TRANSACTION COSTS AND THE PERFORMANCE OF MARKETS FOR POLLUTION CONTROL

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ABSTRACT

Tradeable-permit systems are at the center of current interest and activity in market-based reforms of environmental policy, because these systems can offer significant advantages over conventional approaches to pollution control. Unfortunately, claims made for their relative cost-effectiveness have often been exaggerated. Transaction costs, which are ubiquitous in these markets, reduce trading levels and increase abatement costs. Furthermore, in some cases, equilibrium permit allocations and hence aggregate control costs are sensitive to initial permit distributions, providing an efficiency justification for politicians' typical focus on permit distribution mechanisms. These and other findings are consistent with available empirical evidence on the performance of pollution-control markets.

TRANSACTION COSTS AND THE PERFORMANCE OF MARKETS FOR POLLUTION CONTROL

Robert N. Stavins*

1. INTRODUCTION

The past four years have witnessed a dramatic increase in the attention given by policy makers to market-based environmental policy instruments as supplements to the conventional command-and-control standards that dominated the previous two decades of environmental law and regulation. One market-based instrument -- tradeable emission permits[1] -- has been the center of much of this activity. The enthusiasm for this new approach has been so great that policy action and implementation has, in some cases, advanced well beyond understanding of some fundamental design issues. This paper seeks to illuminate an area that has received little attention: the effects of transactions costs on the performance of markets for pollution control. Because such transaction costs are common and may be significant in tradeable permit markets, the findings can have important implications for public policy.

The importance of examining critically this class of policy instruments, particularly with regard to practical design considerations, is indicated by the pending implementation of the sulfur-dioxide (SO_2) allowance trading program authorized in the Clean Air Act Amendments of 1990,[2] the ongoing discussions of potential tradeable-permit approaches for carbon dioxide (CO_2) control (in the context of concerns regarding global climate change),[3] and the serious political attention now being given to such systems for water-pollution control, the achievement of recycling targets, and a variety of other environmental problems.[4]

The claims made for the cost-effectiveness of tradeable-permit systems have unfortunately exceeded what can reasonably be anticipated. Two major problems have been associated with

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[1] A variety of phrases are used to describe what is essentially the same concept: marketable emission (or ambient) permits/licenses, pollution rights, pollution reduction credits, transferable discharge permits, and pollutant allowances.

[2] Clean Air Act Amendments of 1990, Public Law No. 101-549, section 401-403, 104 Statute 2399, 2584-2634 (1990).

[3] See, for example: Bohm 1992.

[4] See: Stavins and Grumbly 1993.

most analyses, where conventional standards are compared with permit systems and potential gains from trade in permits are simulated. First, this approach assumes that all participating firms are profit-maximizers (or cost-minimizers) and that all potential gains from trade will hence be achieved, independent of the firm's regulatory environment.[5] Second, most analyses use highly stylized benchmarks for comparison that ignore real constraints, such as various market imperfections. In the context of both of these problems, it should be noted that Tietenberg (1985) assimilated the results from ten analyses of the costs of air pollution control, and in a frequently cited table, indicated the ratio of cost of actual command-and-control programs to least-cost benchmarks. Unfortunately, the resulting ratios (which ranged from 22.0 to 1.1) have been taken by others to be directly indicative of the potential gains from adopting specific ("cost effective") mechanisms such as tradeable emission permits. A more realistic and appropriate comparison would be between actual command-and-control policies and either actual trading programs (such as EPA's bubble policy) or a *reasonably constrained* theoretical permit program (Hahn and Stavins 1992).

Economists have typically estimated the gains from trade in moving to a market-based system in which there are no transactions costs, even though previous work on actual applications suggests that transactions costs in tradeable-permit markets can be substantial. And, as this paper indicates, such transactions costs -- depending upon their specific nature -- can have profound effects on the level of trading and hence on the relative cost effectiveness of a given tradeable-permit system. Furthermore, with transaction cost functions of the form experienced in practice, the quantity of transactions, the equilibrium allocation of permits, and hence the aggregate costs of control (again, the degree of relative cost effectiveness) are all sensitive to the initial allocation of permits. This contrasts sharply with the typical response of economists to politicians' concerns with permit allocations, namely, with the claim that the equilibrium allocation of permits and the aggregate costs of control are independent of the initial allocation.

Thus, the presence of significant transaction costs in tradeable pollution-permit markets can be very important in policy terms because of their potential impacts on: the relative cost effectiveness of permit systems compared with other market-based approaches and compared with conventional, command-and-control environmental standards; the distribution of gains from trade in permit markets; and the sensitivity of trading (and hence the equilibrium allocation of control responsibility) to the initial allocation of permits.

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[5] Such assumptions are not reasonable in situations where firms are heavily regulated. For example, the dominant players in the sulfur dioxide (SO_2) tradeable allowance program for acid rain, codified in the 1990 amendments to the Clean Air Act, will be public utilities. This act made no attempt to ensure that state public utility commissions would adopt or consider regulations that would give appropriate incentives to electrical utilities to participate in the trading program. Yet, such regulations are likely to be critical to the success of the market. For example, if regulated utilities cannot retain some fraction of the benefits from trading, they will have little or no incentive to engage in trades. See: Bernstein, Farrell, and Winebrake 1992.

1.1 Markets for Pollution Control and the Potential Role of Transaction Costs

More than two decades ago, Crocker (1966) and Dales (1968) developed the idea of using transferable discharge permits to allocate the pollution-control burden among firms or individuals. A short time later, Montgomery (1972) offered the first rigorous proof that a tradeable-permit system could, in theory, provide a cost-effective policy instrument for pollution control. A sizeable literature on tradeable permits has followed,[6] with some of the earliest work on design and implementation problems done by Hahn and Noll (1982). It is now recognized - - as a result of theoretical modeling -- that a number of factors can adversely affect the performance of tradeable permit systems: concentration in the permit market (Hahn 1984);[7] concentration in the output market (Malueg 1990); non profit-maximizing behavior, such as sales maximization or staff maximization (Tschihart 1984); the pre-existing regulatory environment, as in the case of electrical utilities (Bohi and Burtraw 1992); and the degree of monitoring and enforcement by government (Keeler 1991).

Although many authors have commented on the potential importance of transaction costs in tradeable permit markets,[8] there has been only one attempt to allow for transaction costs within a model of tradeable-permit activity (Tschirhart 1984). In this case, the author allowed for a dispersion between a constant selling price and a constant purchase price of permits, but did not pursue the implications of this and other forms of transaction cost functions for the performance of the respective markets.[9]

This lack of attention to the role of transaction costs in permit markets is striking because of the evidence -- both theoretical and empirical -- that such transaction costs exist and are significant. In general, transaction costs are ubiquitous in market economies and can arise from the transfer of virtually any property right because parties to potential exchanges must find one another, communicate, and exchange information. Thus, there may be a necessity to inspect and measure the goods to be transferred, draw up contracts, consult with lawyers or other experts, and transfer title. Depending upon who provides these services, transaction costs can thus take

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[6] Extensive surveys of the literature are found in: Tietenberg 1980 and 1985. A more recent, though less comprehensive survey is provided by Cropper and Oates (1992).

[7] Whereas Hahn (1984) examined "cost-minimizing manipulation" of tradeable-permit markets by a dominant firm, Misiolek and Elder (1989) investigated "exclusionary manipulation" of such markets.

[8] See, for example: Hahn and Hester 1989a; Tripp and Dudek 1989; and Baumol and Oates 1988.

[9] 1n an unrelated analysis, Kohn (1991) examined the effect of transaction costs on the optimal (efficient) level of pollution control by assuming an arbitrary magnitude for transaction costs and comparing the consequent efficient level of control with that predicted when a pollution tax (again with an arbitrarily assumed amount of transaction costs present) is employed. The model of transaction costs is itself problematic, since Kohn assumes that the magnitude of these costs increase with the level of control, as opposed to the level of exchange.

one of two forms: inputs of resources -- including time -- by a buyer and/or a seller; and as a margin between the buying and selling price of a commodity in a given market (Niehans 1987).[10] Clearly then, transaction costs are fundamental to decentralized markets, and are no more than the counterpart of administrative costs in centrally-planned economies. Since most types of transaction costs arise because of uncertainty in markets, they have been aptly described as "the costs of transportation from ignorance to omniscience" (Stigler 1967).

There is abundant anecdotal evidence indicating the prevalence of significant transaction costs in tradeable permit markets.[11] Hahn and Hester (1989a) suggest that the Fox River water-pollutant trading program failed due to high transaction costs in the form of administrative requirements that essentially eliminated potential gains from trade.[12] Likewise, under EPA's Emissions Trading Program (ETP)[13] for criteria air pollutants, there is no ready means for buyers and sellers to identify one another, and -- as a result -- buyers frequently pay substantial fees to consultants who assist in the search for available permits (Hahn and Hester 1989b).

At the other extreme, the high level of trading that took place under the program of lead rights trading among refineries as part of EPA's leaded gasoline phasedown,[14] has been attributed to the program's minimal administrative requirements and the fact that the potential trading partners (refineries) were already experienced at striking deals with one another (Hahn and Hester 1989a). In other words, the transactions costs in the lead rights market were less than in the ETP markets (Nichols 1992). Similarly, Tripp and Dudek (1989) claim that the success of the New Jersey Pinelands transferable development rights program was due to its design which minimized transaction costs (by government taking on a brokerage role).

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[10] For analytical convenience, this paper focuses on the latter characterization of transaction costs.

[11] Atkinson and Tietenberg (1991) survey a half dozen empirical analyses that have found the level of trading -- and hence the cost savings -- in actual permit markets to be lower than anticipated by frictionless theoretical models. Liroff (1989, p. 2) states that the U.S. experience with tradeable permit systems "demonstrates the need for ... recognition of the administrative and related transaction costs associated with transfer systems. "

[12] It should be noted that alternative explanations of low observed trading levels have also been advanced, including: lumpy investment in pollution-control technology; concentration in the permit or product markets; the sequential and bilateral nature of the trading process leading to some initial trades that then preclude better trades from being carried out subsequently (Atkinson and Tietenberg 1991); and the regulatory environment (Hahn and Noll 1983; Bohi and Burtraw 1992). At the same, some of these potential explanations of low trading levels are themselves special cases of transaction costs, such as the Atkinson and Tietenberg "trading process hypothesis" which depends, after all, on the limited information available to firms.

[13] See: Environmental Protection Agency, Emissions Trading Policy Statement; General Principles for Creation, Banking, and Use of Emission Reduction Credits, 51 Federal Register, pp. 43,814-43,829 (1986).

[14] See: Environmental Protection Agency, Control of Lead Additives in Gasoline, 38 Federal Register, page 33,734 (1973).

Another body of empirical (but anecdotal) evidence of the prevalence of significant transaction costs in permit markets comes from the well known bias in actual trading toward "internal trading" (within firms, as opposed to "external trading" among firms). It has been hypothesized that the crucial difference favoring the internal trades and discouraging the external trades is the existence of significant transaction costs that arise once trades are between one firm and another.[15] Finally, the existence of commercial brokers charging significant fees to facilitate transactions -- as discussed below -- is another body of evidence of the existence of transaction costs in tradeable permit markets.

1.2 Preview of the Paper

Having reviewed the evidence that suggests that transaction costs may indeed be of significant magnitude in tradeable permit markets, the remainder of the paper builds upon this as a premise and seeks to investigate the likely consequences of such transaction costs. A necessary first step is to develop an analytical framework, and so in part two part of the paper, we develop a model of cost-effective pollution control, and examine the relationship between the necessary conditions emerging from that model and a model of a simple system of tradeable emission permits. In part three, we introduce transaction costs to this model of tradeable emission permits, and use the expanded model to explore the potential consequences of transactions costs in terms of: the sensitivity of the trading outcome to who actually pays transaction costs; and the impact of transaction costs on permit prices, trading volumes, aggregate control costs, and deadweight loss. We also investigate how the initial allocation of permits -- in the presence of transaction costs -- can have profound effects on market performance, in contrast to the usual finding of insensitivity. Three principal categories of transaction cost function are investigated: constant marginal transaction costs; increasing marginal transaction costs; and decreasing marginal transaction costs. In the fourth and final part of the paper, the major findings of the analysis are summarized, and implications for future research and for public policy are developed.

[15] See, for example: Hahn and Hester 1983b. For an examination of bow the structure of programs may result in significant transaction costs, see: U.S. General Accounting Office 1982.

2. POLLUTION-CONTROL MARKETS IN THE ABSENCE OF TRANSACTION COSTS

2.1 A Model of Cost-Effective Pollution Control

As a benchmark for assessing the performance of markets for pollution control, we first examine the characteristics of a cost-minimizing pollution control program, investigating the case of a uniformly-mixed, flow pollutant,[16] for which it is appropriate to focus on aggregate emissions per unit of time. This simplifies the analysis and is consistent with the nature of actual tradeable pollution permit systems that have been implemented or considered seriously by policy makers.[17] Thus, the relationship between emissions, e_i from N individual firms (or sources)[18] and aggregate emissions, E, is straightforward:

$$\sum_{i=1}^{N} e_i = E \tag{1}$$

Since actual emissions from each source are the difference between unconstrained emissions, u_i, and emission reductions, r_i, we can rewrite the previous equation as:

$$\sum_{i=1}^{N} \left[u_i - r_i\right] = E \tag{2}$$

A cost-effective emission-control program is one which achieves aggregate emissions at minimum total cost, that is, an allocation of emissions among sources that satisfies the following constrained optimization problem:[19]

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[16]For a uniformly-mixed pollutant, the location of individual emissions has no effect on ambient pollution concentrations. A flow pollutant is one which does not accumulate in the environment over time.

[17]The results developed in this paper can be extended to the more complex case of nonuniformly-mixed pollutants by considering a system of ambient tradeable permits, rather than emission permits.

[18]To simplify the discussion, we henceforth assume that each firm controls a single source.

[19]We are assuming that all prices, except those associated with pollution, are unaffected by pollution-control efforts. Later, when firms and eventually permit-trading are introduced into the model, other assumptions implicit in this partial-equilibrium framework are made explicit.

$$\min_{\{r_i\}} C = \sum_{i=1}^{N} c_i(r_i) \tag{3}$$

$$\textit{subject to:} \quad \sum_{i=1}^{N} \left[u_i - r_i\right] \leq \bar{E} \tag{4}$$

$$0 \leq r_i \leq u_i \tag{5}$$

where C is the aggregate cost of control; $c_i(\bullet)$ is the cost of control for source I; and E is the aggregate emission target. As is generally assumed, we let $c_i(\bullet)$, $c_i'(\bullet)$ and $c_i''(\bullet)$ be positive.

If the N heterogeneous pollution-control cost functions are convex within their relevant ranges, then the necessary and sufficient conditions for a cost-effective allocation of control obligations among sources are:[20]

$$\frac{\partial c_i(r_i)}{\partial r_i} - \lambda \geq 0 \tag{6}$$

$$r_i \cdot \left[\frac{\partial c_i(r_i)}{\partial r_i} - \lambda\right] = 0 \tag{7}$$

$$\sum_{i=1}^{N} \left[u_i - r_i\right] - \bar{E} \leq 0 \tag{8}$$

$$\lambda \cdot \left[\sum_{i=1}^{N} \left[u_i - r_i\right] - \bar{E}\right] = 0 \tag{9}$$

$$r_i \geq 0 \quad \textit{and} \quad \lambda \geq 0 \tag{10}$$

[20] These are the Kuhn-Tucker conditions for inequality constrained optimization (Kuhn and Tucker 1951).

Equation (7) indicates that at the optimum those sources that carry out pollution control ($r_i > 0$) will have realized marginal costs of control equal to λ, the Lagrange multiplier, representing the cost savings experienced by incrementally relaxing the control constraint, E. Equations (6) and (7), taken together, indicate that firms for whom the marginal costs of control are greater than λ at any positive level of r_i should exercise no control whatsoever *($r_i = 0$)*. This is the classic result that in a cost-effective allocation of the pollution-control burden the marginal cost of control will be the same among all sources that carry out positive levels of control (and would be greater than this at those sources which do not carry out any control). Thus, it is not the *level* of control that is equilibrated across sources, as with a conventional uniform standard, but the marginal cost of control. Any other allocation will result in higher aggregate control costs, *C*.

To achieve such a cost-effective allocation of the pollution-control burden, the government could conceivably establish a non-uniform (source-specific) standard to ensure that all firms would control emissions at the same marginal cost of control. But to establish such a system of individual standards the government would require detailed information about the costs faced by each source, which could be obtained only at very great cost, if at all.[21] One way out of this impasse is a system of marketable emission permits.

2.2 A System of Tradeable Emission Permits

Having established a benchmark for analysis, we next examine the behavior of firms operating within the flexibility and the constraints of a system of tradeable emission permits.[22] Under such a system, the responsible authority, typically the government, allocates a total of E emission permits, q_{0i} to each firm (i = 1 ... N):

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[21] If the government were to survey firms regarding their costs of control, individual firms would have clear incentives to overestimate those costs. Additionally, the political feasibility of establishing an explicit, non-uniform standard system is questionable. See: Hahn and Stavins 1991.

[22] To use the taxonomy of Tietenberg (1980), we are considering an undifferentiated discharge permit (UDP), which gives any holder the same emission privileges (it makes no difference in our investigation of static efficiency if we examine permits that allow some specified rate of emission in perpetuity or ones that are for a limited amount of time, such as one year). Thus, transfers among firms are on a one-for-one basis. This is the appropriate system for uniformly mixed assimilative pollutants, such as volatile organic compounds (VOC's) as a precursor of ground-level ozone (Tietenberg 1985). There are four reasons for considering this simplest type of system. First, it is analytically the most convenient. Second, the results generalize to the case of ambient permits for non-uniformly mixed pollutants. Third, in contrast to what may have been thought at the time of Montgomery's seminal paper (on ambient pollution permits), simple emission permits have been the form of system used in all actual implementations -- under EPA's Emissions Trading Program, the lead phasedown, and the Clean Air Act amendments of 1990. Fourth, all of the systems currently being considered seriously are likewise simple emission permit systems. For example, attention is now being given to potential use of tradeable permits for carbon dioxide (CO_2) control, a global commons problem which is clearly uniformly mixed.

$$\sum_{i=1}^{N} q_{0i} = \bar{E} \tag{11}$$

Firms are free to trade permits among themselves, and may meet government standards by exercising control and/or by possessing permits for their residual emissions. Without loss of generality for the purposes at hand, we can model these profit-maximizing firms as pollution-control cost minimizers (Montgomery 1972),[23] where the cost faced by an individual firm is the algebraic sum of pollution-control costs plus (positive) costs of purchasing permits or (negative) "costs" of selling permits.[24]

Recall that actual emissions, $e_i = u_i - r_i$, and that initially permitted emissions equal q_{0i}. Thus, to be in compliance, a firm chooses its control level, r_i, and must purchase $u_i - r_i - q_{0i}$ permits if $u_i - r_i - q_{0i} > 0$; if this quantity is less than zero, the firm can sell this number of permits on the open market. Therefore, a risk-neutral, price-taking firm faces the following decision problem:

$$\min_{\{r_i\}} \left[c_i(r_i) + p \cdot (u_i - r_i - q_{0i}) \right] \tag{12}$$

$$\textit{subject to:} \quad r_i \geq 0 \tag{13}$$

where p is the market-determined price of an emission permit.

Under the conditions specified above, the result for each of the sources seeking to solve this cost-minimization problem is the following:

$$\frac{\partial c_i(r_i)}{\partial r_i} - p \geq 0 \tag{14}$$

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[23]Conceptually, there are three ways that a firm can reduce pollution: (1) reduce its scale of output or change its mix of products; (2) change its production processes (including fuel switching); and/or (3) adopt pollution-control technologies that remove polluting substances from emissions (Montgomery 1972).

[24]It is assumed that firms are operating in a region that is small relative to the entire economy, meaning that output changes due to pollution control will have only negligible effects on output and input prices. Otherwise changes in pollution-control efforts could lead to changes in demand for products such as scrubbers, thereby affecting their price and thus the marginal cost of control functions firms face.

$$r_i \cdot \left[\frac{\partial c_i(r_i)}{\partial r_i} - p \right] = 0 \qquad (15)$$

$$r_i \geq 0 \qquad (16)$$

First, note that since the total of the q_{0i} permits issued to the N sources is $\bar{E}$, we know that the environmental constraint (that no more than E units of pollution be emitted) is satisfied. Second, this private-market solution indicates that the marginal costs of control are equated among sources for those firms carrying out a positive level of control; and that sources with marginal costs of control greater than this level for any degree of control will not exercise control.[25] This is coincident with the previously established condition for a cost-minimizing allocation of the control burden among sources. Thus, the permit system achieves the cost-effective allocation of emissions control among sources, but without the government needing to acquire information about control costs and set individual standards. Third, since any expenditure on licenses by one firm is necessarily revenue for another firm, the total cost experienced by all firms complying with the pollution-control program is simply the aggregate cost of emission control, *C*. Fourth, as Montgomery (1972) has proven and as we show below, the final, equilibrium allocation of the control burden, r_i $(i = 1,...,N)$, is the same for any initial allocation of permits, q_{0i} . Fifth and finally, the market-determined pollution permit price, p, is equivalent to the shadow price of the control constraint.

At this point, it is useful to consider a two-source scenario, i.e. an application of the model embodied in equations (12) and (13), with $N = 2$. In this case, the solution described by equations (14), (15), and (16) can be viewed graphically, as in Figure 1, where: the vertical axis is in monetary terms; control for source 1, r_1, increases to the right; control for source 2, r_2, increases to the left; and every point along the horizontal axis represents compliance with the aggregate emission constraint, E_2. Since, in the general case,

$$\bar{E} = \sum_{i=1}^{N} q_{0i} = \sum_{i=1}^{N} \left[u_i - r_i \right] = \sum_{i=1}^{N} u_i - \sum_{i=1}^{N} r_i \quad , \qquad (17)$$

we have drawn the figure such that each point along the horizontal axis represents a combination of emission reductions that satisfy the policy constraint:

[25] If the pollution-control cost functions are twice differentiable with the usual signs on the first and second derivatives, then these convex cost functions -- assuming interior solutions -- yield first-order conditions (of marginal costs being equated) that are both necessary and sufficient.

$$r_1 + r_2 = u_1 + u_2 - \bar{E}_2 \qquad \textbf{(18)}$$

The plots of the marginal-cost functions of the two sources depict the case of an interior solution, where marginal costs are equilibrated at a positive level of control for both sources.

For example, if total unconstrained emissions (Σu_i) were 100 tons of pollutant, the policy constraint (E) were 90 tons, then the aggregate reduction target (Er_i) would be 10 tons. The graph in Figure 1 is set up such that total control at each point along the horizontal axis is this amount, 10 tons. The equilibrium level of control (r_1, r_2) is denoted r^* and the market-determined permit price is p. If the initial allocation of emission permits is q_{01} and q_{02}, respectively, as indicated in the figure, then in the absence of trades the emission control *required* by each of the two sources is implicitly $r_i = u_i - q_{0i}$ for i = 1, 2.

For any total number of permits allocated, the distribution of these permits between the two sources has no effect on the equilibrium level of control, emissions, or aggregate costs. For example, if each source had unconstrained emissions of 50 tons and the initial allocation of emission permits were 45 to each source, this would be equivalent to requiring each source to reduce its emissions by 5 tons. Given the marginal costs faced by source #1, however, it is in the interests of this source to control even more if it can sell some of its surplus permits for more than c_1. Likewise, it is in the interests of source #2 to cut back on its control efforts by buying an additional permit for less than c_2. These private incentives will drive the two firms to the equilibrium allocation indicated, where the first source is reducing emissions by 7 tons and the second source is reducing emissions by only 3 tons.

Note that no matter what the initial allocation, market forces will drive the two sources to trade permits until the same equilibrium allocation is reached.[26] We can begin from any point on the horizontal axis; the individual optimizing decisions of the two firms lead them to the same cost-minimizing allocation of the control burden. Indeed, by taking the vertical line indicating the initial control levels as the vertical axis of a new graph, the truncated marginal control cost functions of sources 1 and 2 are seen to be the tradeable-permit supply and demand functions, respectively (Figure 2). The truncated marginal control-cost function for the first

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[25] Montgomery (1972), Krupnick, Oates, and Van de Verg (1983), Hahn (1984), and others have proven in frictionless models the independence of the least-cost outcome from the initial permit allocation. This is not to suggest, however, that even under those conditions -- without transaction costs -- the initial allocation of permits has no consequences. On the contrary, even if the equilibrium allocation is unaffected, the initial allocation can affect total private sector costs and government revenues, depending upon how the permits are initially allocated, i.e. via an auction or via free distribution. Furthermore, if permits are distributed freely by the authority, there will be distributional impacts among individual firms, although the overall position of private industry will be unaffected. Nichols (1992) summarizes: "If shares are determined at the outset and do not depend on future behavior, the method of allocation does not [emphasis in original] affect the total level of emissions, nor which sources control at what levels. The allocation method, however, does strongly affect the net benefits that different parties reap" (p. 117).

source gives us the supply function of permits, since the marginal cost of pollution-reduction is the cost to the firm of offering a permit to the market. Likewise, the truncated marginal control-cost function for the second source yields the demand function for permits, since the avoided-cost of pollution-control is the marginal benefit for that source associated with acquiring an additional emission permit.

3. TRADEABLE EMISSION PERMITS IN A MARKET WITH TRANSACTION COSTS

We now introduce transaction costs into the analysis, beginning with an examination of the likely sources of transaction costs in tradeable permit markets. Next, we modify the optimization model developed above to allow for transaction costs of the most general type (with unspecified functional form) and examine the consequences in regard to permit prices, trading levels, cost burdens, and welfare. In order to carry the analysis further, we then consider three reasonable functional forms -- constant, increasing, and decreasing marginal transaction costs.

3.1 Sources of Transaction Costs in Tradeable Permit Markets

In the most general terms, transaction costs may be defined as those that "arise *not* from the production of goods but from their transfer from one owner to another" (Niehans 1971, p.774).[27] This suggests three categories of transaction costs: (1) search and information costs; (2) bargaining and decision costs; and (3) monitoring and enforcement costs.[28] The first category, the search and information costs, may be the most obvious in the context of a functioning tradeable permit market. Due to the public-good nature of some information (any firm making a trade provides a potentially important positive externality to other firms in the form of information once the permit price is made available), it is reasonable to assume that this information is under-provided by the typical market. Brokers step in, provide information about

[27]Niehans (1971) proceeds to explain that transaction costs may thus arise because "parties have to communicate, the goods have to be inspected, measured and marked, a title search may be necessary, contracts have to be drawn up, title of ownership has to be transferred in certain prescribed forms, the transfer may have to be recorded, etc."

[28]Dahlman (1979) notes that all three categories can be interpreted as representing costs due to lack of information. Foster and Hahn (1993) posit three different categories of transaction costs in tradeable-permit markets: direct financial costs of engaging in a trade; costs of regulatory delay; and indirect costs associated with uncertainty of completing a trade.

firms' (least-cost) pollution-control options and potential trading partners, and thus reduce transaction costs (while also absorbing some as fees).[29]

Although sometimes less obvious, the second category of transaction costs, bargaining and decision costs, is potentially as important. There are real resource costs to a firm involved in entering into negotiations (Kohn 1991), including time and/or fees for brokerage, legal, and insurance services (Hahn and Noll 1982; Dwyer 1992). Although typically borne by the responsible governmental authority and not by trading partners (and in those cases not falling within our notion of transaction costs incurred by firms), the third category of transactions costs -- monitoring and enforcement costs -- can also be significant. In addition to its usual monitoring and enforcement responsibility, the government agency may need to provide a title registry so that buyers and sellers can legally transfer rights (Ackerman and Stewart 1985). The nature of the specific system will determine how the economic burden of securing government approval (often pre-approval) for a trade is distributed among buyer, seller, and government authority.

In general, there are two sets of circumstances in which transaction costs might be very high: (1) transfer is expensive for technological reasons; and (2) institutions are designed to impede trade. Both apply in the tradeable permit context. Indeed, as Hahn (1989) has suggested, high transaction costs in EPA's Emissions Trading Program are partly due to environmentalists' intended effect of making it difficult to trade. Likewise, resistance or indifference by government regulators can result in significant transaction costs (Dwyer 1992). A 1982 study by the U.S. Government Accounting Office of EPA's Los Angeles air-pollutant trading program found that regulators were highly resistant to the notion of giving firms a "property right to pollute" and, as a result, had erected unreasonably high hurdles to trades (Tripp and Dudek 1989; Hahn and Hester 1989; Dwyer 1992).[30]

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[29] In the newly established sulfur dioxide (SO_2) trading program under the Clean Air Act amendments of 1990, the total number of potential trading partners is relatively small, and so lack of information appears not to be as significant a problem in this program as in others (such as the criteria air pollutant ETP of EPA). Nevertheless, there is a substantial role for brokers for consulting with electrical utilities to help them understand their options. Furthermore, since the SO_2 program is national, not local, information requirements are driven up for the utilities. Brokerage firms maintain computer models used to predict the supply and demand for permits to provide forecasting services for the utilities (Thomas Brooks, AER*X, personal communication, September 17 1992). In local programs, such as the ETP, the broker may also carry out air-quality modeling required for trades between noncontiguous sources of non-uniformly mixed pollutants (Krupnick, Oates, and Van de Verg 1983).

[30] The difference in reporting requirements and other such regulatory barriers is another important and striking difference between the Emissions Trading Program and the lead-rights program (Hahn and Hester 1989).

3.2 Modifying the Basic Model to Allow for Transaction Costs

We now consider a market for tradeable emission permits in which transaction costs are associated with the exchange of permits among sources. First, let t_i denote the quantity of permits traded by source is

$$t_i = |u_i - r_i - q_{0i}| \tag{19}$$

We define a common transaction cost function, $tc(t_i)$, for which $tc'(t_i) > 0$ and for which $tc''(t_i)$ may be positive, negative, or zer-valued, as investigated below.[31] Each firm faces the following problem:

$$\min_{(r_i)} \; [c_i(r_i) + p \cdot (u_i - r_i - q_{0i}) + tc(t_i)] \tag{20}$$

$$\text{subject to:} \quad r_i \geq 0 \tag{21}$$

This problem yields the following solution:

$$\frac{\partial c_i(r_i)}{\partial r_i} + \frac{\partial tc(t_i)}{\partial r_i} - p \geq 0 \tag{22}$$

$$r_i \cdot \left[\frac{\partial c_i(r_i)}{\partial r_i} + \frac{\partial tc(t_i)}{\partial r_i} - p \right] = 0 \tag{23}$$

$$r_i \geq 0 \tag{24}$$

As in the previous case, the environmental constraint is satisfied. But in contrast to the cost-effective and tradeable-permit solutions without transaction costs, in this case we find that rather than equilibrating marginal control costs among sources, the result of trading -- for situations in which positive levels of control occur -- is to equilibrate the *sum* of marginal control costs and marginal transaction costs. Also, the total cost incurred by all regulated firms is no longer the simple sum of control costs, *C*, but rather this amount plus total transaction costs.

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[31] We assume that $tc(t_i)$ is known with certainty. This is not unreasonable, but it is restrictive, since we partly motivate transaction costs as search costs.

3.3 Consequences of Transaction Costs

How should we think about the condition that the sum of marginal control costs and marginal transaction costs be equilibrated across sources? Indeed, what is the meaning of marginal transaction costs with respect to control level? First, by the chain rule, we know that:

Hence, if a source is a purchaser of permits ($u_i - r_i - q_{0i} > 0$), then $t_i = u_i - r_i - q_{0i}$ and so in this case:

$$\frac{\partial t_i}{\partial r_i} = -1 \quad \text{and} \quad \frac{\partial tc(t_i)}{\partial r_i} = -\frac{\partial tc(t_i)}{\partial t_i} \tag{26}$$

On the other hand, if a source is a seller of permits ($u_i - r_i - q_{0i} < 0$), then $u_i - r_i + q_{0i}$, and instead we have:

$$\frac{\partial t_i}{\partial r_i} = 1 \quad \text{and} \quad \frac{\partial tc(t_i)}{\partial r_i} = \frac{\partial tc(t_i)}{\partial t_i} \tag{27}$$

By substituting the results from equations (26) or (27) into equation (23), it becomes clear that the marginal cost of pollution control will equal the equilibrium permit price only when marginal transaction costs are zero. Hence, if marginal transaction costs are non-zero, the cost-effective equilibrium, where marginal control costs are equated across all sources, will not be achieved.

These relationships can be pictured most easily in the context of the two-source scenario previously developed. Assuming for the time being that marginal transaction costs are constant (i.e., that $tc''(t_i) = 0$), that these costs ($tc' = \alpha$) are paid directly by the seller of permits (as with most brokerage fees), and that -- as in Figures 1 and 2 -- the initial allocation of permits is equivalent to requiring both sources to reduce emissions by 5 tons, we can view the effect of marginal transaction costs and the new equilibrium condition in Figure 3, where the outcome of trading is the pollution-control allocation r^*_A, different from the equilibrium without transaction costs, r^*. If, instead, the initial allocation of control responsibility is located to the

right of the cost-effective equilibrium[32] (for example, source #1 being required to reduce emissions by nine tons and source #2 by one ton), then the locus of points representing the sum of marginal control costs and marginal transaction costs is found above source #2's control cost function (achieving outcome r^*_B in Figure 3). Thus, as has been observed in the more general context of the Coase Theorem, "transaction costs convey inertia to initially erected property rights" (Griffin 1991, p. 607).[33]

These effects are not dependent upon the transaction costs being linear (constant marginal transaction costs), as is portrayed in Figures 1, 2, 3, and 4. To see this, we posit supply and demand functions for permits:

$$\mathbf{Q}_s = \mathbf{S}(\mathbf{P}) \quad \text{and } \mathbf{Q}_d = \mathbf{D}(\mathbf{P},\mathbf{TC}) \tag{28}$$

where we have treated transaction costs as being paid by the permit buyer and where we know that:

$$\frac{dS}{dP} > 0 \qquad \frac{\partial D}{\partial P} < 0 \qquad \frac{\partial D}{\partial T} < 0 \tag{29}$$

At the equilibrium level of trading, Q:

[32]This refers to the equilibrium in the absence of transaction costs, which can be reached only from an initial allocation that results in no trading. Thus, when Hahn (1971) examined how the usual properties of an Arrow-Debreu economy change in the presence of transaction costs, one of his findings is that initial endowments would matter, in terms of the relative efficiency of equilibria. As we see below, as transaction costs increase, the differential impact of the initial assignment of property rights increases. In any event, transaction costs can be real resource costs and thus their existence also affects the optimal level of control (Downing and Watson 1974; Kohn 1991).

[33]This result that the trading equilibrium is sensitive to the initial allocation in the presence of transaction costs is fully consistent with the Coase Theorem - in the presence of transaction costs, the anticipated outcome from a process of bilateral negotiation is variant with respect to the initial assignment of property rights (Coase 1960). In the present context, this refers to giving all the permits to one source or the other, and observing that we reach different equilibria, and ones on different sides of the zero-transaction-cost equilibrium.

$$\bar{Q} = \bar{Q}_d = \bar{Q}_s \tag{30}$$

and

$$D(\bar{P},TC) - S(\bar{P}) = 0 \tag{31}$$

where $\bar{P}$ is the equilibrium (demand) price. Therefore, by the implicit function rule,

$$\frac{d\bar{P}}{dT} = - \frac{\partial D/\partial T}{\partial D/\partial \bar{P} - \partial dS/\partial d\bar{P}} < 0 \tag{32}$$

Finally, by applying the chain rule to the equilibrium relationship, $\bar{Q} = S[\bar{P}(T)]$, we have:

$$\frac{d\bar{Q}}{dT} = (dS/d\bar{P}) \cdot (d\bar{P}/dT) < 0 \tag{33}$$

and, so, the effect of increasing transaction costs is unambiguously to decrease the volume of permit trading. This is true regardless of the specific forms that the marginal control cost functions (permit supply and demand functions) and transaction cost functions take. All that is required is that the marginal control cost functions be non-decreasing over the relevant ranges.

We next ask whether the initial allocation of permits can affect the outcome of trading, putting aside the most obvious effect of the initial allocation being located on one side or the other of the cost-effective equilibrium. In other words, does the frequently re-stated finding of Montgomery *(1972)* that the equilibrium allocation of control and hence the aggregate costs of control are independent from the initial permit allocation still hold in the presence of transaction costs? The answer is that "it depends." To see this, we can continue to pursue a two-source model, in which source 1 is a potential permit seller and source 2 a potential permit buyer. Also, without loss of generality, we will assume that transaction costs are paid by the seller of permits.[34]

Thus, for positive levels of control by the two sources, equations (23) and (27) yield the following market equilibrium condition:

[34] The insensitivity of the outcome to which party pays the transaction costs is established below.

$$c_1'(r_1) + tc'(t_i) = c_2'(r_2) \tag{34}$$

where $t_1 = -u_1 + r_1 + q_{01}$, as indicated above for a permit seller. In order to investigate the effect of the initial allocation on the equilibrium outcome, we differentiate both sides of equation (34) with respect to the primary variables, r_1, r_2, and q_{01}:

Any change in t_1 is necessarily equal to a corresponding change in t_2. Since u_1 and u_2 do not -- by definition -- change and since any change in q_{01} must of necessity be equal to minus one times the change in q_{02}, it must be the case that any change in r_1 is equal to minus one times the change in r_2. In other words, holding constant the total quantity of permits, aggregate emissions reductions must be unchanged. Hence, we can substitute $-dr_1$ for dr_2 in equation (35). Also, note that from the definition of t_1, we know that:

This enables us to examine the impact of the initial allocation on the equilibrium control level:

$$If \quad tc''(t_1) = 0 \quad then \quad \frac{dr_1}{dq_{01}} = 0 \tag{39}$$

$$If \quad tc''(t_1) > 0 \quad then \quad \frac{dr_1}{dq_{01}} < 0 \tag{40}$$

$$If \quad tc''(t_1) < 0 \quad then \quad \frac{dr_1}{dq_{01}} \geq ? \leq 0 \tag{41}$$

Thus, if there are no transaction costs or if marginal transaction costs are constant *(tc "(t_1) =* 0), the typical result in the absence of transaction costs holds: the initial allocation of permits has no effect on the equilibrium allocation of control responsibility (and aggregate control costs). On the other hand, if marginal transaction costs are increasing *(tc"(t_1) >* 0*),* then the initial allocation *will* affect the post-trading outcome. In particular, as we increase the allocation of emission permits to a source (reduce its initial control responsibility) we will also reduce its equilibrium control level, thus increasing the departure of the post-trading equilibrium outcome from the "cost-effective equilibrium," driving up the aggregate costs of control in the process. Finally, if marginal transaction costs are decreasing (tc"(t_1) < 0), then the result is ambiguous, and will depend upon the relative magnitudes of the slopes of the marginal transaction cost functions and the marginal control cost functions of the two sources. As we will see below graphically, it is possible that a shift in the initial permit allocation *away* from the cost-effective equilibrium can actually have the effect of leading to a post-trading outcome that is *closer* than otherwise to the cost-effective equilibrium.

In the presence of transaction costs, the initial distribution of permits matters in terms of efficiency, not just in terms of equity. In his 1972 paper, Montgomery observed that because of the assumed independence of the equilibrium from the initial allocation, "the management agency can distribute licenses as it pleases. Considerations of equity, of administrative convenience, or of political expediency can determine the allocation. The same efficient equilibrium will be achieved." Not so, unfortunately, in the presence of transaction costs. This reduces the discretion of the environmental agency and the legislature, and may thereby reduce the political attractiveness and feasibility of a tradeable permit system.

What if the transaction costs are not paid by the seller of permits, but the buyer? Then the respective equilibria are as illustrated in Figure 4. In this case, as equation (26) illustrates, the locus of points representing the sum of marginal control costs and marginal transaction costs is found *below* the respective control cost functions. What stands out is that r^*_A and r^*_B are identical in the two figures. Whether transaction costs are paid by one party or the other to a

permit exchange has no effect on: the quantity of trading that occurs; the equilibrium allocation of control effort; or the aggregate costs of control.[35]

Next, we focus on the effect of transaction costs on tradeable permit prices. Referring to equations (23), (26), and (27), we first observe that marginal control costs are not equated across sources and that transaction costs lead to the existence of two distinct prices -- a price paid by permit demanders, P_D, and a (lower) price received by permit suppliers, P_S, with the difference being equal to marginal transaction costs at the new trading equilibrium:

$$p_D = c_i'(r_i) \qquad p_S = c_j'(r_j) \qquad p_D - p_S = tc'(t_{i,j}) \tag{42}$$

In order to analyze what effect transaction costs have on the prices received by sellers and paid by buyers of permits, it is most convenient to work with the supply and demand functions for permits, derived from the two marginal-cost-of-control functions. The previous equations yield the following inverse supply and demand functions for permits:

$$p_S = c_1'(r_{01} + q) \qquad p_D = c_2'(r_{02} - q) \tag{43}$$

where P_S and P_D are the prices received and paid for permits, r_{01} and r_{02}, are the initial allocations of control responsibility (associated with the initial allocation of permits), and q represents the quantity (volume) of trading. The equilibrium level of trading in the absence of transaction costs is found by setting $P_S = P_D$ and solving for q. In the presence of constant marginal transaction costs, we have instead:

$$p_D - p_S = tc'(\cdot) \tag{44}$$

$$dp_D - dp_S = dtc'(\cdot) \tag{45}$$

Next, we let the supply and demand functions for permits associated with the previously defined inverse supply and inverse demand functions be:

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[35] These results and some of the others derived below are perfectly analogous to familiar results in the theory of tax incidence regarding the equivalent effects of taxes imposed on the demand or supply side of the market. As will be more obvious below, the case of constant marginal transaction costs is analytically identical to that of a per-unit tax on buyers or sellers (except for who receives the tax/transaction cost revenues). Furthermore, the distinction - - highlighted below -- between the buyer's price and the seller's price in a permit market with transaction costs is analogous to the difference between before-tax and after-tax prices.

$$q_S = S(p) \qquad q_D = D(p) \tag{46}$$

with $S'(p) \geq 0$ and $D'(p) \leq 0$, and the equilibrium requirement that $q_S = q_D$. Therefore,

$$dq_D = D' dp_D \tag{47}$$

$$dq_S = S' dp_S = S' \cdot [dp_D - dtc'(\cdot)] \tag{48}$$

$$dq_S = dq_D \tag{49}$$

This yields:

$$\frac{dp_S}{dtc'(\cdot)} = \frac{D'}{S' - D'} = \frac{\eta_D}{\eta_S - \eta_D} \tag{50}$$

$$\frac{dp_D}{dtc'(\cdot)} = \frac{S'}{S' - D'} = \frac{\eta_S}{\eta_S - \eta_D} \tag{51}$$

where η_S and η_D are the price elasticities of supply and demand, respectively.[36] Since we know that $D' \leq 0$, $\eta_D \leq 0$, $S' \geq 0$, and $\eta_S \geq 0$, it must be the case that:

$$\frac{dp_S}{dtc'(\cdot)} \leq 0 \qquad \textit{and} \qquad \frac{dp_D}{dtc'(\cdot)} \geq 0 \tag{52}$$

Thus, as transaction costs increase, the price received by sellers is depressed and the price paid by purchasers is driven upwards.[37] Further, the degree of these price effects is dependent upon the relative elasticity values. Most significantly, given the relative slopes of the marginal cost-of-control functions, equations (50) and (51) indicate that change in price will

[36] The numerators and denominators in equations (50) and (51) are multiplied by p/q to obtain the expressions with elasticities instead of slopes.

[37] The effect of transaction costs is parallel to the effect of transportation costs, which obstruct arbitrage and result in a single market price being replaced by a cluster of prices.

always be greater for the relatively high-cost controller.[38] For example, $(P_D - P) > (P - P_S)$ in Figure 3. The logic behind this result is that high-cost controllers have less flexibility in decision making.

This leads naturally to the closely related question of how the burden of transaction costs is shared between any pair of trading partners. To address this question, we examine the impact of transaction costs on the gains from trade which accrue to a pair of trading partners. In the context of the supply and demand for permits, a change in the gains from trade is, in effect, a change in the producers' surplus and consumers' surplus arising from exchange. Referring to Figure 2, it is clear that if we introduce transaction costs, the effect on the supplier of permits (change in producers' surplus) is approximately equal to the change in the price received times the initial quantity of permits supplied, and the effect on the purchaser of permits (change in consumers' surplus) is approximately equal to minus one times the change in the price paid times the initial quantity of permits demanded. Thus, the change in the permit suppliers' gains from trade and the change in the permit purchasers' gains from trade are as follows:

$$\frac{\partial PS}{\partial tc^{i}(\cdot)} = \frac{dp_S}{dtc^{i}(\cdot)} \cdot S(p) = \frac{\eta_D S(p)}{\eta_S - \eta_D} \leq 0 \tag{53}$$

$$\frac{\partial CS}{\partial tc^{i}(\cdot)} = \frac{-dp_D}{dtc^{i}(\cdot)} \cdot D(p) = -\frac{\eta_S D(p)}{\eta_S - \eta_D} \leq 0 \tag{54}$$

where *PS* and *CS* represent producers' surplus and consumers' surplus, respectively. Given the signs of the elasticities, we know that the gains from trade accruing to *both* parties to a transaction will decrease as a consequence of transaction costs, and we observe that the distribution of the burden will be a function of the relative elasticities of the underlying cost-of-control functions. The burden (loss of potential gains from trade) of transaction costs will always fall most heavily on the higher-cost controller *(steeper* marginal control-cost function), regardless of which partner to a trade may actually have paid out direct transaction costs, such as brokerage fees.

The total loss of potential gains from trade is divided between transaction-cost transfers (payments to brokers, for example) and deadweight loss due to reduced trading activity. In the case illustrated in Figure 2, most of the loss of gains from trade accrues to the recipient of transaction costs (the rectangular area DEHG in the figure), with the deadweight loss represented by the triangle EBH. As marginal transaction costs become greater (i.e., as a in Figure 2

[38] By "high-cost controller," we mean the source with the steeper marginal control cost function. In the graphic example developed above, this would be the buyer of permits, but for other allocations of the initial control responsibility, the high-cost controller could actually be the seller of permits. In either case, it is the high-cost controller who experiences the greater price impact due to transaction costs.

increases), aggregate transaction costs (transferred from the permit buyer or permit seller to the broker) increase up to a point, and then actually decrease, due to the lower trading level that is induced. Deadweight loss, however, increases monotonically, until eventually permit trading is reduced to zero and the entire loss of potential gains from trade consists of deadweight loss.

In general, in the presence of transaction costs, we find that if the initial allocation deviates from what would be the equilibrium allocation in the absence of transaction costs, marginal control costs will not be equated, and thus total expenditures on pollution control (even putting aside transaction costs themselves) will exceed the cost-minimizing solution. Thus, transaction costs reduce welfare -- partly by absorbing resources directly and partly by suppressing exchanges that otherwise would have been mutually beneficial.

3.4 Alternative Types of Transaction Cost Function

We can now be more explicit about three categories of transaction-cost functions. Transaction costs may be some constant amount per permit exchanged, they may be roughly proportional to the size or value of trades, or there may be volume discounts on brokerage fees (Atkinson and Tietenberg 1991; Dwyer 1992). This yields three classes -- constant, increasing, and decreasing marginal transaction cost functions.

We examined constant marginal transaction costs in Figure 3. In this and other cases, whether trading will take place at all depends upon whether the difference between the marginal control costs of the two sources at the initial allocation is greater than the transaction costs of trading the minimal size permit.[39] In those situations in which trading does take place, the magnitude of individual trades will be less than in the absence of transaction costs. Hence, constant marginal transaction costs may reduce the total number of trades and will certainly reduce the aggregate trading volume. As a consequence, the cost-effective equilibrium allocation will not be achieved, and total costs of compliance will be driven upward not only by transaction costs themselves but *also* by greater costs of pollution control. This latter effect occurs because increases in transaction costs mean increases in the disparity in realized marginal control costs at the trading equilibrium; and the greater the disparity in equilibrium marginal control costs, the greater will be the aggregate costs of pollution control for all sources combined, all other things held equal.

Through the introduction of a buy-sell price spread and a contraction of trading volume, gains to trade accruing to both transacting parties are reduced, with the greater impact being on the high-cost controller. Changes in the initial allocation from "one side" of the cost-effective equilibrium to the other change the equilibrium allocation (compare Figures 3 and 4), the total volume of trading, and the total costs of compliance. But other changes in the initial allocation

[39] The marginal costs of trading the minimal size permit may equivalently be thought of as the fixed costs of trading plus the variable cost of trading the first unit.

do not affect the final equilibrium: referring to Figure 4, if the initial allocation of permits was equivalent to initial control responsibilities of $r_1 = 2$ and $r_2 = 8$, for example, the equilibrium allocation with transaction costs would still be the same r^*_A, as indicated. Although the *direct,* total costs of control are therefore unaffected, aggregate transaction costs themselves increase, as the initial allocation of control responsibility becomes more remote from the cost-effective equilibrium allocation.

Increasing marginal transaction costs are pictured in Figure 5. This pattern is typical of *explicit* transaction costs associated with third-party brokers, such as those for real estate transactions, trading of stocks and bonds, ships and airplanes, and most auctions. In this case, *in addition* to the effects described above, the initial allocation of permits among sources affects the equilibrium allocation for firms that trade, the total trading volume, and the aggregate costs of control. As we shift the initial allocation of control responsibility from r_0 to r_0', the trading equilibrium also changes (from r_* to r_{1*}'), because $tc''(t\ r_i) \geq 0$. Under these circumstances, the consequences of employing an initial allocation which is remote from the cost-effective equilibrium can be severe indeed. As a result of employing the initial allocation r_0' instead of r_0, both transaction costs *and* deadweight loss have increased.

Finally, decreasing marginal transaction costs might occur, for example, where brokers offer quantity discounts on their services (Figure 6).[40] As in the case of increasing marginal transaction costs, the initial allocation of permits among sources affects the equilibrium allocation for firms that trade, the total trading volume, and the aggregate costs of control. As we shift the initial allocation of control responsibility in Figure 6 from r_0 to r_0', the trading equilibrium changes from r_* to r_*'. But in this case, due to the fact that $tc''(t_i) \leq 0$, a move in the initial allocation away from the cost-effective equilibrium has the effect of causing the final equilibrium to be *closer* to the cost-effective allocation (i.e. *lower* aggregate control costs). If, however, the transaction-cost economies of scale are such that marginal transaction costs are reduced to zero before the cost-effective equilibrium is reached, then the effect of more remote allocations is the usual one that aggregate cost effectiveness is reduced.

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[40] A related and extreme case is the situation where there are substantial fixed costs of trading (high marginal costs for the first unit traded) and negligible variable costs. As indicated previously, if $tc(t_i) = \alpha$ and $tc'(t_i) = 0$, then trading will occur, *ceteris paribus,* in the simple N = 2 model if the difference between the marginal control costs of the two potential trading partners is greater than α at the initial allocation of permits (and control responsibility), otherwise not. In this case, sources may have incentives to reduce the number of separate trades but the equilibrium level of each trade is not affected. In the aggregate, of course, the result is decreased trading volume. Note that the case of fixed transaction costs is analytically identical to Hahn's (1990) examination of EPA's "20% rule" on criteria air-pollutant trading: if all sources engage in trading, the cost-effective equilibrium allocation of the control burden among sources *will* be achieved, *but* in the presence of fixed transaction costs, there may be fewer trades than would otherwise occur, in which case the cost-effective allocation will *not* be achieved. The critical factor, as indicated above, is the magnitude of the difference between the marginal control costs (at the initial allocation) of potential trading partners, relative to the magnitude of the fixed costs of a transaction.

Thus, in all three cases -- constant, increasing, and decreasing marginal transaction costs -- real resource costs are associated with increasing the remoteness of the initial assignment of emission permits (or control responsibility) from the cost-effective equilibrium. Whether or not these resource costs -- consisting of transaction costs plus increased control costs -- ought to outweigh political concerns regarding the initial allocation will depend, at a minimum, upon the nature of both the control cost functions of sources *and* the transaction cost functions associated with the particular trading system. If marginal transaction costs are non-constant, the equilibrium outcome is sensitive to the initial permit allocation, because each source's costs on the margin (and hence its behavior) depends not only upon its control-cost function, but also upon its permit-asset position.[41]

4. CONCLUSIONS

In this final part of the paper, we summarize the major findings of the analysis, and examine the implications of the analysis, both for future research on tradeable permit systems and for public policy.

4.1 Summary of Major Findings

The available evidence suggests that transaction costs are ubiquitous in tradeable permit markets. They are associated with search and information activities, bargaining and negotiations, and monitoring and enforcement. For this reason alone, it is important to investigate their consequences.

Our analysis indicates that in the presence of transaction costs, inertia is conveyed to the initial distribution of property rights and that less trading activity will occur. As transaction costs increase, the price received by sellers is depressed and the price paid by purchasers is driven upwards. But whether transactions costs are paid by one party or the other to a permit exchange has no effect on the quantity of trading that occurs, the equilibrium allocation of control effort, or the aggregate costs of control. What does matter are the relative elasticities of the permit supply and demand functions and hence the relative slopes of the marginal cost-of-control functions of the parties to a potential exchange.

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[41]Even in the absence of transaction costs, the initial allocation of tradeable permits can be important. Indeed, it dominated the political debates on the 1990 acid rain permit program. This should not be surprising, since the initial allocation is an implicit distribution of massive quantities of wealth. Because of this, Hahn and Noll (1982) predicted more than a decade ago that "the principal focus of the political debate over alternative market designs is likely to be wealth distribution, not efficiency" (p.132). Their prediction has been borne out by the subsequent reality.

The gains from trade accruing to *both* parties to a transaction decrease as a consequence of transaction costs, and the distribution of the burden is a function of the relative elasticities of the underlying cost-of-control functions. The burden of transaction costs inevitably falls most heavily on the high-cost controller, regardless of which partner to a trade actually pays direct transaction costs. Furthermore, this loss of potential gains from trade does not fully accrue to the recipient of transaction costs, such as a broker; there is also a deadweight loss associated with the process, due to the reduced level of trading activity.

In general, in the presence of transaction costs, if the initial allocation deviates from what would be the equilibrium allocation in the absence of transaction costs, marginal control costs will not be equated, and thus total expenditures on pollution control (even putting aside transaction costs themselves) will exceed the cost-minimizing solution. Thus, transaction costs reduce welfare -- partly by absorbing resources directly and partly by suppressing exchanges that otherwise would have been mutually beneficial.

For three classes of transaction cost function -- constant, increasing, and decreasing marginal costs -- whether trading will take place at all depends upon whether the difference between the marginal control costs of any two sources at the initial allocation is greater than the transaction costs of trading the minimal size permit. In those situations in which trading does take place, the magnitude of individual trades will be less than in the absence of transaction costs.

Constant marginal transaction costs may reduce the total number of trades and will certainly reduce the aggregate trading volume. As a consequence, the cost-effective equilibrium allocation is not achieved, and total costs of compliance are driven upward by transaction costs and by consequently greater costs of pollution control. Through the introduction of a buy-sell price spread and a contraction of trading volume, gains to trade accruing to transacting parties are reduced, with the greater impact being on the higher-cost controller.

In the case of increasing marginal transaction costs, in addition to the effects described above, the initial allocation of permits among sources affects the equilibrium allocation for firms that trade, the total trading volume, and the aggregate costs of control. Under these circumstances, the consequences of employing an initial allocation that is remote from the cost-effective equilibrium can be severe.

Finally, in the case of decreasing marginal transaction costs, the initial allocation of permits among sources affects the equilibrium allocation for firms that trade, the total trading volume, and the aggregate costs of control. But in this case, a move in the initial allocation away from the cost-effective equilibrium can have the effect of causing the final equilibrium to be either further from *or* closer to the cost-effective allocation (i.e. higher or lower aggregate control costs).

The major predictions of the analysis are consistent with the (limited) empirical evidence available on the performance of markets for pollution control. First, the analysis indicates that the level of trading should be significantly greater in markets with systematically lower transaction costs. The market for lead rights, implemented from 1982 through 1987 during the EPA phasedown of leaded gasoline, is generally believed to have involved much lower transaction costs than EPA's Emissions Trading Program (EMT) for criteria air pollutants. This is because the sources involved in the lead program were relatively homogeneous -- all were gasoline refineries, because the firms and sources were already used to striking deals with one another, and because the program involved substantially less regulatory constraint and uncertainty than did the EMT. Due to these significant differences in transaction costs, we would predict a much higher level of trading in the lead program than in the EMT. This is precisely what happened. Nearly 15% of total lead rights used were traded, and 35% of available lead rights were banked for later use or trading (U.S. Environmental Protection Agency 1985, 1986). At the height of the program, in 1985, over half of qualified refineries participated in trading. In contrast to this, the EMT program involved trading of less than one percent of the emissions that could have been traded (Hahn 1989).

Second, transaction costs should be substantially lower for trades between two sources within the same firm, since intermediaries will not be required, costly search procedures will be unnecessary, and, in general, the risk and uncertainty associated with attempting to trade with another firm will be minimal. If these "internal" (intrafirm) trades have significantly lower transaction costs than that "external" (interfirm) trades, then the analysis here would suggest that a very high proportion of executed trades would be of the internal variety. This is also borne out by experience with trading systems. In the case of the Emissions Trading Program, 98% of bubbles, 90% of offsets, and about 80% of banking actions were of the internal type during the period 1977-1986.[42]

4.2 Implications for Research

Our analysis indicates why and how it can be misleading to use the standard practice of comparing conventional policy instruments with a least-cost benchmark and assuming that the latter represents the performance of a market-based instrument. The existence of transaction costs means that the performance of a tradeable permit system will depart -- possibly substantially -- from the least-cost ideal. The comparison ought to be with an appropriately modeled tradeable-permit system, allowing for the existence and the impact of transaction costs (and any other significant factors).

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[42]The numbers reported by Hahn and Hester (1989b) are: offsets (1800 internal transactions, 200 external); bubbles (129 internal; 2 external); and banking (< 100 internal; <20 external). The fourth component of the Emissions Trading Program, "netting," involved 5,000 to 12,000 internal transactions and no external ones, but this is because this component of the program applies only to intrafirm decisions (Hahn and Hester 1989b). Foster and Hahn (1993) present a consistent picture of internal versus external trading volumes, based upon brokerage firm data.

The effects of transaction costs are, of course, parallel to the roles played by transportation costs in trade models and taxes in partial equilibrium analyses of fiscal policies. There are, however, important differences, as well. We typically *know* the transportation costs of concern and the size of a given tax (and we can change them), but we do not know the magnitude of transaction costs, which consist not only of brokerage fees, but also the "intangibles" of regulatory delay and uncertainty. The model developed here could form the basis for estimating the magnitude of effective transaction costs econometrically by appropriate parameterization, for example, of the differences between internal and external trading in an actual market, such as the EPA leaded gasoline phasedown.

4.3 Implications for Public Policy

Since tradeable permit systems are currently being considered for a variety of environmental problems -- ranging from local water pollution (Letson 1992) to global climate change (Hahn and Stavins 1993) -- it is important to examine the implications of the present analysis for public policy in three regards: choosing between conventional, command-and-control and market-based instruments; choosing between charges and tradeable permits; and designing better tradeable permit systems.

4.3.1 Choosing Between Command-and- Control and Market-Based Instruments

Increasingly in the 1990's, the choice faced by legislators and regulators is whether to continue to rely on conventional, command-and-control environmental policy instruments -- such as technology standards and performance standards -- or to adopt one of the newer breed of market-based instruments.[43] At the most basic level, the message of this analysis is that these choices ought to take into account the imperfect world in which these instruments are applied. Since transactions costs are essentially the market counterpart of administrative costs in command-and-control systems, both need to be considered. [44]

To keep things in perspective, we should also note that even if transaction costs prevent significant levels of trading from occurring, the aggregate costs of control will most likely not exceed those that would be incurred with some conventional command-and-control approaches, such as uniform standards. A trading system *with no trading* occurring is likely to be less costly than a technology standard (in aggregate cost terms) because a trading system provides flexibility to firms regarding their chosen means of control. On the other hand, it is certainly possible that

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[43]The include pollution charges, tradeable permits, deposit-refund systems, reducing market barriers, and eliminating government subsidies.

[44]For a description of the administrative costs associated with command-and-control environmental policy instruments, see: Ackerman and Stewart 1985.

in some circumstances the total cost of compliance (including transaction costs) of a tradeable permit system could exceed (depending upon the initial allocation of permits) the costs of a uniform performance standard (which exhibited small administrative costs). There is no simple answer, no policy panacea. Inevitably, case-by-case examinations are required.

Nevertheless, some general implications of the analysis do emerge. In particular, the existence of trade-offs in the policy realm is striking. Transaction costs increase the aggregate costs of control indirectly by reducing total trading volume and directly by adding to total costs of control. These effects can be exacerbated as the number of potential trading sources increases. First, as the pool of potential trading partners increases, the uncertainty which sources face as they consider entering the trading market increases and thereby the marginal transaction costs they are likely to face.[45] At the same time, a greater number of potential trading sources is likely to mean a greater number of trades. Thus, the multiplicative result can be significant increases in aggregate transaction costs, and significant decreases in the overall cost effectiveness of trading.[46] This may argue in favor of using tradeable permit systems in contexts in which the number of potential traders is not excessively large. There is another effect, however, that operates in the opposite direction, namely the effect of market concentration and strategic behavior, analyzed by Hahn (1984). In this case, all other things held equal, cost effectiveness of tradeable permit systems decreases as the number of potential traders decreases.[47]

In addition to this relationship with the number of potential traders, there is another tradeoff between transaction costs and market thinness, associated with the "distance" of the initial allocation of permits from the cost-effective equilibrium. In this case, the presence of transaction costs can argue for an initial allocation close to what would be the equilibrium in the absence of transaction costs, but this will result in a thin market, itself tending to increase information problems.

Both trade-offs suggest that permit systems may be most appropriate for markets of intermediate size. The 111 affected utilities under Phase One of the Clean Air Act amendments

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[45]Somewhat mitigating this effect may be the fact that a larger number of firms can mean more frequent transactions which can generate information, thereby *reducing* uncertainty (Noll 1982).

[46]On the other hand, in a model with many sources, transaction costs in any given trade are not only a function of the size of that trade, but also are a function of total volume of trading in the market, since trades may produce positive informational externalities. This effect operates in the opposite direction.

[47]Ultimately, of course, the crucial factor is not simply the number of potential traders in the market, but whether firms present credible threats of entry to the market, i.e., whether the market is "contestable" (Baumol, Panzar, and Willig 1982).

of 1990 may provide just such an example.[48] On the other hand, a system of CO_2 emission permits at the individual firm or source level would pose hopelessly excessive transaction costs,[49] while the use of CFC tradeable production rights could pose concentration problems of strategic behavior and erection of effective barriers to entry (if implemented in the context of constant or growing demand for CFC's). The existence of significant transaction costs will argue for initial allocations that are relatively close to the equilibrium, but the necessity of avoiding an overly thin market if information is to be generated and trading is to be robust will argue, in some cases, in precisely the opposite direction.

4.3.2 Choosing Between Tradeable Permits and Pollution Taxes

Economists have tended to give greater emphasis to the symmetry between tradeable permits and pollution charges,[50] than to their differences. But the two approaches are not symmetric under conditions of uncertainty (Weitzman 1974) or in the presence of transaction costs.[51] Those analyses that have compared taxes and permits have inevitably assumed zero transaction costs,[52] which is troubling considering the evidence that these costs are in fact ubiquitous in tradeable permit markets. Systems of pollution taxes, on the other hand, can also involve substantial administrative costs, including both fixed (per firm) and variable (Polinsky and Shavell 1982).

This suggests that it is necessary to compare these instruments on a case-by-case basis. Certain factors will be particularly relevant. How many firms (or individuals) will be charged the tax (and what will be the associated administrative costs); how many firms will potentially be engaged in trading? More broadly, will the class of regulated firms be large and diffuse or small and relatively homogeneous, since the former conditions imply greater transaction costs in a permit market (Buchanan and Tullock 1962).

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[48] If transaction costs are positively correlated with the number of trades, with sizeable fixed costs of trading, then there are economies of scale in trading, and we would want to discourage, in general, small trades. On these grounds, Tietenberg (1974) argues for excluding small emitters from programs, but transaction costs themselves will provide appropriate incentives to sources to engage in trades or not.

[49] "Carbon rights" trading, analogous to the "lead rights" used as the trading currency in the EPA leaded gasoline phasedown, would involve a much smaller set of potential traders, lead to lower transaction costs, and for these reasons be preferable to CO_2 emissions permit trading system (Hahn and Stavins 1993).

[50] The assumed symmetry is between taxes and auctioned permits, and between freely allocated permits and taxes with specific redistribution of revenues to selected firms (Dewees 1983).

[51] There are a variety of other ways in which these two instruments are *not* symmetric, both in an efficiency and an equity sense. For discussion of this, see: Stavins and Whitehead 1992.

[52] See, for example: Dowlatabadi and Harrington 1989.

4.3.3 Implications for Design of Tradeable Permit Systems

In those cases in which tradeable permit systems are the environmental policy instrument of choice, our analysis can offer some guidance to proper design. We focus on three design issues: the choice between emission and ambient permits; ways of reducing uncertainty in the market; and deciding how to allocate permits among sources.

4.3.3.1 Emission Versus Ambient Permits

There are a variety of points in the "product cycle" at which pollution can be regulated. The simplest systems (whether in the case of tradeable permits or other instruments) may focus on *inputs* to the production process, such as the lead content of gasoline or the carbon content of fossil fuels. One step toward greater sophistication but also substantially greater administrative complexity and transaction costs is represented by *emissions* permit trading. Further in the same direction is *ambient* or *concentration* permit trading. And further still would be *exposure* trading (Roumasset and Smith 1990), and finally *risk* trading (Portney 1988). As we move along this path, each system may come closer to a theoretical ideal, but each system is also likely to bring greater public costs associated with monitoring and enforcement and greater private transaction costs. Indeed, these practical considerations provide the explanation of why, contrary to the models going back to Montgomery (1972), it has only been input trading and simple emissions trading that have actually been adopted or seriously considered by public authorities.

4.3.3.2 Reducing Uncertainty

Given the close linkage between uncertainty and transaction costs, one obvious implication of the analysis is that programs should be designed to reduce uncertainty. Inprincipal, there are three ways that such uncertainty in tradeable permit markets can be reduced: government can take actions that directly reduce regulatory uncertainty; barriers to private brokerage services can be reduced; and allowance can be made for the development of futures markets.

In the first case, at a minimum, the government authority can avoid creating regulatory barriers (such as requirements for government pre-approval of trades) that drive up transaction costs and discourage trading. More actively, the government can seek to reduce market uncertainty by helping supply information about potential buyers and sellers and thus help sources identify one another (Tripp and Dudek 1989). In the context of the new SO_2 trading program, for example, it has been argued that "EPA should establish and maintain a strong data reporting and information dissemination program that would convey information about allowance trades to all interested parties" (Bohi, Burtraw, Krupnick, and Stalon 1990, p.38).

Private provision of brokerage services can also play an important role in reducing uncertainty. Thus, although commercial brokers can certainly be recipients of transaction costs, their activities are also likely to reduce uncertainty and in this and other ways reduce transaction costs below what they would otherwise be. Intermediaries, in general, can contribute to social welfare by helping parties economize on transaction costs. Indeed, transaction costs are the *raison d'etre* of such intermediaries.

In a tradeable permit market, brokers can take on at least three distinct functions. First, they can play the role of consultants, adding value by understanding the regulatory process and by maintaining information about prospective suppliers and demanders of permits. Second, under the more conventional function of bringing together buyers and sellers ("brokering deals" by matching buy orders and sell orders), these firms absorb and reduce transaction costs. Third, brokers may assume risk buy buying, holding, and selling permits.[53] Such brokerage services generate economic advantages by: (1) reducing search and information costs; *(2)* increasing the ability of transactors to discover prices for permits that equal approximately the real value of the permits; and *(3)* by reducing the time which the transaction process takes (Stigler 1961). On the other hand, brokers can introduce their own inefficiencies into the market; principal-agent problems can lead to significant deviations from an optimal pattern of information and exchange (Crockett 1982).

Finally, open exchange of "futures contracts" on tradeable emission permits can improve the price information available to emissions permit traders and thereby reduce transactions costs and increase trading levels.[54]

4.3.3.3 How to Allocate the Permits

The initial allocation of tradeable permits takes on added significance in the presence of transaction costs. In the Congressional debate over the Clean Air Act amendments of 1990, three major methods of distribution of permits were considered: free distribution (endowment); auction; and sale at a fixed price (Bohi, Burtraw, Krupnick, and Stalon 1990). For any tradeable permit system, political feasibility can be established or destroyed over this single

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[53]For example, the emissions brokerage firm, AER*X, Inc., is involved both in Title 4 (SO_2,) trading under the Clean Air Act Amendments of 1990 for acid rain control and in criteria air pollutant trading under the Emissions Trading Program. Newer entrants, such as Clean Air Capital Markets, Kidder Peabody, and the Eagles Group, are apparently working exclusively with the Title 4 program.

[54]In July, 1991, the Chicago Board of Trade announced that the Exchange will trade "cash forward" contracts beginning in 1993 (agreements to deliver emission allowances after they are issued in 1995) and will ask the Commodity Futures Trading Commission for permission to establish a continuing futures market. See: Passell 1991. It has been predicted that the market for these pollution futures could be as large as $10 billion per year. On this, see: Zweig 1991.

aspect of design. Because of the necessity of establishing a constituency for a proposed system, the route that has inevitably been chosen for distributing permits has been free distribution. Thus, free endowment of permits has been employed because it reduces political resistance by distributing valuable property rights to private industry. [55]

If permits are to be freely distributed, it is still necessary to identify a means of allocating the permits among sources. Three potential methods stand out:[56] (1) base the permit distribution on emissions as they existed prior to attempts to control them; (2) base permit allocation on emissions allowed under current standards; or (3) base allocation on the projected equilibrium that would result from a perfectly competitive, efficient market in permits.

The problem with using prior emissions as the criterion for allocation is that this can "punish" firms which tended to clean up first. On the other hand, since there are perverse incentives associated with basing the initial allocation on measures that can be affected by current behavior, on efficiency grounds it is problematic to use current emissions as the basis. This suggests the third approach -- using the projected equilibrium under a perfectly competitive market, an approach that is particularly attractive in the presence of transaction costs. But this means more emission permits for high-cost controllers and less for low-cost controllers, an allocation that could face significant political barriers. Furthermore, identifying the costeffective allocation requires knowledge of the cost functions of all sources. Not only is this information unavailable to government, but firms have no incentive to produce it; indeed, this is the very reason for considering incentive-based approaches instead of command-and-control, in the first place.

Another problem of using the cost-effective allocation as the basis for distribution is that this can result in thinness of the permit market. In the extreme, trading might occur only for new or modified sources (new entrants or expansions). This thin market increases the likelihood of market-power problems (moving us away from cost effectiveness) and delays in reaching a stable equilibrium price for permits.[57] Note, however, that some other methods of allocation - - including historical or current emissions -- also bring up problems of market power.[58] A final

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[55] As Zeckhauser (1981) has noted, the distribution of gains and losses arising from a policy is likely to have greater effects on whether that policy is adopted (in a democratic society) than the magnitude (or even the sign) of net benefits.

[56] See: Hahn and Noll 1982.

[57] We may, by way of analogy, think of a ball positioned on a surface that is lowest at one point, but that has a very gradual slope (and even some non convexities). If we start the ball rolling too close to the low point, it may take longer to get there or the ball may not move at all, due to friction.

[58] Hahn and Noll (1982) found that for Southern California SO_2 permits, either approach would favor monopsonistic behavior by the firm with the largest number of permits.

problem with using the theoretical cost-effective allocation to allot permits is that doing so may increase vulnerability to legal challenges and delay.[59]

In order to get around the various problems that are involved in using the projected competitive equilibrium as the basis for the initial permit allocation, one might consider the economist's favorite, auctions.[60] Auctions eliminate the preferential status of existing sources, and under specified circumstances, auctions exhibit the optimal efficiency properties of a competitive market. Also, auctions can generate substantial revenues for government that could be used to offset distortionary taxes, with potential related efficiency gains.[61] Moreover, in the presence of transaction costs, auctioning of permits is *even more* attractive than otherwise. We are left, however, with the reality that political barriers against permit auctions are likely to remain in place for the foreseeable future.

The general message for public policy that arises when we begin to consider the presence of significant transaction costs in markets for tradeable permits is that the "devil is likely to be in the details." Although the existence of transaction costs may make the choice between ambient and emission permits more obvious, it may well make the choice between conventional approaches and permits more difficult because of the ambiguities that are introduced. Likewise, the supposed symmetry of taxes and permits becomes questionable, and the need to compare these two instruments on a case-by-case basis becomes more compelling. Finally, with transaction costs as with other departures from frictionless markets, greater attention is required to the details of design of specific systems, in order to lessen the risk of over-selling these policy ideas and in order to create systems that stand a chance of being implemented successfully.

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[59]According to Hahn and Noll (1982), the information requirements mentioned above raise the possibility that the inexact cost estimates required would be vulnerable to challenges that they are not sufficiently precise to support a regulatory decision.

[60]Various intermediate approaches are also possible, such as what has actually been done in the acid rain program, namely, permits are allocated on an historical basis, and some additional ones are held by the regulatory authority for periodic auctions -- and many, more complications besides.

[61]On this point, see: Terkla 1984.

FIGURE 1:
POLLUTION CONTROL, TWO-SOURCE CASE, INTERIOR SOLUTION

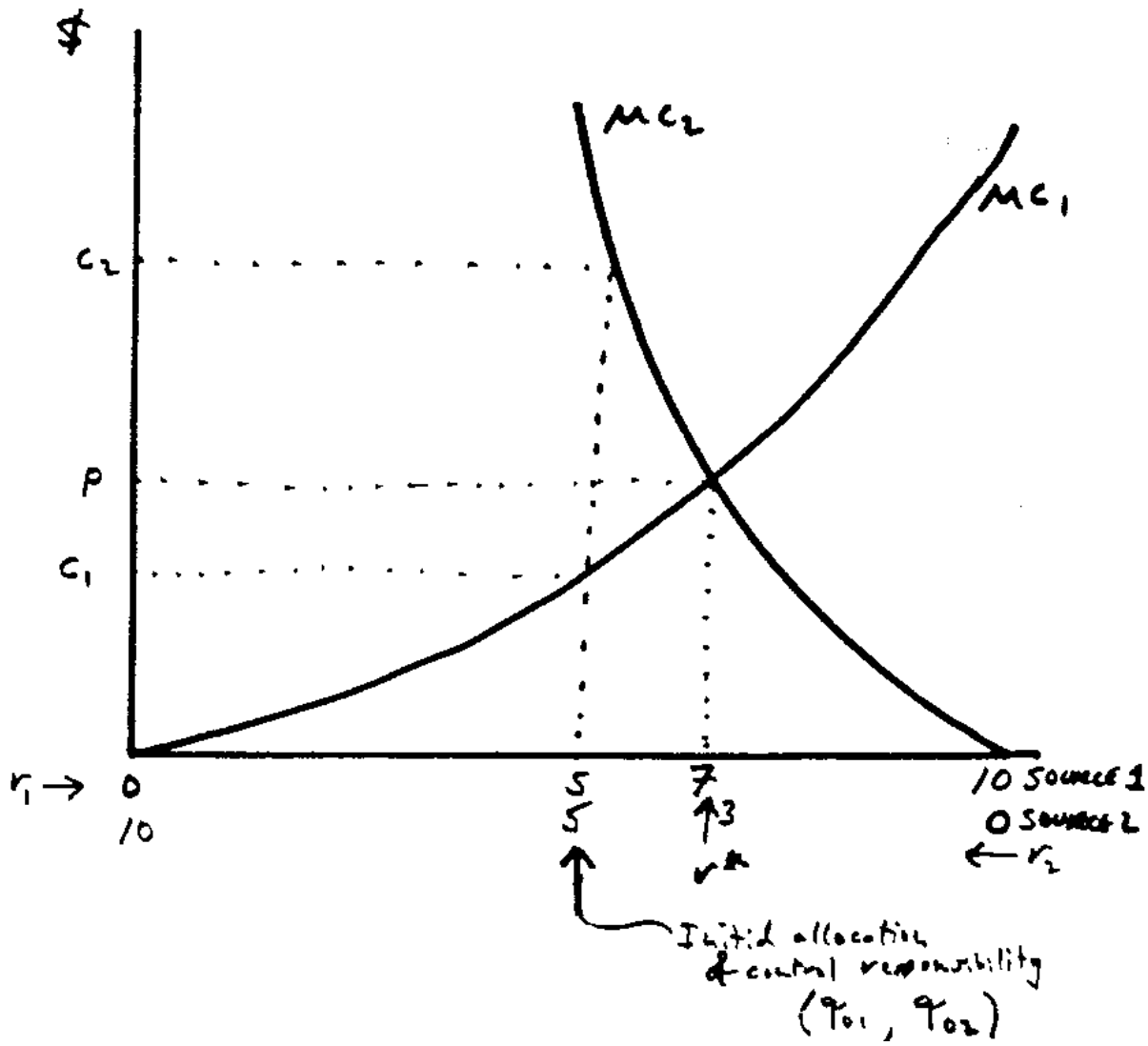


FIGURE 3:
CONSTANT MARGINAL TRANSACTION COSTS PAID BY PERMIT SELLER

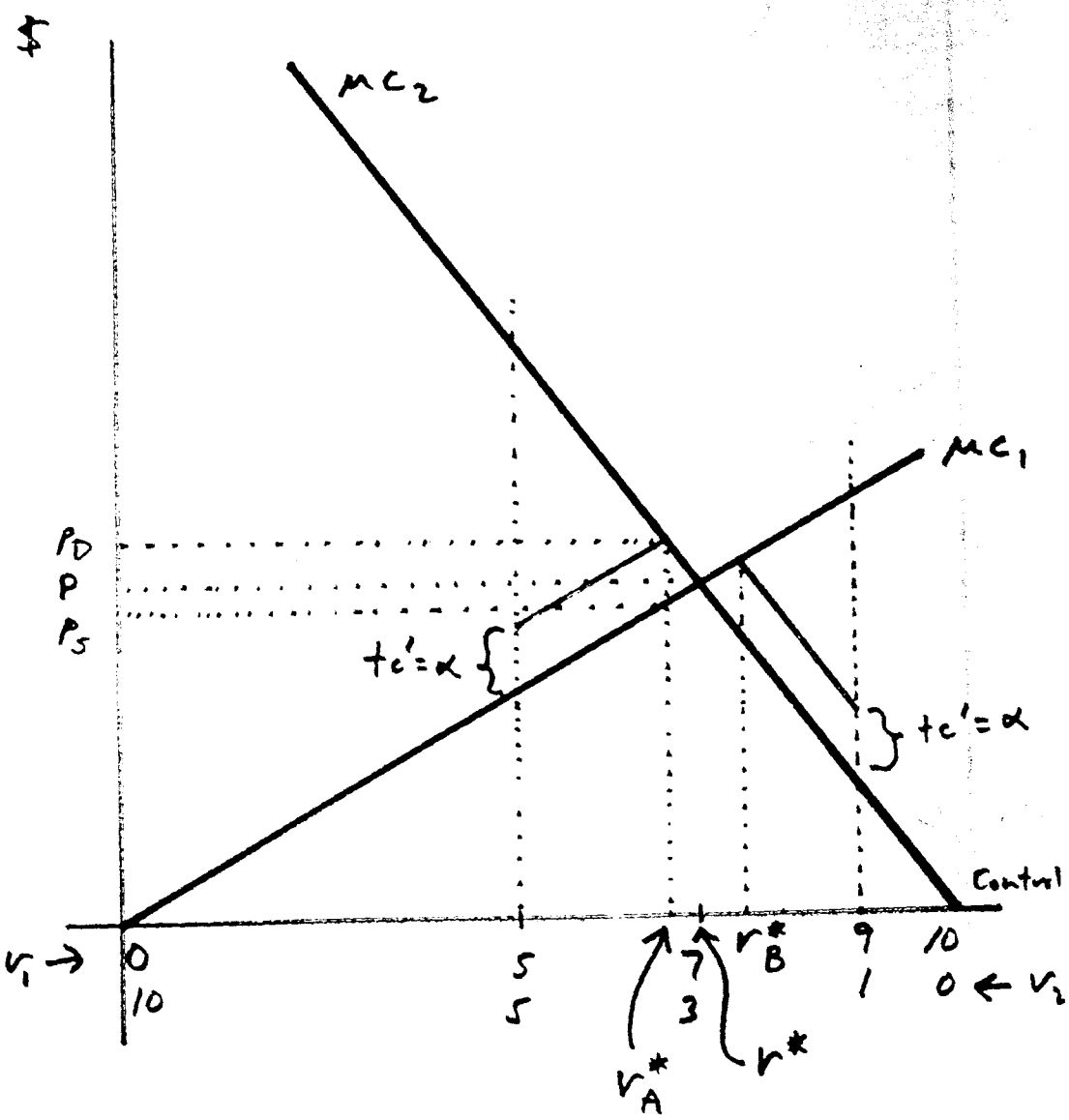


FIGURE 4:
CONSTANT MARGINAL TRANSACTION COSTS
PAID BY PERMIT BUYER

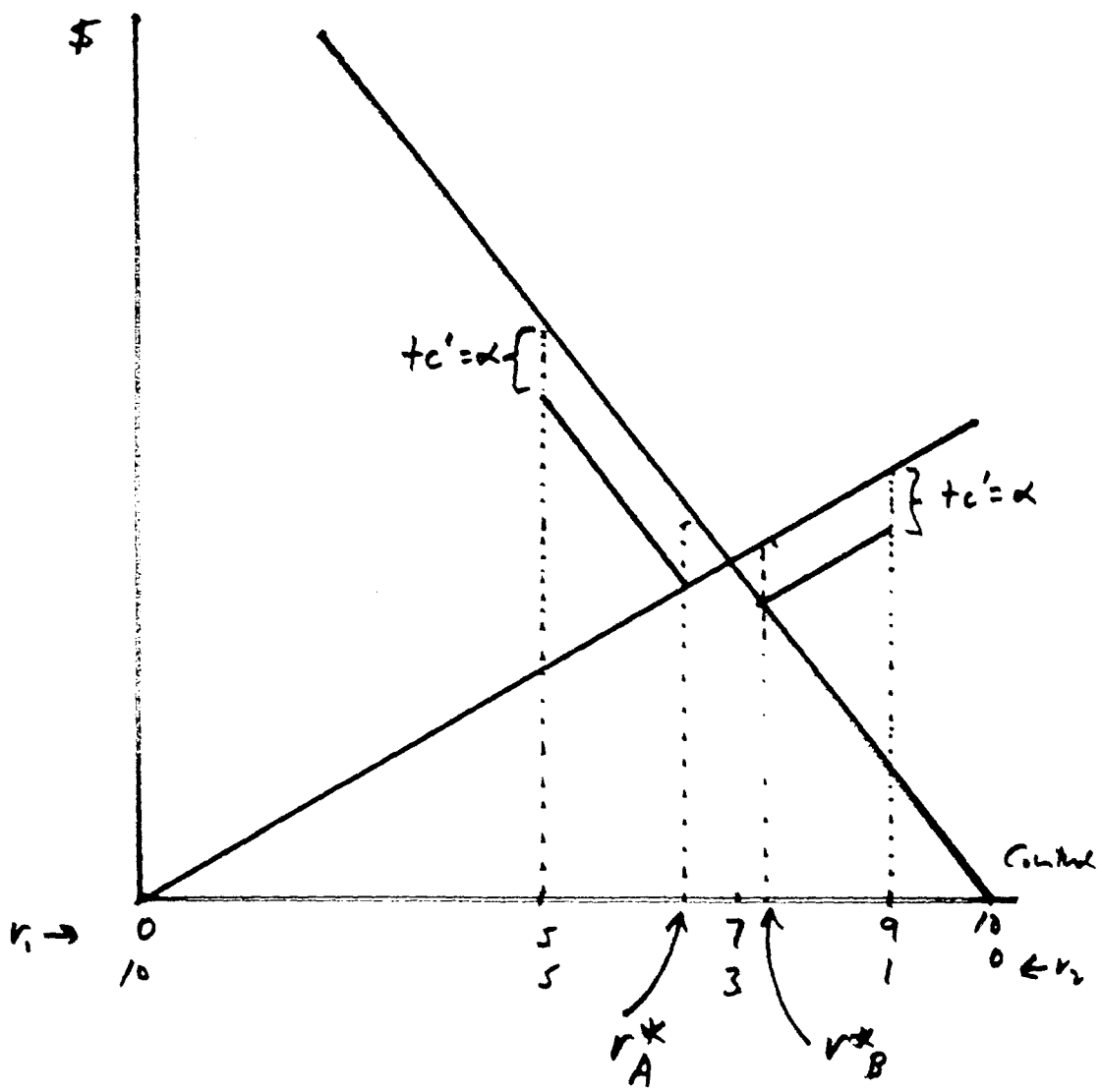


FIGURE 5:
INCREASING MARGINAL TRANSACTION COSTS

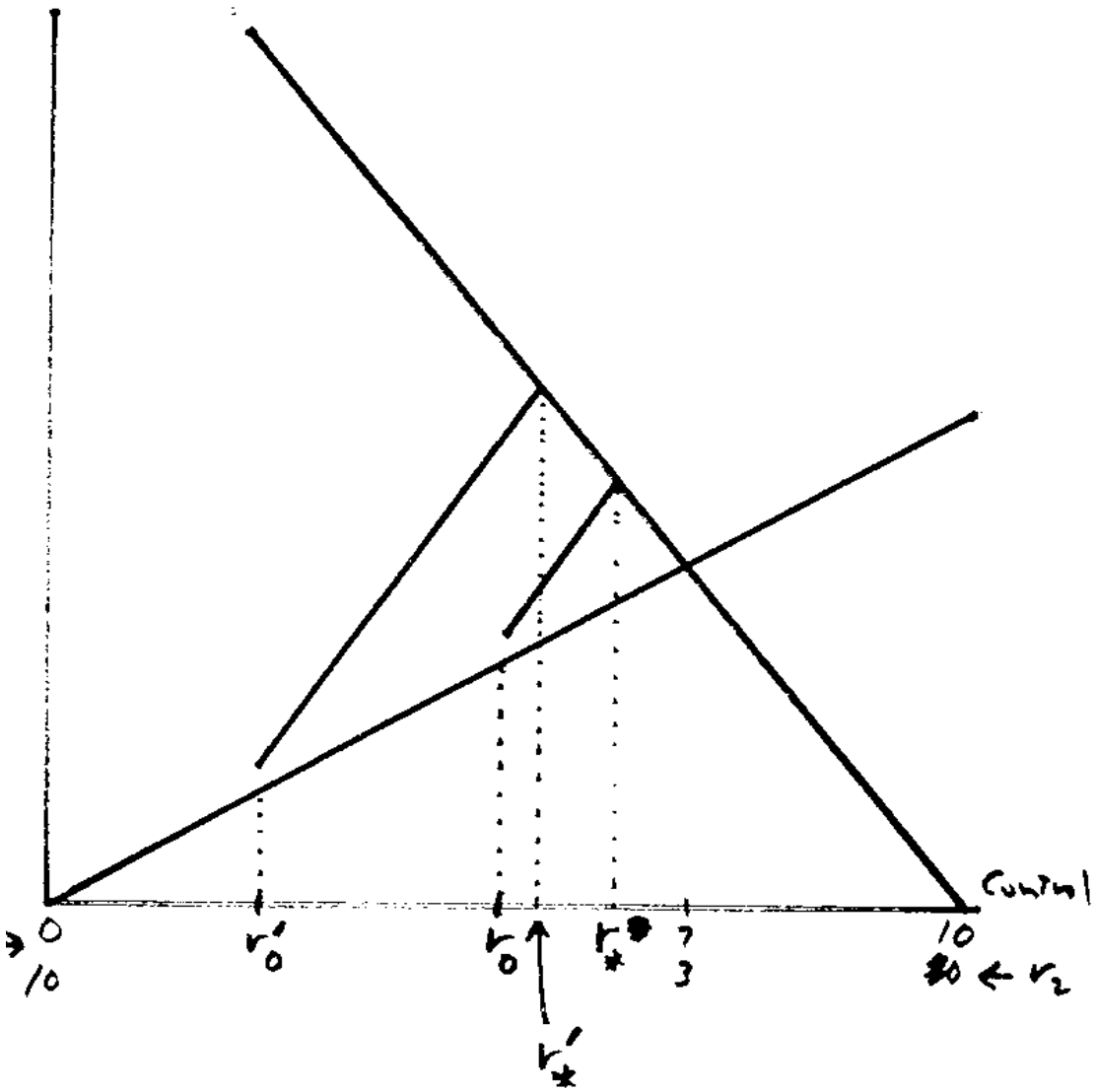
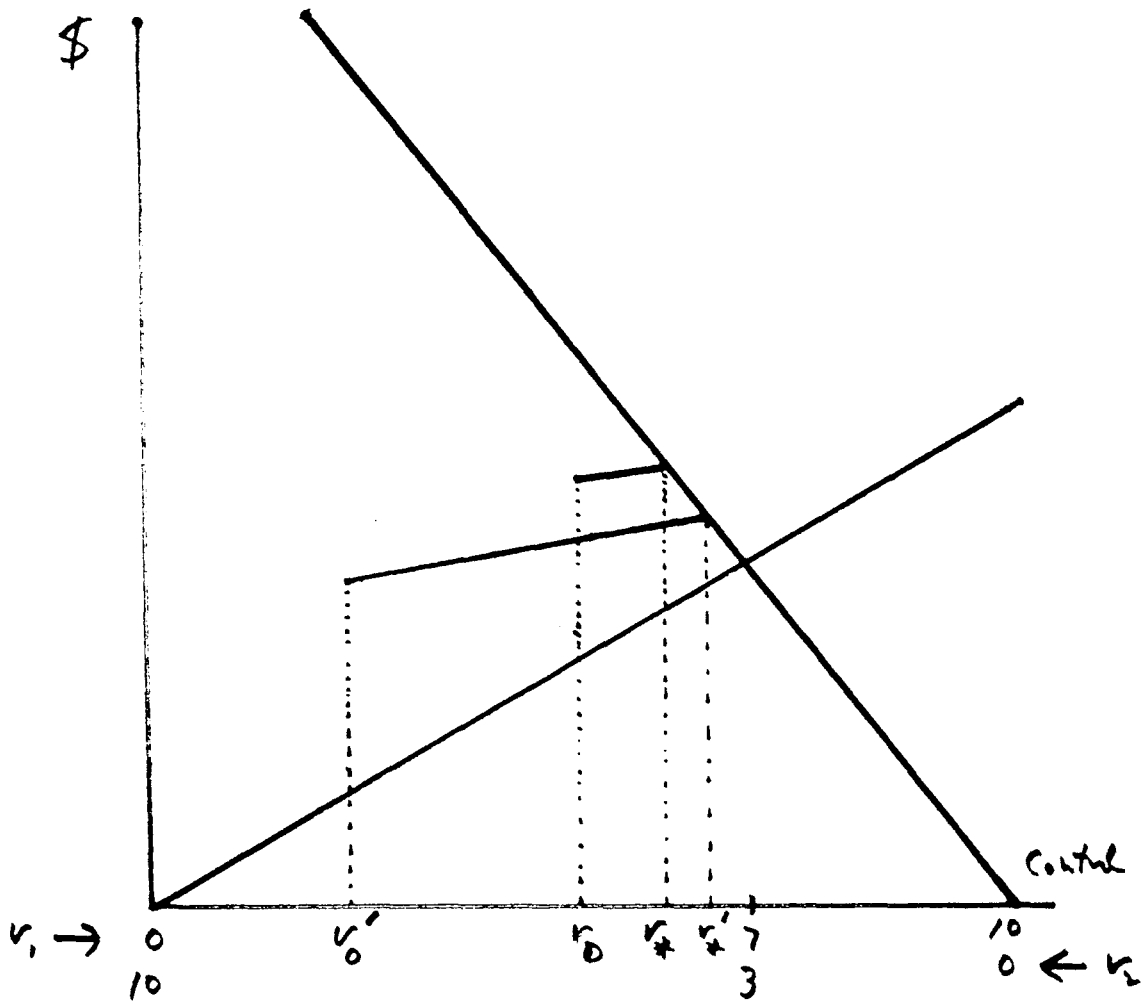


FIGURE 6:
DECREASING MARGINAL TRANSACTION COSTS



REFERENCES

Ackerman, Bruce A. and Richard B. Stewart. "Reforming Environmental Law." *Stanford Law Review* 37(1985):1333-1365.

Atkinson, Scott and Tom Tietenberg. "Market Failure in Incentive-Based Regulation: The Case of Emissions Trading." *Journal of Environmental Economics and Management* 21(1991):17-31.

Bernstein, Mark A., Alexander E. Farrell, and James J. Winebrake. "The Clean Air Act's SO_2 Emissions Market: An Estimate of Regulator Restrictions and Market Uncertainty." Working Paper, Center for Energy and the Environment, University of Pennsylvania, Philadelphia, 1993.

Baumol, William J., John Panzar, and Robert Willig. *Contestable Markets and the Theory of Industrial Structure.* New York: Harcourt Brace Jovanovich, 1982.

Baumol, William J. and Wallace E. Oates. *The Theory of Environmental Policy.* Second Edition. Cambridge, United Kingdom: Cambridge University Press, 1988.

Bohi, Douglas R. and Dallas Burtraw. "Utility Investment Behavior and the Emission Trading Market." *Resources and Energy* 14(1992):129-153.

Bohi, Douglas R., Dallas Burtraw, Alan J. Krupnick, and Charles G Stalon. "Emissions Trading in the Electric Utility Industry." Resources for the Future, Quality of the Environment Division, Discussion Paper QE9015, March 1990.

Bohm, Peter. "Distributional Implications of Allowing International Trade in CO_2 Emission Quotas." *The World Economy* 15(1992):107-114.

Buchanan, James M. and Gordon Tullock. *The Calculus of Consent: Logical Foundation of Constitutional Democracy.* Ann Arbor: University of Michigan Press, 1962.

Coase, Ronald H. "The Problem of Social Cost." *Journal of Law and Economics* 3(1960):1-44.

Crocker, Thomas D. "The Structuring of Atmospheric Pollution Control Systems." *The Economics of Air Pollution,* ed. Harold Wolozin, pp. 61-86. New York: W. W. Norton & Company, Inc., 1966.

Crockett, John H. "Competition and Efficiency in Transacting: The Case of Residential Real Estate Brokerage." *AREUEA Journal* 10(1982):209-227.

Cropper, Maureen L. and Wallace E. Oates. 1992. "Environmental Economics: A Survey." *Journal of Economic Literature* 30:675-740.

Dahlman, Carl J. "The Problem of Externality." *Journal of Law and Economics* 22(1979):141-162. Dales, J. *Pollution, Property and Prices.* Toronto: University Press, 1968.

Dewees, Donald N. "Instrument Choice in Environmental Policy." *Economic Inquiry* 21(1983):53-71.

Dowlatabadi, Hadi and Winston Harrington. "The Effects of Uncertainty on Policy Instruments: The Case of Electricity Supply and Environmental Regulations." Resources for the Future, Quality of the Environment Division, Discussion Paper QE89-20. Washington, D.C., July 1989.

Downing, Paul B. and William D. Watson, Jr. "The Economics of Enforcing Air Pollution Controls." *Journal of Environmental Economics and Management* 1(1974):219-236.

Dwyer, John P. "A Free Market in Tradeable Emissions is Slow Growing." *Public Affairs Report,* January, 1992, pp.1, 6-7.

Foster, Vivien and Robert W. Hahn. "ET in LA: Looking Back to the Future." Working Paper, American Enterprise Institute, Washington, D.C., March 1993.

Griffin, Ronald C. "The Welfare Analytics of Transaction Costs, Externalities, and Institutional Choice." *American Journal of Agricultural Economics* 73(1991)601-614.

Hahn, F. H. "Equilibrium with Transaction Costs." *Econometrica* 39(1971):417-439.

Hahn, Robert W. "Market Power and Transferable Property Rights." *Quarterly Journal of Economics* 99(1984):753-765.

Hahn, Robert W. "Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders." *Journal of Economic Perspectives* 3(1989):95-114.

Hahn, Robert W. and Gordon L. Hester. "Marketable Permits: Lessons for Theory and Practice." *Ecology Law Quarterly* 16(1989a):361-406.

Hahn, Robert W. and Gordon L. Hester. "Where Did All the Markets Go? An Analysis of EPA's Emissions Trading Program." *Yale Journal on Regulation* 6(1989b):109-153.

Hahn, Robert W. and Roger G. Noll. "Designing a Market for Tradable Emissions Permits." *Reform of Environmental Regulation,* ed. Wesley A. Magat, pp.119-146. Cambridge: Ballinger Publishing Company, 1982.

Hahn, Robert W. and Roger G. Noll. "Barriers to Implementing Tradeable Air Pollution Permits: Problems of Regulatory Interactions." *Yale Journal of Regulation* 1(1983):63-91.

Hahn, Robert W. and Robert N. Stavins. "Incentive-Based Environmental Regulation: A New Era From An Old Idea?" *Ecology Law Quarterly* 18(1991):1-42.

Hahn, Robert W. and Robert N. Stavins. "Economic Incentives for Environmental Protection: Integrating Theory and Practice." *American Economic Review Papers and Proceedings* 82(1992):464-468.

Hahn, Robert W. and Robert N. Stavins. "Trading in Greenhouse Permits: A Critical Examination of Design and Implementation Issues." *Global Climate Policy,* eds. William Clark and Henry Lee, Harvard University Press, forthcoming 1993.

Keeler, Andrew G. "Noncompliant Firms in Transferable Discharge Permit Markets: Some Extensions." *Journal of Environmental Economics and Management* 21(1991):180-189.

Kohn, Robert E. "Transactions Costs and the Optimal Instrument and Intensity of Air Pollution Control." Policy Sciences 24(1991):315-332.

Krupnick, Alan J., Wallace E. Oates, and Eric Van De Verg. "On Marketable Air-Pollution Permits: The Case for a System of Pollution Offsets." *Journal of Environmental Economics and Management* 10(1983):233247.

Kuhn, H. W. and A. W. Tucker. "Nonlinear Programming." *Proceedings of the Second Berkeley Symposium On Mathematical Statistics and Probability,* ed. J. Neyman. Berkeley: University of California Press, 1951.

Letson, David. "Point/Nonpoint Source Pollution Reduction Trading: An Interpretive Survey." *Natural Resources Journal* 32(1992):219-232.

Liroff, Richard A. "The Evolution of Transferrable Emission Privileges in the United States." Paper prepared for Workshop on "Economic Mechanisms for Environmental Protection," Jelenia Gora, Poland, September 1989.

Malueg, D.A. 1989. "Emission Credit Trading and the Incentive to Adopt New Pollution Abatement Technology." *Journal of Environmental Economics and Management* 16:52-57.

Misolek, Walter S. and Harold W. Elder. "Exclusionary Manipulation of Markets for Pollution Rights." *Journal of Environmental Economics and Management* 16(1989): 156-166.

Montgomery, W. David. "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory* 5(1972):395-418.

Niehans, Jurg. "Money and Barter in General Equilibrium with Transactions Costs." *American Economic Review* 61(1971):773-783.

Niehans, Jurg. "Transaction Costs." *The New Palgrave: A Dictionary of Economics,* eds. John Eatwell, Murray Milgate, and Peter Newman. New York: Stockton Press, 1987.

Nichols, Albert L. *Emission Trading Program for Stationary Sources of NO_x in Ontario.* Cambridge, Massachusetts: National Economic Research Associates, Inc., October 1992.

Noll, Roger G. "Implementing Marketable Emissions Permits." *American Economic Review Papers and Proceedings* 72(1982):120-124.

Passell, Peter. "A New Commodity to Be Traded: Government Permits for Pollution." *New York Times,* July 17, 1991, pp. Al, A14.

Polinsky, A. Mitchell and Steven Shavell. "Pigouvian Taxation with Administrative Costs." *Journal of Public Economics* 19(1982):385-394.

Portney, Paul R. "Reforming Environmental Regulation: Three Modest Proposals." *Issues in Science and Technology* 4(1988):74-81.

Roumasset, James A. and Kirk R. Smith. "Exposure Trading: An Approach to More Efficient Air Pollution Control." *Journal of Environmental Economics and Management* 18(1990):276-291.

Stavins, Robert and Thomas Grumbly. "The Greening of the Market." *Mandate for Change,* eds. Will Marshall and Martin Schram, pp. 197-216. New York, New York: Berkley Books, 1993.

Stavins, Robert N. and Bradley W. Whitehead. "Pollution Charges for Environmental Protection: A Policy Link Between Energy and Environment." *Annual Review of Energy and the Environment* 17(1992):187-210.

Stigler, George J. "Imperfections in the Capital Market." *Journal of Political Economy* 75(1967):287-292. Stigler, George J. "The Economics of Information." *Journal of Political Economy* 69(1961): 213-225.

Tietenberg, T.H. *Emissions Trading: An Exercise in Reforming Pollution Policy.* Washington, D.C.: Resources for the Future, Inc., 1985.

Tietenberg, Thomas H. "Transferable Discharge Permits and the Control of Stationary Source Air Pollution: A Survey and Synthesis." *Land Economics* 56(1980):391-416.

Tripp, James T. B. and Daniel J. Dudek. "Institutional Guidelines for Designing Successful Transferable Rights Programs." *Yale Journal on Regulation* 6(1989):369-391.

Tschirhart, John T. "Transferable Discharge Permits and Profit-Maximizing Behavior." *Economic Perspectives on Acid Deposition Control,* ed. Thomas D. Crocker, pp.157-171. Boston: Butterworth Publishers, 1984.

U.S. Environmental Protection Agency. "Quarterly Reports on Lead in Gasoline." Office of Air and Radiation, Field Operations and Support Division, Washington, D.C., 1985, 1986.

U.S. General Accounting Office. *A Market Approach to Air Pollution Control Could Reduce Compliance Costs Without Jeopardizing Clean Air Goals.* Washington, D.C.: U.S. Government Printing Office, 1982.

Weitzman, Martin L. "Prices vs. Quantities." *Review of Economic Studies* 41(1974):477-491.

Zeckhauser, Richard. "Preferred Policies When There Is a Concern for Probability of Adoption." *Journal of Environmental Economics and Management* 8(1981):215-237.

Zweig, Jason. "Market-Driven Environmentalist." *Forbes,* September 2, 1991, p. 154.