \$125 billion annually, compensating tax cuts could increase GNP by up to \$40 billion relative to under a grandfathered system.

The “double dividend” argument is that not only are environmental goals achieved in a tax or tradeable permit system, but the tax system is also made more efficient through revenue recycling so that the overall cost of the policy is negative. Because of interactions with existing taxes, however, the carbon regulation could have higher costs than are immediately apparent (Bovenberg and Goulder 1996). For example, if the carbon regulation reduces the return to labor, it exacerbates the existing distortion from the labor tax. These tax interactions will occur regardless of the form of regulation. Research strongly suggests that US carbon regulation will not generate a double dividend. The numbers above are consistent with this. Nevertheless, even if there is no double dividend from raising revenue through environmental regulation, it is always more efficient to auction. Parry, Williams and Goulder (1998) estimate that, the cost of reducing emissions by 10 % would be more than three times higher under grandfathered allowances than under a tax, or equivalently an auctioned permit system.<sup>17</sup> Grandfathering permits, and hence losing the value of revenue recycling, could triple the cost of regulation relative to an auction system.

<sup>16</sup> One criticism of the efficient revenue raising argument is that government spending is not exogenous. Raising revenue through auctions may not lead to equivalent tax cuts. Preliminary work by Becker and Mulligan (1997) suggests that more efficient tax systems are associated with larger governments. If this is the case, the efficiency gain from auction revenue will depend on the actual size of the tax cuts and what is done with the additional government spending.

<sup>17</sup> Their results suggest that the interaction effects are so serious that unless the benefit of reductions are greater than \$18 per ton, a grandfathered permits would not yield any net social benefits.

## Dynamic efficiency

The choice of auctions over grandfathering has dynamic advantages. Innovation reduces abatement costs. This is always advantageous to firms so they always have an incentive to innovate when economic instruments are used.<sup>18</sup> Innovation, however, also reduces scarcity rents by lowering permit prices. Industry incentives to innovate are even greater with auctions than grandfathering because, when permits are auctioned, innovators do not receive scarcity rents so they unambiguously benefit from the innovation-induced fall in permit prices (Milliman and Prince 1989; Fischer, Parry and Pizer 1998). In contrast, in a grandfathered system the scarcity rents belong to the industry so there is no aggregate gain to industry from reducing them.<sup>19</sup>

Some argue that we should grandfather permits because energy companies need the resources to innovate and make investments to abate emissions. The industrial organization and corporate finance literature tends to show a positive relationship between cash-flow and both R&D / innovation and adoption of new technology, but the results are ambiguous.<sup>20</sup> The energy and environment literature has repeatedly documented the related “energy paradox” where households have a tendency not to buy energy efficient appliances and house features despite very high apparent returns.<sup>21</sup> For example the implicit discount rate when households choose between more and less efficient air conditioners and refrigerators often greatly exceeds 20 percent. The effect of liquidity constraints, while real, is likely to be weaker for the likely recipients of grandfathered permits, large energy companies. Many of the firms that will need to innovate and make technology investments will be new firms that will not receive grandfathered permits. A tax cut will more effectively provide resources to liquidity-constrained households and small firms.

## Distributional effects of auctions

In studying the distributional effects we break them into two parts, the effects which arise through changes in prices and returns to factors, and the wealth effects of changing ownership of a resource. Ownership is being transferred from the commons to either the taxpayer, under auctions, or the recipients of grandfathered permits. The price effects, which are the most complex effects, are the same regardless of the form of carbon regulation. In particular, they are unaffected by whether permits are auctioned or grandfathered. The aggregate distributional effects depend on the sum of price and wealth effects.

Three aspects of the distribution of costs of carbon regulation are important because of concerns about equity, political feasibility or both. The extent to which “the polluter pays” is important for equity reasons, and from the point of view of environmental groups.<sup>22</sup> The way that costs are distributed across the income distribution, and the effects on

---

<sup>18</sup> Under technology standards, regulators sometimes respond to new innovations by increasing the stringency of regulation – requiring the use of the new innovation and the higher environmental standards it allows, or they do not recognize the new technology and hence the firm is still required to meet the old technology standard and the innovation has no value.

<sup>19</sup> In fact the incentive to innovate depends not on whether permits are auctioned or grandfathered, but on who owns the permits at the time of innovation. If permits are auctioned many years in advance, the incentives are identical under auctions and grandfathering. (Kerr, 1998)

<sup>20</sup> For a survey of the literature on innovation see Cohen (1995). The literature on technology adoption puts liquidity constraints forward as one reason why small firms appear to adopt new technologies more slowly than larger firms even controlling for other factors that affect profitability. See for example Saloner and Sheppard (1995).

<sup>21</sup> See Hausman (1979) and Jaffe and Stavins (1995).

<sup>22</sup> In the case of carbon, “polluter pays” may be inappropriately judgmental in tone. However the logical replacement “user pays” has the same equity implications.

particularly vulnerable groups, have clear equity impacts. The costs borne by specific, powerful interest groups are critical for political feasibility.

### Theory of cost incidence

Three groups ultimately bear costs: consumers, workers (owners of human capital), and capital owners, especially current owners of physical capital. Consumers suffer loss of consumer surplus, workers suffer a fall in income, and capital owners suffer a fall in the value of their capital. Who bears costs does not depend on the legal form of the regulation, only on its effects on prices.

At every point in the economy, economic actors can pass changes in price due to carbon regulation forward to buyers, and backward to suppliers of factors of inputs.<sup>23</sup> When a domestic carbon permit system is instituted, carbon becomes scarce and the cost (inclusive of the permit) of domestic fuels containing carbon rises. If this rise in cost does not lead to an equivalent rise in wholesale price, the owners of the fuel sources lose.<sup>24</sup> The change in wholesale price depends on the relative elasticities of supply and derived demand. The elasticity of domestic supply depends partly on fossil fuel producers' access to international markets. The long run supply elasticity will be higher than the short run, because producers can alter exploration and development behavior. The elasticity of demand for fuel from producers depends partly on all the possible ways that downstream producers and consumers can reduce their use of specific fuels through fuel switching, increased fuel efficiency and changes in consumption. The cost incidence also depends on the industrial structure (Atkinson and Stiglitz 1980). In a monopoly, if supply is inelastic, producers will tend to bear the cost. If supply is elastic, the price rise will depend on the shape of the supply curve, the price could rise by more than the tax leading to a negative incidence on producers.<sup>25</sup>

In the same way that producers pass part of the cost forward with an increase in fuel prices, some can be passed backward through reductions in factor returns, to factors used in fossil fuel production, such as coal miners' labor. The effect on coal miners' wages depends on the elasticity of demand for coal miners, and their elasticity of labor supply to mining. In the short run at least, coal miners may be geographically and occupationally immobile, so may face significant wage reductions and unemployment.

We can identify similar effects throughout the economy. As each producer faces a cost increase they pass some on to their demanders, as increased prices, and some back to their workers. In general, part of the cost increase can also be passed backward to owners of capital. If capital is specific to a particular industry, its supply is inelastic in the short run. The return to its use will fall, leading to a fall in its value. Carbon-inefficient coal fired electric utilities and industrial boilers are examples of immobile capital that will fall in value. The current owners of these assets will face losses. Some forms of relatively carbon-efficient capital, such as gas fired, nuclear or hydro plants will rise in value. Ultimately the price changes reach the final consumer of fossil fuel or any good produced using fossil fuel. How much of the cost consumers bear depends on the elasticity of demand for fuels and goods containing carbon, relative to the elasticity of supply. In the short run, consumer demand for fuel may be relatively inelastic, because they can only

---

<sup>23</sup> Prices of substitutes and complements to factors, inputs and outputs will also be affected through cross elasticities. Some factors and consumers may benefit from rising returns or falling prices.

<sup>24</sup> As with a tax on land rent (Feldstein (1977)), not all the tax is borne by fossil fuel reserve owners even though in the short run they can do nothing to change their behavior.

<sup>25</sup>  $MR = p(1-1/\eta^D)$  where MR is marginal revenue, p is the price and  $\eta^D$  is the price elasticity of demand. With a constant elasticity demand curve, MC as marginal cost and tax =  $\tau$ ,  $MR = MC + \tau$  so  $dp/d\tau = (1/(1-1/\eta^D))$  which is greater than one for a monopolist.

respond by reducing usage. In the longer run, they can invest in new heating systems, cars, houses, and appliances that allow them to switch fuels and increase energy efficiency.

Figure 3 Fossil Fuel Price and Quantity Effects from Carbon Regulation

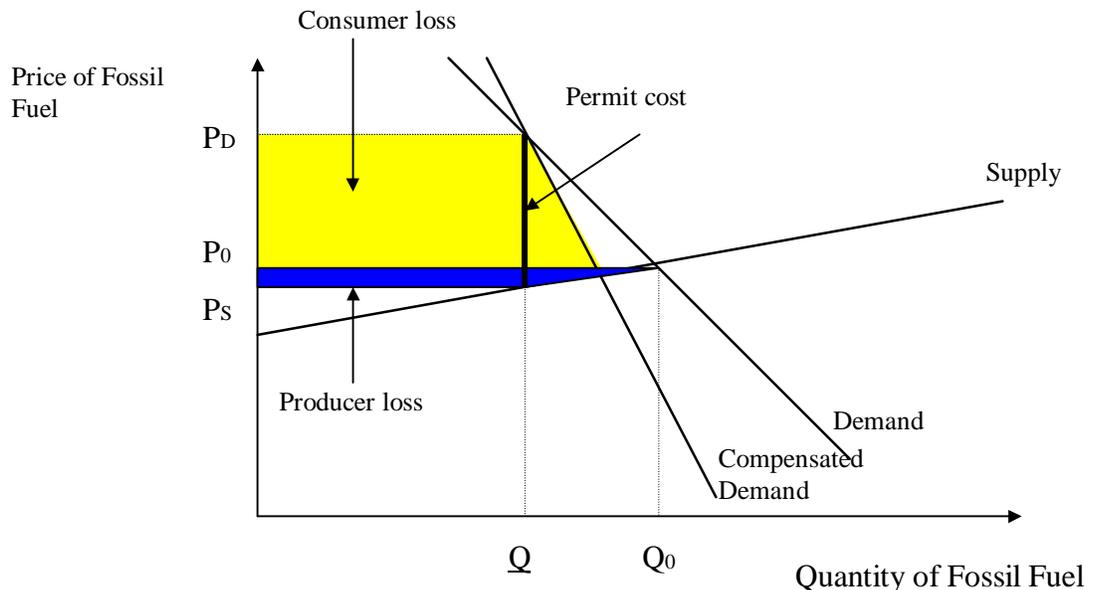


Figure 3 illustrates the losses to consumers and producers (passed on to factors). It uses the same simple example as Figure 2.  $Q_0$  is uncontrolled fossil fuel demand.  $Q$  is the carbon cap translated into a fossil fuel cap. The figure shows how as the fossil fuel is restricted the price buyers pay rises to clear the market, and the price suppliers receive falls. The permit price is the difference between these prices. In this illustration the buyer has inelastic demand and hence bears most of the price rise. The social cost is the sum of the loss of consumer and producer surplus. Consumer surplus is measured as the area under the compensated demand curve to reflect the amount consumers would be willing to pay to have the price lowered to its original level. We could draw similar figures for specific labor markets, specific intermediate product markets and physical capital markets.

In summary, the relative changes in prices (including wages and dividends) in response to the regulation, depend on relative elasticities of supply and demand for crude fossil fuels, specific types of capital and labor, and consumer goods. The overall cost to the economy of a given carbon target will fall with higher elasticities. The costs to specific individuals depend on these price changes, their ownership of different types of physical and human capital, and their consumption patterns.

#### Empirical evidence on the incidence of carbon regulation

A variety of empirical studies shed light on the incidence of carbon regulation. All current models assume that the tax is fully passed through to consumers. Thus they implicitly assume perfectly elastic supply of factors, or equivalently full factor mobility. Poterba (1990) considers the relative expenditure shares directly devoted to energy across the expenditure distribution. Casler and Rafiqui (1993) use a similar methodology for direct expenditures. They also use an input-output framework to estimate indirect incidence through the purchase of goods produced using energy. Dowlatabadi, Kopp and Tschang (1994) consider only direct effects but allow for partial equilibrium responses to energy

prices. Jorgenson, Slesnick and Wilcoxon (1992) use a general equilibrium model to consider the lifetime incidence of carbon taxes through all possible channels.

The different models have several consistent qualitative results. All agree that the impact of the tax will be relatively, but not dramatically, regressive.<sup>26</sup> The indirect effects tend to reduce the regressivity. Consumer incidence varies significantly by region. The Midwest bears the highest costs; the Pacific States bear the lowest. Other results are less clear. Casler and Rafiqui find that rural households are harder hit, and the young less affected. Jorgenson et al. find the opposite. Jorgenson et al. find that large households are more affected.

None of these models can say anything about loss of capital income and therefore loss of capital value. Bovenberg and Goulder estimate that the coal industry loses around 28% of their equity while the oil & gas industry loses between 4.8 and 6.3% of their equity. However they point out that while these are significant to the industries concerned, they are a small fraction (4.3 and 15 percent respectively) of potential revenues.

The models currently can say nothing about the effects of carbon regulation on labor markets. Also the models all assume perfectly competitive pricing, which may not be appropriate in some of the key industries.

The regional effects on employment and consumption may exacerbate each other to create short-run macroeconomic effects on local economies particularly in the East South Central region. The wide dispersion of owners and the high mobility of financial capital imply that the regional effects on capital value are unlikely to have local macroeconomic effects.

Identifying the cost distribution is a non-trivial exercise. It seems likely that costs will be slightly regressive across consumers, will reduce the income of shareholders in parts of the energy sector (especially coal producers and users), and will have impacts on immobile workers in the coal sector. Clearly more research is needed to clarify these relative effects on individuals.

#### Distributional effects under auctions and grandfathering

Prior to compensation, an auction system distributes costs in the same way as a grandfathered system. Both systems lead to a distribution of costs that is determined by general equilibrium cost incidence, factor endowments and consumption patterns. The underlying distribution is broadly consistent with polluter pays. Those heavily dependent on fossil fuels for capital or wage income, or in their consumption patterns, will bear more costs. Groups that respond significantly and rapidly to the pressure to reduce fossil fuel use will be rewarded by lower shares of costs. The ultimate distribution of costs varies between the options depending on how the auction revenue is used - who benefits and how much efficiency is increased - and to whom the permits are grandfathered.

The government can use auction revenue to reduce tax distortions and thus reduce costs throughout the economy. It can be used to reduce labor or consumption taxes, benefiting all taxpayers. Payroll taxes can be cut or personal exemptions increased, benefiting the poor and middle classes. The deficit can be reduced, providing benefits to current borrowers and future generations. Auction revenue can be used to directly compensate afflicted workers, and provide transition assistance to help them change industries or

---

<sup>26</sup> As Poterba (1990) points out, for consumers in the lowest expenditure quintiles who are receiving transfers, an automatic partial compensation mechanism exists through the indexation of transfers. This compensation is not captured in measures of regressivity.

locations. It can be used cut the capital gains tax and hence benefit capital owners. Bovenberg and Goulder (2000) show that the coal and oil&gas industries could be compensated for their equity losses through an industry-specific corporate income tax cut and that this would even be efficient revenue-recycling. It can provide assistance to afflicted communities and regions during their transition to a less fossil fuel dependent economy. Only the political process and the normal constraints on redistribution limit the flexibility of compensation under auctions.

In contrast, grandfathering permits does not yield efficiency benefits so total costs are higher. It redistributes wealth only to those who directly receive permits. If the government grants permits to coal companies, electric utilities, and their ilk, it will yield no benefits for workers in those industries, local economies or consumer prices. Grandfathering could compensate some current owners of specific capital if permit allocations are carefully targeted. Because total abatement costs are small relative to revenue raised, and industry only bears a share of costs, only a small fraction of permits would need to be grandfathered to leave fossil-fuel industries equity neutral. These owners, however, can be adequately and more efficiently compensated, if such compensation is thought necessary, through targeted tax breaks. It would be theoretically possible to grandfather the permits to a wide range of workers, consumers and capital owners, but this would be a cumbersome way to achieve a less efficient result than a tax-cut auction.

Equity can be better achieved under auctions. Cost bearing is widely spread, and, in the long run, all costs are borne by consumers. Therefore compensation should also be more widely spread. Auctions can provide more flexibility than grandfathering in compensation. In addition, poorer people tend to be workers and consumers more than they are shareholders, so they are unlikely to benefit from grandfathering. These arguments were also true for the Acid Rain program, where grandfathering was chosen, but as Joskow and Schmalensee (1997) point out, the effects were attenuated because the recipients of permits were electric utilities subject to rate regulation. Utilities were expected to pass on the scarcity rents as lower electricity prices. In contrast, the energy sector does not generally face economic regulation, so prices will not reflect rents.

## The politics of auctions and grandfathering

### Grandfathering

If permits are grandfathered, interest groups will fight bitterly for a share of annual rents of up to \$134 billion.<sup>27</sup> This fight will lead to direct costs during the design of the policy. Groups will invest in lawyers, government lobbying, and public relations campaigns. Government officials will spend enormous amounts of time preparing and analyzing options and in negotiations. This will lead to high administrative costs and probably considerable delays in implementation. Problems of this nature in the allocation of the telecommunications spectrum ultimately led to industry support for the recent FCC auctions.

In addition, the enormous rents mean that interest groups will continue to seek changes in the allocation over time. Firms may end up putting as much effort into rent capture as into finding efficient ways to reduce carbon usage. Investments may be delayed in the hope that high observed marginal costs would lead to more generous allowance allocations as compensation. The increased complexity of the program, which grandfathering tends to

---

<sup>27</sup> Some industry people say that they would not want to have grandfathering because of this contentious process and because they expect that profit taxes would be levied to extract any rents they gained. They are also concerned about the public relations effects of appearing to exploit consumers through price rises while not bearing costs themselves.

create, may lead some groups to seek exemptions, or bonus allowances in particular circumstances. In the SO<sub>2</sub> case the negotiation process was costly and lengthy and the ultimate allocation formula reflects many special interests and exemptions (Joskow and Schmalensee 1997). Additional permits were allocated to reward behavior such as investment in scrubbers.

### Auctioning

In contrast, the main political economy problem with auctions is that strong vested interests will fight bitterly to claim the rents, by proposing grandfathering and opposing auctions. Industry support is generally needed to pass the regulation as a whole. In the past the vested interests have always won. The industry directly involved usually has much more concentrated interests than consumers, workers and indirectly affected sectors. A key recent example of auctioned rights in the US is the spectrum auctions. In the spectrum auctions the politics may have been altered by the enormous cost to the industry from delays suffered while spectrum rights were fought over. Auctions also had efficiency advantages for the industry because of the extremely complex problem faced when allocating heterogeneous permits with highly interdependent values. The design of the Spectrum Auction reflected this difficulty. In addition, in a fast growing industry, many powerful players were non-incumbents who were unlikely to receive grandfathered permits. This may also be true in the electricity sector in the wake of deregulation.

In the case of carbon permits, the energy industry is already beginning to lobby for some form of grandfathering. The more efficient and equitable outcome of auctions will only be achieved if it becomes clear how the true costs will be spread, and if other affected groups are mobilized to protect their interests. Carbon is different from previous environmental regulations because of its potential scale and the pervasiveness of energy use. The scale will make the distribution of rents more transparent. Powerful players in non-energy sectors may well find it worth while to engage in this debate.

Transparency, however, can also have a down side for auctions. The auction price would be publicly visible, and large amounts of money would be transferred between the private and public sectors. This will affect perceptions of the distribution of costs. It may hinder the passing of the carbon regulation as a whole. It will raise opposition from those who are skeptical that the program will be revenue neutral, with tax cuts completely offsetting the auction revenue.

## Conclusion

We have addressed one key question concerning how best to meet carbon targets set in international negotiations. Assuming that the choice of domestic regulation will be a tradeable permit market, we outlined and argued for a tax-cut auction of the permits.

Scarce permits can be allocated through auctions or grandfathering. Vested interests argue for grandfathering – that permits should be allocated based on past energy output. Such a system gives energy companies all the scarcity rents. This would represent a huge windfall gain to the owners of energy companies.

A much better approach is for the government to auction permits on a regular basis. An auction gets the permits to those who most need them, complementing the secondary market. Most importantly, in an auction the government gets the scarcity rents, rather than the energy companies. Auction revenues can be applied to reduce distortionary taxes, thereby providing an efficiency benefit. The equity benefit is that tax cuts spread the scarcity rents broadly across society, more closely reflecting the distribution of costs.

Designing a carbon permit auction is especially simple. CO<sub>2</sub> is a uniformly mixed, accumulative pollutant. Neither the source nor timing of emissions is important. Hence, carbon permits can be auctioned as a homogeneous and bankable good. Even in an upstream system, which minimizes administrative costs by requiring permits where monitoring is easiest, market power is not an issue. The largest firm has only a 5.6% market share. Firms with less than a 1% share of the energy industry hold the vast majority.

In this setting, we recommend a standard ascending-clock auction. The auction begins at a low price. With each round, the bidders are asked what quantity they demand at the price posted on the auction clock. If there is excess demand, the price is increased. This process continues until the excess demand falls to zero. The bidders then receive their quantity bid at the final price. This auction generates a uniform price for carbon permits. All bidders get their demands at the market price. A secondary market will allow the sale and purchase of permits as circumstances change. This design assures a highly efficient allocation of the permits.

We have proposed a tax-cut auction for carbon permits. In the carbon case, the permit design is simple, and the costs are very high and dispersed throughout the economy. These factors make the design of an auction simple. Auctions are feasible and efficient. The normative case for auctioned carbon permits is strong. Given that the forces of supply and demand, rather than who is legally liable to meet the regulation, determine costs, the government has neither an efficiency nor an equity reason to give scarcity rents to industry. The best way to control climate change is to minimize the costs and distribute the rents fairly with a tax-cut auction. Whether these advantages, and the unique political economy of a problem on the scale of carbon regulation, will overcome the power of vested interests and lead to the choice of auctioned permits is still an open question.

## References

- Ausubel, Lawrence M. (1997), "An Efficient Ascending-Bid Auction for Multiple Objects," Working Paper, University of Maryland.
- Ausubel, Lawrence M. and Peter Cramton (1996), "Demand Reduction and Inefficiency in Multiple-unit Auctions," Working Paper No. 96-07, University of Maryland.
- Ausubel, Lawrence M. and Peter Cramton (1998), "The Optimality of Being Efficient," Working Paper, University of Maryland.
- Atkinson A. and J. Stiglitz (1980), *Lectures in Public Economics* (New York: McGraw Hill) pp. 206-217.
- Ballard, Charles L., John B. Shoven, and John Whalley (1985), "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States," *American Economic Review*, 75, 128-138.
- Becker, Gary S. and Casey B. Mulligan (1997), "Efficient Taxes, Efficient Spending, and Big Government" Draft, University of Chicago.
- Bovenberg, A. Lans, and Lawrence H. Goulder (2000) "Neutralizing the Adverse Industry Impacts of CO<sub>2</sub> Abatement Policies: What does it cost?" NBER Working Paper 7654, April
- Bovenberg, A. Lans, and Lawrence H. Goulder (1996), "Optimal environmental taxation in the presence of other taxes: general equilibrium analysis", *American Economic Review*, 86 (4) September.
- Casler, Stephen D. and Aisha Rafiqui (1993), "Evaluating Fuel Tax Equity: Direct and Indirect Distributional Effects" *National Tax Journal* 46(2), 197 – 205.

- Cason, Timothy N. (1995), "An Experimental Investigation of the Seller Incentives in EPA's Emission Trading Auction," *American Economic Review*, 85, 905 - 922.
- Cason, Timothy N. and Charles R. Plott (1996), "EPA's New Emissions Trading Mechanism: A Laboratory Evaluation," *Journal of Environmental Economics and Management*, 30, 133-160.
- Cline, William (1991), *The Economics of Global Warming* (Institute of International Economics: Washington, DC).
- Clinton, President (October 22, 1997), "Remarks by the President on Global Climate Change" National Geographic Society, Washington, D.C.
- Cohen, Wesley (1995), "Empirical Studies of Innovative Activity" *Handbook of the Economics of Innovation and Technological Change* (Blackwell Publishers: Malden MA)
- Cramton, Peter (1997), "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy*, 6:3, 431-495.
- Dowlatabadi, Hadi, Raymond J. Kopp and F.Ted Tschang (1994), "Distributional and Environmental Consequences of Taxes on Energy" Resources for the Future Discussion Paper 94-19, March.
- Feldstein, Martin S. (1977), 'The Surprising Incidence of a Tax on Pure Rent: A New Answer to an Old Question' *Journal of Political Economy* 85(2) April. 349 - 360
- Fischer, Carolyn, Suzi Kerr and Michael Toman (1998), "Using Emissions Trading to Regulate US Greenhouse Gas Emissions: An Overview of Policy Design and Implementation Issues" *National Tax Journal* 51(3) September
- Fischer, Carolyn, Ian W. H. Parry, William A. Pizer (1998), "Instrument Choice for Environmental Protection When Technological Innovation is Endogenous" RFF Discussion Paper 99-04.
- Gaskins, D. W. and J. P. Weyant (1993), "Model Comparisons of the Costs of Reducing CO<sub>2</sub> Emissions" *American Economic Review* (AEA papers and Proceedings), Vol. 83 (2), pp. 318-323.
- Hargrave, Tim (1997), "U.S. Greenhouse Gas Emissions Trading: Description of an Upstream Approach" Airlie Papers, Center for Clean Air Policy, September.
- Hausman, Jerry A. (1979), "Individual Discount Rates and the Purchase and Utilization of Energy Using Durables" *Bell Journal of Economics* 10(1) Spring, pp. 33-54
- IPCC (2001) *Summary for Policymakers A Report of Working Group I of the Intergovernmental Panel on Climate Change*, [www.ipcc.ch](http://www.ipcc.ch)
- IPCC (Intergovernmental Panel on Climate Change) (1996), *The Science of Climate Change Vol. 1 of Climate Change 1995: IPCC Second Assessment Report*, (Cambridge University Press, Cambridge).
- Jaffe, Adam and Robert N. Stavins (1995), "Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion" *Journal of Environmental Economics and Management* 29(3) Part 2 November, pp. S43-63
- Jorgenson, Dale W., Daniel T. Slesnick and Peter J. Wilcoxon (1992) "Carbon Taxes and Economic Welfare" Brookings Papers: Microeconomics.
- Jorgenson, Dale W., and Peter J. Wilcoxon (1992), "Reducing U.S. Carbon Dioxide Emissions: The Cost of Different Goals" in *Advances in the Economics of Energy and Natural Resources* ed. By John R. Moroney, vol. 7 (JAI Press: Greenwich, Connecticut).
- Joskow, Paul L., and Richard Schmalensee (1998), 'The Political Economy of Market-Based Environmental Policy: The U.S. Acid Rain Program' *Journal of Law and Economics*, 41(1):37-83

- Joskow, Paul L., Richard Schmalensee, and Elizabeth M. Bailey (1998), "The Market for Sulfur Dioxide Emissions" *American Economic Review* 88(4) September
- Kerr, Suzi C. ed. (2000) *Global Emissions Trading: Key Issues for Industrialized Countries* (Edward Elgar: Glos. UK)
- Manne, Alan S., and Richard G. Richels (1992), *Buying greenhouse insurance: The economic costs of CO<sub>2</sub> emission limits* (MIT Press: Cambridge, Massachusetts).
- Milliman Scott R. and Raymond Prince (1989), "Firm Incentives to Promote Technological Change in Pollution Control" *Journal of Environmental Economics and Management* 17, 247 – 265.
- Noll, Roger G. (1989), "Economic Perspectives on the Politics of Regulation" in *Handbook of Industrial Organization, Volume II*, ed. R. Schmalensee and R. D. Willig (Amsterdam: Elsevier) 1234-1287.
- Nordhaus, William D. (1991), "The Cost of Slowing Climate Change: A Survey" *The Energy Journal*, 12(1).
- Nordhaus, William D. (1994), *Managing the Global Commons: The Economics of Climate Change* (MIT Press: Cambridge, Massachusetts).
- Parry, Ian W. (1995), "Pollution Taxes and Revenue Recycling," *Journal of Environmental Economics and Management*, 29:3, S64-77.
- Parry, Ian W. H., Roberton C. Williams, and Lawrence H. Goulder (1998), "When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets" *Journal of Environmental Economics and Management*, forthcoming
- Poterba, James (1990), "Is the Gasoline Tax Regressive?" MIT Working Paper 586, Nov.
- Poterba, James (1991), "Tax Policy to Combat Global Warming: On Designing a Carbon Tax" in eds. Rudiger Dornbusch and James Poterba *Global Warming: Economic Policy Responses* (MIT Press, Cambridge, Massachusetts).
- Repetto, Robert and Duncan Austin (1997), *The Costs of Climate Protection: A Guide for the Perplexed* (World Resources Institute: Washington DC).
- Saloner, Garth and Andrea Shepard (1995), "Adoption of technologies with network effects: an empirical examination of the adoption of automated teller machines" *Rand Journal of Economics* Vol. 26, No. 3 Autumn, pp. 479 - 501
- Stavins, Robert N. (1997), 'What Can We Learn from the Grand Policy Experiment? Positive and Normative Lessons from SO<sub>2</sub> Allowance Trading,' *Journal of Economic Perspectives*, 12(3):69-88.
- Tietenberg, Tom (1985), *Emissions Trading: An Exercise in Reforming Pollution Policy*, Washington: Resources for the Future
- U.S. Department of Energy, Energy Information Administration (1996), *Petroleum Supply Annual*.
- U.S. Department of Energy, Energy Information Administration (1997), "Coal Production Industry Profile" Unpublished Report.
- U.S. Department of Energy, Energy Information Administration, "Oil and Gas Production Industry Profile" Unpublished Report.
- Van Dyke, Brennan (1991), "Emissions Trading to Reduce Acid Deposition" *Yale Law Journal*, 100: 2707-2726.
- Vickrey, William (1961), "Counterspeculation, Auctions, and Competitive Sealed Tenders," *Journal of Finance*, 16, 8-37.

Weyant, J. P. and J. N. Hill (1999) 'Introduction and overview' in Weyant, J. P. (ed), *The Costs of the Kyoto Protocol: A multi-model evaluation*, The Energy Journal, Kyoto Special Edition, pp. vii-xiv

Wilson, Robert (1997), "Activity Rules for the Power Exchange," Report to the California Trust for Power Industry Restructuring, March 14.