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Enforcing Transferable Permit Systems in the Presence of Transaction Costs

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Abstract:

In this paper we examine the impacts of transaction costs on enforcing a transferable emissions permit system. We derive an enforcement strategy with a self-reporting requirement that achieves complete compliance in a cost-effective manner. In the absence of transaction costs targeted enforcement—the practice of monitoring some firms more closely than others—is neither necessary nor desirable. In the presence of constant marginal transaction costs, buyers of permits should be monitored more closely than sellers, but within groups of buyers and sellers monitoring should be uniform. When marginal transaction costs are not constant, effective monitoring will depend on whether a firm is a buyer or seller, its demand for permits relative to its initial allocation, and whether marginal transaction costs are increasing or decreasing. We also show that the initial distribution of permits can have an impact on total enforcement costs in the presence of transaction costs, but only if marginal transaction costs are not constant. However, firm conclusions about the impact of the initial distribution of permits on enforcement costs will, in general, be situation-specific.

Keywords: Compliance, Emissions Trading, Environmental Regulation, Enforcement, Transferable Permits

JEL Classification: K42, L51, Q50

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1. Introduction

Among a number of concerns about whether market-based emissions policies can achieve their theoretical promise, the existence of transaction costs is one of the most important. Transactions costs can arise in a transferable emissions permit system for a number of reasons. There may be costs associated with seeking out trading partners, negotiating and consummating trades, and overcoming institutional barriers to trade. In the absence of these costs, and provided that emissions permits are traded competitively, regulated firms can be expected to choose emissions levels that minimize aggregate abatement costs. Furthermore, the equilibrium distribution of emissions is independent of the initial distribution of permits, giving program designers some freedom to pursue other goals—such as those motivated by political realities or equity concerns—without upsetting the cost-efficiency outcome [Montgomery (1972)]. However, recent theoretical analyses suggest that transaction costs can limit permit trading and cause firms to choose emissions levels that deviate from the cost-efficient distribution of emissions [Stavins

(1995), Montero (1997)]. In addition, deviations from the cost-efficient distribution of emissions may depend on the initial distribution of permits, suggesting that there are efficiency consequences of the initial distribution that program designers must consider.[1]

In this paper, we show that the presence of transaction costs in transferable permit systems can also have significant consequences for the manner in which market-based policies are enforced, particularly with respect to targeted enforcement—the practice of monitoring some firms more closely than others. To derive these consequences we combine the work of Stavins (1995) on transaction costs in otherwise perfectly competitive permit systems, and our earlier work [Stranlund and Chavez (2000)] on enforcing competitive and frictionless permit systems.[2] In that paper we designed an enforcement strategy for a perfectly competitive permit system that would generate perfect compliance in the cheapest manner possible, which is what we choose to call effective enforcement. We also incorporated a requirement that firms provide the enforcement authority with reports of their own emissions.[3] Under these conditions, enforcement

[1] A number of authors have considered how transaction costs have affected the performance of actual trading programs. Cason and Gangadharan (2003) provide an excellent review of this literature. The primary motivation of their paper is to use laboratory markets to test the impacts of transaction costs on transferable permit markets. Their results generally support the conclusions of Stavins (1995).

[2] A few authors have considered the consequences of noncompliance on the performance of transferable permit systems, but most have not attempted to design appropriate enforcement strategies [Malik (1990), Keeler (1991), Malik (1992), Hahn and Axtell (1995), and vanEgteren and Weber (1996)]. Beavis and Walker (1984) characterize a uniform monitoring strategy with fixed penalties to achieve an aggregate emissions target in a cost-effective manner, but they do not consider any of the issues that are important in this paper; namely, self-reporting, targeted monitoring, and transaction costs. Stranlund and Dhanda (1999) only consider the desirability of targeted monitoring in the context of maximizing aggregate compliance with a fixed enforcement budget. They do not allow for transaction costs, nor do they consider self-reporting.

[3] Stranlund, Chavez, and Field (2002) contend that the enforcement strategies of the Sulfur Dioxide Allowance Trading program and the RECLAIM program of southern California were clearly designed to achieve very high rates of compliance, and have been largely successful in doing so. Furthermore, self-reporting of emissions is a key component of the enforcement strategies of these programs. Others who have considered the role of self-reporting have focused

of a transferable permit system appears to be relatively straightforward: an effective enforcement strategy calls for tying monitoring and penalties for emissions and reporting violations directly to the equilibrium permit price, not to any specific characteristic of individual firms. Since the strategy does not depend on firm-specific information, it should treat firms equally in the sense that as long as penalties are applied uniformly, monitoring across firms should also be uniform. This result stems from the standard result that firms' marginal abatement costs are all equal in equilibrium, and therefore, there are no relevant deviations among firms that a regulator can use to target its monitoring effort.[4]

After laying out the basic model in section 2 of this paper, in section 3 we show that the uniform monitoring result of our earlier work is overturned in the presence of non-zero marginal transaction costs. At the very least, enforcement should distinguish between net buyers of permits and net sellers. In fact, we show that net buyers of permits have a stronger incentive to be non-compliant than net sellers, and hence, they need to be monitored more closely. The requirements for targeted enforcement become quite complicated when marginal transaction costs are not constant. Not only should a monitoring strategy distinguish between buyers and sellers of permits, it should also distinguish among firms in each group according to the number of permits each holds relative to their initial allocation, and according to whether marginal transaction costs are increasing or decreasing.

In section 4 we examine how the initial distribution of permits can affect the costs of enforcing a transferable permit system when at least some firms face transaction costs. Stavins

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exclusively on enforcing standards [Harford (1987), Malik (1993), Kaplow and Shavell (1994), and Livernois and McKenna (1998)].

[4] In contrast, in the case of emissions standards, it is easy to show that firms with high marginal abatement costs and/or stricter standards need to be monitored more closely than others [Garvie and Keeler (1994)].

(1995) showed that when firms face marginal transaction costs that are not constant, the initial distribution of permits could have a significant impact on the aggregate abatement costs of achieving a fixed aggregate emissions standard. Similarly, we show that when marginal transaction costs are not constant, the initial distribution of permits will affect the costs of enforcing a permit system. In general, however, any reallocation of the initial distribution of permits will have an ambiguous effect on enforcement costs; hence, whether enforcement costs rise or fall with a change in the initial distribution of permits will be situation-specific.

2. A Model of a Firm's Choices in the Presence of Transaction Costs

Imagine a transferable emissions permit system in which a total of L permits have been issued to a fixed number of risk-neutral firms. The goal of a regulator is to choose an enforcement strategy that, when communicated to the firms, will induce complete compliance by each of them in the cheapest way possible. To derive the appropriate strategy, we focus on the choices of a single firm. The firm has an abatement cost function $c(e)$ that is strictly decreasing and convex in its emissions e; that is, $c'(e) < 0$ and $c''(e) > 0$. Let l^0 be the number of emissions permits that are initially allocated to the firm, and let l be the number of permits that the firm holds after trade.

We assume that a system is in place to track permit trades so that, at any point in time, the regulator knows how many permits a firm holds, as well as its initial allocation of permits. In contrast, the regulator has no information about the firm's abatement costs, and it cannot observe the firm's emissions without a costly audit. However, the firm is required to provide the regulator with a report of its emissions. Denote its emissions report as r and assume that a report is submitted without cost. Note that there are two types of possible violations. First, an emission violation occurs when the firm's emissions exceed the number of permits it holds ($e - l > 0$).

Second, a reporting violation occurs when the firm's actual emissions exceed its reported emissions ($e - r > 0$). If the firm is fully compliant, $e = r = l$.

We assume that an audit of the firm reveals its actual emissions. Let the probability, π, that the regulator audits the firm be a function of the firm's reported violation; that is, $\pi = \pi(r - l)$. We follow Harford's (1987) approach to modeling penalties. A penalty of $f(r - l)$ is imposed automatically if a firm reports an emissions violation. If an audit reveals that the firm under-reported its emissions, a penalty for the reporting violation, $g(e - r)$, is imposed, as well as the incremental penalty for its emissions violation, $f(e - l) - f(r - l)$. For zero reporting and emissions violations, we assume that these penalties are zero [$g(0) = f(0) = 0$], but that the marginal penalties are greater than zero [$g'(0) > 0, f'(0) > 0$]. For positive reporting and emissions violations, the penalties are increasing at an increasing rate in the violations.

Our approach to modeling transaction costs follows that of Stavins (1995). A transaction is the difference between the number of permits a firm holds and its initial allocation, and will be denoted $\tau = |l - l^0|$. Let $d\tau/dl = \tau_l$, and note that $\tau_l = +1$ if a firm is a net buyer of permits ($l > l^0$) and $\tau_l = -1$ if the firm is a net seller of permits ($l < l^0$). All transactions involve costs which are summarized by $t(\tau) = t(|l - l^0|)$. The marginal effect on transaction costs of a change in permit demand depends on whether a firm is a net buyer or seller of permits. Specifically,

$$\frac{\partial t}{\partial l} = t'(|l - l^0|) \times \tau_l = \begin{cases} t'(|l - l^0|) > 0, \text{if } l > l^0 \text{ (net buyer);} \\ -t'(|l - l^0|) < 0, \text{if } l < l^0 \text{ (net seller).} \end{cases} \qquad \textbf{[1]}$$

Marginal transaction costs may be decreasing, increasing, or constant. The transaction cost function is common to all firms and that the regulator knows this function.

We assume that the firm never chooses to be over-compliant ($e \geq l$), that it never reports that it is over-compliant ($r \geq l$), that it never reports a level of emissions that exceeds its actual emissions ($e \geq r$), and that it will always hold a positive number of permits. Taking these constraints together, we restrict the analysis by $e \geq r \geq l > 0$. Then, the firm chooses its actual emissions, its reported emissions, and its permit demand to solve:

$$min \;\; c(e) + p(l - l_0) + t(|l - l^0|) + f(r - l) + \pi(r - l)[g(e - r) + f(e - l) - f(r - l)] \qquad \textbf{[2]}$$
$$s.t. \; e \geq r \geq l > 0.$$

The Lagrange equation is $\theta = c(e) + p(l - l_0) + t(|l - l^0|) + f(r - l) + \pi(r - l)[g(e - r) + f(e - l) - f(r - l)] - \beta(e - r) - \mu(r - l)$, and the Kuhn-Tucker conditions are:

$$\theta_e = c'(e) + \pi(r - l)[g'(e - r) + f'(e - l)] - \beta = 0 \qquad \textbf{[3a]}$$

$$\theta_l = p + t'(|l - l^0|)\tau_l - f'(r - l) - \pi'(r - l)[g(e - r) + f(e - l) - f(r - l)]$$
$$+ \pi(r - l)[f'(r - l) - f'(e - l)] + \mu = 0 \qquad \textbf{[3b]}$$

$$\theta_r = f'(r - l) + \pi'(r - l)[g(e - r) + f(e - l) - f(r - l)]$$
$$- \pi(r - l)[g'(e - r) + f'(r - l)] + \beta - \mu = 0 \qquad \textbf{[3c]}$$

$$\theta_\beta = r - e \leq 0, \;\; \beta \geq 0, \;\; \beta \times (r - e) = 0 \qquad \textbf{[3d]}$$

$$\theta_\mu = l - r \leq 0, \;\; \mu \geq 0, \;\; \mu \times (l - r) = 0 \qquad \textbf{[3e]}$$

We assume that [3a-e] are necessary and sufficient to determine the firm's optimal choices of emissions, reported emissions, and permit demand uniquely.

Before we consider the firm's compliance choices, let us first characterize its choice of emissions.[5] By doing so we confirm Stavin's (1995) primary results about the effects of transaction costs on emissions choices in a transferable permit system.

***Proposition* 1:** *Regardless of a firm's compliance status, it chooses its emissions so that*

$$p + t'(|l - l^0|)\tau_l + c'(e) = 0. \qquad \textbf{[4]}$$

***Proof of Proposition* 1:** Combine [3b] and [3c] to obtain

$$p + t'(|l - l^0|)\tau_l - \pi(r - l)[g'(r - l) + f'(e - l)] + \beta = 0. \qquad \textbf{[5]}$$

From [3a], $c'(e) = -\pi(r - l)[g'(e - r) + f'(e - l)] + \beta$. Substitute this into [5] to obtain [4]. QED.

In the absence of transaction costs, the standard results about competitive permit trading obtain. Specifically, each firm chooses its emissions so that its marginal abatement costs are equal to the permit price; that is, $p = - c'(e)$. Since each firm faces the same permit price, in a permit market equilibrium, the firms' marginal abatement costs are all equal to each other which implies, in turn, that aggregate abatement costs are minimized. In addition, the firms' emissions choices, and hence, the equilibrium distribution of emissions and the abatement cost-minimization result, are independent of the initial distribution of permits.

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[5] Proposition 1, as well as the rest of our results hold only if $\partial\pi/\partial r = - \partial\pi/\partial l$, which, of course, is satisfied when $\pi = \pi(r - l)$.

In the presence of marginal transaction costs, these favorable characteristics of permit trading fall away because firms face different effective prices for permits. Suppose that marginal transaction costs are a constant α. Then, net buyers of permits choose emissions so that their marginal abatement costs are equal to the effective price of permits that they face, $p + \alpha$. Net sellers of permits choose their emissions so that their marginal abatement costs are equal to $p - \alpha$. Thus, in the presence of constant marginal transaction costs, marginal abatement costs are not equal across all firms, and hence, the distribution of emissions-choices will not minimize aggregate abatement costs. Note, however, that the firms' choices of emissions remain independent of the initial distribution of permits. When marginal transaction costs are not constant, the effective permit price faced by sellers of permits is $p - t'(|l - l^0|)$, and buyers face $p + t'(|l - l^0|)$. It is clear that not only will the equilibrium distribution of emissions deviate from that which minimizes aggregate abatement costs, but the equilibrium distribution of emissions depends on the initial distribution of permits as well.

The effects of transaction costs on choices of emissions can also serve to preview the effects of transaction costs on enforcement strategies that we will consider more directly in the next section. Since, in the absence of transaction costs, each firm's choice of emissions is simply determined by $p = -c'(e)$, emissions-choices are independent of the particular enforcement strategy the firm faces. Furthermore, since in a permit market equilibrium all firms' marginal abatement costs are equal regardless of the chosen enforcement strategy, there is nothing specific to individual firms that a regulator can use to target its monitoring strategy.

When marginal transaction costs are a positive constant, firms' emission-choices remain independent of the enforcement strategy. However, since buyers and sellers of permits face different effective permit prices, their marginal abatement costs are different in equilibrium and they have different compliance incentives. A regulator can therefore use the distinction between buyers and sellers to target its monitoring effort. When marginal transaction costs are not constant, the effective permit price a firm faces depends on whether it is a net buyer or seller of permits, its demand for permits relative to its initial allocation, and whether marginal transaction costs are increasing or decreasing. Therefore, an enforcement strategy that is intended to induce complete compliance in a cost-effective manner will involve a fairly complicated targeted monitoring strategy that takes account of all the things that impact the effective permit price that a firm faces.

3. Effective Enforcement in the Presence of Transaction Costs

In this section we derive an enforcement strategy that will ensure complete compliance at minimal cost when firms face transaction costs. To do so, we first need to determine when a firm will chose to be fully compliant.

3.1 Necessary and sufficient conditions for complete compliance

We begin the analysis of this section with a firm's incentive to provide a truthful report of its emissions. Because the purpose of a self-reporting requirement is to elicit a report of a firm's actual emissions, it is natural for us to focus on incentive-compatible enforcement strategies.

Proposition 2: *Given an optimal choice of emissions and permits, a firm gives a truthful report of its emissions if and only if*

$$-c'(e) - \pi(r - l)[g'(0) + f'(e - l)] \leq 0, \; \forall \; r - l \in [0, e - l]. \qquad \textbf{[6]}$$

***Proof of Proposition* 2:** From [3b], an optimal choice of permits implies

$$p + t'(|l - l^0|)\tau_l - \pi(r - l)f'(e - l) = f'(r - l)$$
$$+ \pi'(r - l))[g(e - r) + f(e - l) - f(r - l)] - \pi(r - l)f'(r - l) - \mu\,. \qquad \textbf{[7]}$$

Substitute the right hand side of [7] into [3c] to obtain

$$\theta_r = p + t'(|l - l^0|)\tau_l - \pi(r - l)[g'(r - l) + f'(e - l)] + \beta = 0. \qquad \textbf{[8]}$$

Equation [8] characterizes a firm's optimal emissions-report given *some* choice of emissions and an optimal choice of permits. From Proposition 1, a firm's optimal choice of emissions must satisfy $p + t'(|l - l^0|)\tau_l = -c'(e)$. Substitute this into [8] to obtain

$$\theta_r = -c'(e) - \pi(r - l)[g'(0) + f'(e - l)] + \beta = 0, \qquad \textbf{[9]}$$

which now characterizes a firm's optimal choice of emissions-report, given optimal choices of emission and permit demand.

To prove the necessity of [6] for a firm to give a truthful report of its emissions, suppose that $r = e$. From [3d] $r = e$ implies $\beta \geq 0$. Therefore, [9] clearly implies that [6] is necessary for $r = e$ to be an optimal report. To show that [6] is also sufficient, suppose on the contrary that [6] holds but $e > r \geq l$. From [3d] the first inequality implies $\beta = 0$. Then, $\theta_r = -c'(e) - \pi(r - l)[g'(e - r) + f'(e - l)] < 0$, the sign of which follows from $-c'(e) - \pi(r - l)[g'(0) + f'(e - l)] \leq 0$ and the fact that the strict convexity of $g(e - r)$ implies $g'(e - r) > g'(0)$ for $e > r$. Since $\theta_r < 0$ contradicts [9], we have established the sufficiency of [6] for inducing truthful reports. QED.

Although equation [6] fully characterizes the condition under which a firm has the proper incentive to provide a truthful report of its emissions, an incentive-compatible enforcement strategy cannot be based directly on [6] because the regulator does not have the necessary information. In particular, the regulator cannot observe a firm's marginal abatement costs, nor can it observe a firm's emissions without an audit. However, [6] can be easily modified to overcome these information difficulties. First, Proposition 1 reveals that the regulator can use $p + t'(|l - l^0|)\tau_l$, which is assumed to be observable, in place of the firm's marginal abatement costs. Furthermore, the regulator can use a firm's reported emissions in place of its actual emissions. That is:

***Proposition* 3:** *An enforcement strategy that satisfies*

$$p + t'(|l - l^0|)\tau_l - \pi(r - l)[g'(0) + f'(r - l)] \le 0 \;\forall\; r - l \ge 0, \qquad \textbf{[10]}$$

is an incentive-compatible strategy.

***Proof of Proposition* 3:** To prove the proposition we need only show that if [10] holds, [6] holds as well. Proposition 1 allows us to substitute $p + t'(|l - l^0|)\tau_l$ directly for $-c'(e)$ in [6] to obtain

$$p + t'(|l - l^0|)\tau_l - \pi(r - l)[g'(0) + f'(e - l)] \le 0. \qquad \textbf{[11]}$$

Obviously, if [11] is satisfied, [6] is also satisfied. Now, replace the firm's reported emissions in place of its actual emissions. Because $r - l \le e - l$ and $f(\bullet)$ is strictly convex, $f'(r - l) \le f'(e - l)$. Therefore, if [10] holds, [11] also holds, and hence, [10] is an incentive-compatible enforcement strategy. QED.

Proposition [3] characterizes what is required of an enforcement strategy to elicit truthful emissions reports that is based upon information that is assumed to be available to the regulator. And it is a full characterization in the sense that it applies for every level of violation. However, we are only interested in complete compliance. The following proposition provides the necessary and sufficient conditions under which the firm will choose complete emissions compliance. As the proposition reveals, an incentive compatible strategy is necessary for a firm to choose complete compliance. Such a strategy is not, however, sufficient.

***Proposition* 4:** *A firm chooses complete emissions compliance only if*

$$p + t'(|l - l^0|)\tau_l - \pi(r - l)[g'(0) + f'(0)] \leq 0. \qquad \textbf{[12]}$$

Furthermore, given satisfaction of [12]*, the firm will choose complete emissions compliance if and only if*

$$p + t'(|l - l^0|)\tau_l \leq f'(0). \qquad \textbf{[13]}$$

***Proof of Proposition* 4:** To prove the proposition, we first establish the necessity of [12]. Then, assuming that [12] is satisfied, we prove the necessity and sufficiency of [13].

To establish the necessity of [12], assume that the firm is compliant so that $e = r = l$, but that the inequality in [12] does not hold; that is, assume

$$p + t'(|l - l^0|)\tau_l - \pi(0)[g'(0) + f'(0)] > 0. \qquad \textbf{[14]}$$

From [3b] and [3c], if the firm chooses to be compliant it must be true that

$$\theta_l = p + t'(|l - l^0|)\tau_l - f'(0) + \mu = 0 \quad \textbf{[15]}$$

and

$$\theta_r = f'(0) - \pi(0)[g'(0) + f'(0)] + \beta - \mu = 0 \quad \textbf{[16]}$$

Substitute [16] into [15] to obtain

$$\theta_l = p + t'(|l - l^0|)\tau_l - \pi(0)[g'(0) + f'(0)] + \beta > 0, \quad \textbf{[17]}$$

the sign of which follows from [14] and $\beta \geq 0$, and contradicts [9]. This contradiction establishes the necessity of [12] to achieve full compliance.

Given [12], we now show that [13] is also necessary. Since satisfaction of [12] guarantees a truthful emissions report, evaluating [3b] at $e = r$ yields

$$p + t'(|l - l^0|)\tau_l - f'(e - l) + \mu = 0 \quad \textbf{[18]}$$

If a firm is compliant, $e = r = l$, and hence, [3e] implies $\mu \geq 0$. Then, it is clear that $p + t'(|l - l^0|)\tau_l - f'(0) \leq 0$ is necessary to satisfy [18] when the firm is compliant. To establish sufficiency, suppose that $e = r > l$, while $p + t'(|l - l^0|)\tau_l - f'(0) \leq 0$. From [3e], $r > l$ implies $\mu = 0$. Furthermore, since $e > l$ implies $f'(e - l) > f'(0)$, $p + t'(|l - l^0|)\tau_l - f'(e - l) < 0$, but this contradicts [18]. We have thus established the necessity and sufficiency of (13), given (12), for a firm to have the proper incentive to be compliant. QED.

The reason we have derived conditions under which a firm will provide a truthful emissions report is that, as Proposition 4 indicates, an effective enforcement strategy must provide firms with the proper incentives to submit accurate emissions reports—they will not hold enough permits to cover their emissions otherwise. Equation [12] guarantees that the firm will provide an accurate emissions report, whether its emissions exceed its permit holdings or not. Given the correct incentive to submit accurate emissions reports, equation [13] provides the necessary and sufficient incentive for the firm to hold enough permits to cover its emissions; that is, to choose complete emissions compliance.

The intuition of Proposition 4 is straightforward. Recall that we interpreted $p + t'(|l - l^0|)\tau_l$ as the effective permit price a firm faces in the presence of variable transaction costs. As such, it is also the marginal benefit of non-compliance for this firm, because it represents costs that are avoided when the firm doesn't hold enough permits to cover its emissions. Note that the only reason the firm will have to submit an inaccurate emissions report is to cover up an emissions violation. Therefore, the marginal benefit of misrepresenting an emissions violation is exactly the foregone marginal cost of being in compliance, which is the effective permit price. The expected marginal cost of misrepresenting an emissions violation is the probability that the violations will be discovered times the sum of the penalties for the reporting and emissions violations. Because of the strict convexity of the penalty functions, Equation [12] of Proposition 4 guarantees that the firm will find that the marginal benefit of submitting a false emissions report will never exceed the expected marginal cost of doing so.

Although [12] guarantee truthful emissions reports, it does not guarantee that the firm will choose complete emission compliance. Given the proper incentives for truthful reporting, a firm that chooses to be non-compliant will reveal the extent of its violation with its emissions report. It will then be assessed a penalty $f(\bullet)$ for this violation. If [13] is satisfied the firm's marginal cost of compliance—the effective permit price—is less than the certain marginal penalty for a slight emissions violation and the firm will choose to hold permits sufficient to cover its emissions. If [13] does not hold, the firm will choose to be non-compliant.

3.2 Effective enforcement in the presence of transaction costs

An effective enforcement strategy in the presence of transaction costs—the strategy that generates complete emissions compliance in the cheapest manner possible— is given by the following, which come directly from Proposition 4:

$$\pi(0) = \frac{p + t'(|l - l^0|)\tau_l}{g'(0) + f'(0)}; \quad \textbf{[19]}$$

$$p + t'(|l - l^0|) \leq f'(0). \quad \textbf{[20]}$$

To guarantee complete emissions compliance by every firm, [19] and [20] have to hold for each firm. Equation [19], which specifies minimal amounts of monitoring that guarantee that each firm provides accurate emissions reports, comes from equation [12] of Proposition 4. They specify minimal amounts of monitoring that guarantee that each firm provides accurate emissions reports. Equation [20] is exactly equation [13], which recall guarantees complete emissions compliance by every firm, provided that they have the proper incentives to reveal their true levels of emissions.

To examine the consequences of transaction costs of enforcing a transferable permit system, let us assume that equation [20] is satisfied and focus on the implications of the monitoring strategy specified by [19]. Let us also assume at first that permit trades do not involve transaction costs; that is, monitoring to help ensure truthful emissions reporting and complete emissions compliance is $\pi(0) = p/[g'(0) + f'(0)]$. Notice that the only piece of information that an enforcer requires to implement this strategy is the prevailing permit price. Since the strategy does not depend directly on anything about individual firms, firm-specific information is not valuable to the enforcement authority. This includes information that the enforcer will have access to, such as the initial allocation of permits, as well as information that may be private to firms (and hence, may be very costly to obtain) like details about the firms' production and emissions-control technologies, and, more generally, their abatement costs.

This lack of firm-specificity in the monitoring strategy also suggests that there is no reason for an enforcer to target its effort in a competitive and frictionless transferable permit system. In fact, as long as penalties are applied uniformly, monitoring each firm with probability $\pi(0) = p/[g'(0) + f'(0)]$ will be the cheapest way (in terms of monitoring costs) to help ensure complete emissions compliance.

The reason that the monitoring strategy keys the enforcement variables to the permit price and not to characteristics of individual firms is the equilibrating nature of competitive transferable permit system. If the enforcement strategy is designed properly and there are not transaction costs, each firm chooses its emissions to equate its marginal abatement costs to the prevailing permit price. So characteristics of a firm that determine its abatement costs are of no consequence because, at the margin, they are tied to the permit price. Furthermore, since all firms face the same permit price in competitive and frictionless permit system, their marginal control costs are all equal. In a permit market equilibrium there is simply no heterogeneity in firms' marginal control costs that the enforcer can usefully exploit.

However, when permit trading involves variable transaction costs firms do not face the same effective price for permits. Suppose now that marginal transaction costs are a constant α for both buyers and sellers.[6] Then, an effective monitoring requires that net buyers of permits be monitored with probability $[p + \alpha]/[g'(0) + f'(0)]$ and that sellers be monitored with probability $[p - \alpha]/[g'(0) + f'(0)]$. Thus, the presence of constant marginal transaction costs implies that buyers of permits should be monitored more closely than sellers. The reason for this difference is simple: in the presence of variable transaction costs, buyers of permits face higher effective prices than sellers. Since buyers then have a greater incentive to be non-compliant, they must be monitored more closely than sellers to ensure their compliance. In contrast to enforcement in the absence of transaction costs, the presence of variable transaction costs calls for targeted monitoring, with buyers being monitored more closely than sellers. Note, however, that as long as the transaction cost parameter α does not vary by firm, monitoring should be uniform within the group of buyers and the group of sellers.

Targeted monitoring always implies the need for additional information. In the case of constant marginal transaction costs the extra information is whether a firm is a net buyer or seller of permits and the transaction cost parameter. The former bit of information will be readily available to an enforcer, but the latter may not. Fortunately, if the transaction cost parameter does not depend on the characteristics of individual firms, then no privately held, firm-specific information is required by an enforcer.

Monitoring is much more complicated if marginal transaction costs are not constant. In these cases, permit buyers should be monitored with probability $[p + t'(|l - l^0|)]/[g'(0) + f'(0)]$ while sellers should be monitored with probability $[p - t'(|l - l^0|)]/[g'(0) + f'(0)]$. Again, buyers face a higher effective price than sellers, which implies that they should be monitored more

[6] This would capture cases in which the only transaction cost is a broker's fee that is a constant percentage of the value of trades.

closely. However, the effective price that each firm faces depends on how many permits it chooses to hold relative to their initial allocation, as well as whether marginal transaction costs are increasing or decreasing. Effective monitoring would then depend upon these characteristics as well, and hence, would call for non-uniform monitoring within groups. Note that the enforcer must have a good estimate of the transaction cost function for every firm. This information will probably be difficult to obtain, especially if the structure of variable transaction costs vary by firm.

The implications of the structure of the transaction costs function on a minimally effective monitoring strategy are summarized in Figure 1. In this figure we have graphed the minimally effective monitoring of a firm against the number of permits it holds. In the absence of transaction costs the firm, and every firm in the system, is monitored with probability $p/[g'(0) + f'(0)]$, which of course is independent of the number of permits it holds and its initial allocation of permits. If marginal transaction cost is a constant α; that is, when $t'' = 0$, then the firm is monitored more closely if it is a buyer of permits than if it is a seller of permits. Other than this distinction, effective monitoring of the firm is independent of the number of permits it holds relative to its initial allocation; that is, it is independent of the size of its permit transactions.

When marginal transaction costs are not constant, minimally effective monitoring depends on whether the firm is a buyer or seller of permits, the size of its permit transactions and the structure of the transaction costs function. Suppose that the firm is a net buyer of permits ($l > l^0$) and that marginal transaction costs are increasing ($t'' > 0$). Then, as the figure indicates the more permits the firm buys the more closely it needs to be monitored. The opposite is true if marginal transaction costs are decreasing ($t'' < 0$). However, if the firm is a net seller of permits

($l < l^0$) and marginal transaction costs are decreasing, the firm should be monitored more closely the greater the number of permits it sells. The opposite is true when marginal transaction costs are increasing in the size of the firm's transactions.

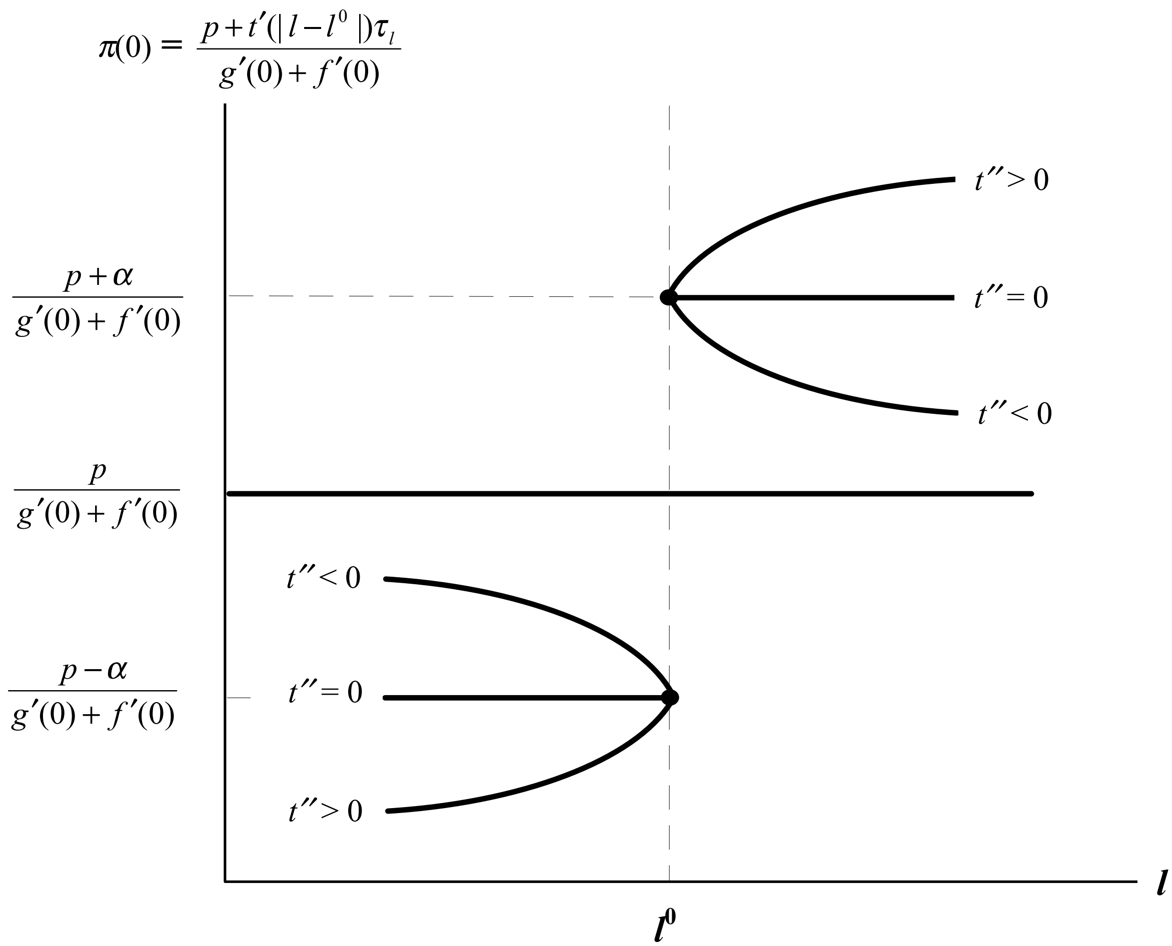

Figure 1: Transaction Costs and Minimally Effective Monitoring

Before we move on, let us say a few words about setting penalties in this context. Equation [20] states that the marginal penalty for a slight emissions violation must not fall below the largest effective permit price faced by buyers of permits. This guarantees that every firm will hold enough permits to cover their emissions when they have the proper incentive to prove truthful emissions reports. The only possible complication here is lack of full information about possible transaction costs. We do not consider this to be a significant problem, because in practice the marginal penalty for emissions violations is likely to be much higher than the equilibrium permit price.[7]

The enforcement strategy given by [19] and [20] suggests that effective enforcement of transferable permit systems does not require a penalty for reporting violations. Truthful reporting and emissions compliance can be achieved without penalizing false reporting. However, given fixed penalties for emissions violations, monitoring can be reduced if penalties for reporting violations are applied in addition to penalties for emissions violations.[8]

4. Enforcement Costs and the Initial Distribution of Permits

In this section we consider the effects of the initial allocation of permits on aggregate enforcement costs in the presence of transaction costs. Our motivation comes from Stavin's (1995) conclusion that, when marginal transaction costs are not constant, the initial allocation of permits can have a significant impact on the aggregate abatement costs of achieving an environmental quality goal with a transferable permit system. Similarly, we show that when marginal transaction costs are not constant, the initial distribution of permits will affect the costs of effective enforcement. Unfortunately, even in the simple case that we analyze, any reallocation of the initial distribution of permits will have an ambiguous effect on enforcement

[7] For example, in the Sulfur Dioxide Trading program the unit penalty for emissions violations has always been many times higher than prevailing permit prices. The penalty was set at $2,000 per ton of emissions in excess of allowances in 1990 dollars, while allowance prices have rarely risen above $200. The penalty for the 2002 compliance year was about $2,850 per ton of excess emissions, while permits traded at prices that were generally less than $170 per allowance (US EPA 2003b).

costs. Therefore, firm conclusions about whether enforcement costs will rise or fall with a change in the initial distribution of permits will be situation-specific.

For simplicity, we assume that there are only two types of firms operating under the permit system. The system contains n_i identical firms of type i, with i =1,2. Let l_i^0 be the initial allocation of permits to each type i firm. As before, the aggregate issuance of permits is fixed at L; therefore, $L = n_1 l_1^0 + n_2 l_2^0$. We consider a reallocation of the initial allocation of permits from type 1 to type 2 firms. We shall reduce each type 1 firm's initial allocation by Δ and redistribute these permits to type 2 firms. This reallocation will increase each type 2 firm's initial allocation by $(n_1/n_2)\Delta$.[9] Assume that given (l_1^0, l_2^0), type 1 firms are sellers of permits and type 2 firms are buyers and that this remains true after we reallocate the initial distribution of permits.

Recall that choices of firms are independent of their initial allocation of permits when there are no transaction costs and when marginal transaction costs are constant. Our purpose, therefore, is to examine how the reallocation of permits affects aggregate enforcement costs in the presence of non-constant marginal transaction costs. We assume that the enforcer of the permit system is able to commit itself to the effective enforcement strategy we presented in the last section. Since every firm will be compliant, the only costs of enforcing the program are monitoring costs. We assume further that only sellers of permits—type 1 firms—bear transaction costs. Denote the minimally effective monitoring of type i firms as π_i^{min}. Then, using equation [19], type 1 firms are monitored with probability

[8] A more complete discussion of the role of self-reporting in the enforcement of transferable permit systems can be found in Stranlund and Chavez (2000).

[9] Holding L fixed, each type 2 firm's allocation must increase by $(n^1/n^2)\Delta$ because $n_1(l_1^0 - \Delta) + n_2(l_2^0 + (n_1/n_2)\Delta) = n_1 l_1^0 - n_1\Delta + n_2 l_2^0 + n_1\Delta = n_1 l_1^0 + n_2 l_2^0 = L$.

$$\pi_1^{min} = \frac{p - t'(|l - l^0|)}{g'(0) + f'(0)}, \qquad \textbf{[21]}$$

while each type 2 firm is monitored with probability

$$\pi_2^{min} = \frac{p}{g'(0) + f'(0)}. \qquad \textbf{[22]}$$

Assuming that the cost of an audit is a constant w, aggregate monitoring costs are $M = w[n_1 \pi_1^{min} + n_2 \pi_2^{min}]$. In this context we have the following:

Proposition 5: *Given increasing (decreasing) marginal transaction costs faced by type 1 firms, a reallocation of permits from type 1 to type 2 firms increases (decreases) the required monitoring of type 1 firms, but decreases (increases) the required monitoring of type 2 firms. Therefore, the reallocation of the initial distribution of permits may increase or decrease total monitoring costs.*

Proof of Proposition 5: The effect of the initial allocation of permits on the required monitoring strategy will work through the firms' demands for permits and the resulting impact on the equilibrium permit price. To determine these relationships, we use Proposition 1 to characterize the firms' permit demands. Because the enforcement strategy induces full compliance, equation [4] suggests that each type 1 firm will choose to hold permits so that

$$p - t'((l_1^0 - \Delta) - l_1) + c_1'(l_1) = 0. \qquad \textbf{[23]}$$

Since type 2 firms do not bear any transaction costs they choose their permits so that

$$p + c_2'(l_2) = 0. \quad \textbf{[24]}$$

Equation [23] implicitly defines a type 1 firm's demand for permits as $l_1(p, \Delta)$. From [23],

$$\partial l_1/\partial p = -1/[c_1'' + t''] < 0. \quad \textbf{[25]}$$

Strict convexity of the firms' objectives requires $c_1'' + t'' > 0$, which we assume holds throughout. From [23] we can also obtain

$$\partial l_1/\partial \Delta = -t''/[c_1'' + t''] = t''[\partial l_1/\partial p], \quad \textbf{[26]}$$

which indicates that

$$sign\,(\partial l_1/\partial \Delta) = sign\,(-t''). \quad \textbf{[27]}$$

For type 2 firms, [24] implicitly defines $l_2(p)$, with

$$\partial l_2/\partial p = -1/c_2'' < 0. \quad \textbf{[28]}$$

Now we must determine how the reallocation of licenses affects the equilibrium permit price. Note that the market-clearing condition, $n_1 l_1(p, \Delta) + n_2 l_2(p) - L = 0$, implicitly defines the equilibrium permit price as $p(\Delta)$. Note that

$$n_1 l_1(p(\Delta), \Delta) + n_2 l_2(p(\Delta)) - L \equiv 0 \quad \textbf{[29]}$$

Differentiate [29] with respect to Δ, substitute $\partial l_1/\partial \Delta = t''[\partial l_1/\partial p]$ from [26], and rearrange the result to obtain

$$dp/d\Delta = -\ t'' \ \lambda, \qquad \textbf{[30]}$$

where

$$\lambda = \frac{n_1(\partial l_1/\partial p)}{n_1(\partial l_1/\partial p) + n_2(\partial l_2/\partial p)} \in (0, 1). \qquad \textbf{[31]}$$

Given $\lambda \in (0,1)$,

$$sign\ (dp/d\Delta) = sign(-t''). \qquad \textbf{[32]}$$

We are now ready to consider the impact of the reallocation of licenses on the monitoring probabilities given by [21] and [22]. Minimally effective monitoring of type 1 firms as a function of the permit price and the reallocation of permits is

$$\pi_1^{min}(\Delta) = \frac{p(\Delta) + t'(l_1(p(\Delta),\Delta) - (l_1^0 - \Delta))}{g'(0) + f'(0)}. \qquad \textbf{[33]}$$

Differentiate $\pi_1^{min}(\Delta)$ and make the appropriate substitutions from [25], [26], and [30] to obtain

$$\frac{d\pi_1^{min}(\Delta)}{d\Delta} = \frac{t''c_1''(1-\lambda)}{[c_1'' + t''][g'(0) + f'(0)]}. \qquad \textbf{[34]}$$

Since $(1 - \lambda) \in (0, 1)$, $c_1'' > 0$, and $[c_1'' + t''] > 0$,

$$sign\ (d\pi_1^{min}(\Delta)/d\Delta) = sign\ (t''). \qquad \textbf{[35]}$$

For each type 2 firm, the probability of an audit should be $\pi_2^{min}(\Delta) = p(\Delta)/[g'(0) + f'(0)]$, with

$$\frac{d\pi_2^{min}(\Delta)}{d\Delta} = \frac{dp(\Delta)/d\Delta}{[g'(0)+f'(0)]} = \frac{-t''\lambda}{[g'(0)+f'(0)]}. \qquad \textbf{[36]}$$

Clearly,

$$sign\ (d\pi_2^{min}(\Delta)\ /d\Delta) = sign\ (-t'') \qquad \textbf{[37]}$$

From [35] and [37] we conclude that:

(a) If $t'' < 0$, then $d\pi_1^{min}(\Delta)\ /d\Delta < 0$ and $d\pi_2^{min}(\Delta))\ /d\Delta > 0$.

(b) If $t'' > 0$, then $d\pi_1^{min}(\Delta)\ /d\Delta > 0$ and $d\pi_2^{min}(\Delta))\ /d\Delta < 0$.

Since total monitoring costs are $M = w[n_1\pi_1^{min}(\Delta) + n_2\pi_2^{min}(\Delta)]$, it follows from ($a$) and ($b$) that a reallocation of permits from type 1 firms to type 2 firms may increase or decrease total enforcement costs M. QED.

Proposition 5 suggests that a reallocation of the initial distribution of permits is likely to have an ambiguous affect on total monitoring costs, primarily because the reallocation has opposite affects on the effective permit prices paid by buyers and sellers. If sellers face decreasing marginal transaction costs ($t'' < 0$), a reallocation of permits from sellers to buyers will result in a higher equilibrium permit price (equation [32]). Since buyers of permits (type 2 firms) do not face transaction costs, and hence, their marginal benefit of non-compliance is simply the equilibrium permit price, the higher permit price requires that type 2 firms be monitored more closely to offset their greater incentive to be non-compliant. On the other hand, the reallocation of permits when the sellers' marginal transaction costs are decreasing reduces the effective permit price faced by sellers of permits. Since their incentive to be non-compliant is lower, they can be monitored less closely.

If marginal transaction costs of increasing ($t'' > 0$), a reallocation of permits from sellers to buyers will result in a lower equilibrium permit price and a higher effective permit price faced by sellers. Since buyers of permits would then have a lower incentive be non-compliant and sellers would have a higher incentive, the reallocation of permits would require less monitoring of permit buyers but closer monitoring of permit sellers.

5. Conclusion

Building on Stavins (1995) analysis of the performance of permit systems in the presence of transaction costs. We have examined the consequence of transaction costs on enforcing otherwise competitive transferable permit systems. In general, enforcement of a permit system is complicated by the presence of transaction costs. In their absence, as long as penalties are applied uniformly, monitoring should also be uniform. In addition, an enforcer should tie its enforcement strategy directly to the prevailing permit price—no other information is relevant. When firms face constant marginal transaction costs, such as might arise from broker's fees, an enforcer should distinguish between buyers and sellers of permits, focusing its monitoring effort more intently on buyers than sellers. Within the groups of buyers and sellers, monitoring should be constant. When marginal transaction costs are not constant, the enforcer's strategy becomes much more complicated. In these situations, effective monitoring calls for not only distinguishing between buyers and sellers, but will also depend on the number of permits each firm holds relative to its initial allocation, as well as whether marginal transaction costs are increasing or decreasing.

In practice, of course, an enforcer may not have very good information about transaction costs, especially if marginal transaction costs are not constant, or if these costs depend on specific characteristics of individual firms. Without perfect information about transaction costs, an enforcer will not be able to perfectly target its enforcement effort in the ways that we have proposed. Instead, to achieve full compliance some firms will have to be over-enforced in the sense that the strategy they face will have to be more the enough to guarantee their complete compliance. At the very least, however, an enforcer will be able to distinguish between buyers and sellers of permits, and will know the size of each firm's transactions. Therefore, the enforcer will still be able to target its enforcement strategy in an attempt to reduce enforcement costs. The conceptual results that we have presented should serve as a good guide to how this should be done, even when perfect targeting is not possible.

We have also shown that transaction costs can impact the costs of achieving complete compliance when marginal transaction costs are not constant. But it appears that whether or not the initial distribution of permits of permits can be used to lower enforcement costs will depend on the specific situation. In fact, attempting to use something as politically sensitive as the initial allocation of permits to reduce enforcement costs may be more trouble than it is worth.

It seems to us that designing permit systems to limit transaction costs would be more fruitful. Reducing or eliminating barriers to trading permits and allowing for brokers that will bear the information costs of permit trading are steps toward reducing transaction costs, and hence, toward the theoretical ideal of minimal aggregate abatement costs. Our results suggest that efforts to limit transaction costs may also make enforcement of transferable permit systems easier.

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