Citizen Participation in Pollution Permit Markets

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November 6, 2003

Abstract

Should citizens lobby the government to reduce pollution permit endowments or should they participate directly in the market by purchasing and retiring permits? We use a two stage model to address this question. In the first stage, citizens and firms exert effort to influence the endowment of permits. In the second stage, firms, and perhaps citizens, participate in the permit market. Under conditions that are likely to hold in many pollution permit markets, we show that citizens may indeed want to purchase permits.

Preliminary Draft

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1 Introduction

When transaction costs preclude voluntary negotiation, one of the "big three" environmental regulations— standards, taxes, and permits— may be used to ameliorate harm from pollution. A large literature compares the performance of these regulations with respect to various criteria such as cost-effectiveness, the incentive to adopt new pollution control technology, and the cost of enforcement.

Permits have an under appreciated feature, however, that clearly distinguishes them from the other environmental regulations. A permit market lowers the transaction costs of post-regulation negotiation. To see this, suppose that firms generate emissions of pollution, citizens are harmed by the pollution, and the endowment of pollution permits is determined by a regulator. If citizens are unhappy with the endowment of permits, they may purchase permits and retire them, thereby reducing the effective level of pollution.[1] Of course, they must outbid the firms for these permits, and thus the negotiations between citizens and firms takes place in a market setting. A similar process is not available to citizens, however, after a tax or standard has been put in place.

At first glance, one might dismiss the importance of citizen participation in permit markets because of the free-rider problem. The free-rider problem, however, also hinders the ability of citizens to organize interest groups to lobby over the structure of regulations in the first place. There is little doubt that citizen interest groups at least partially overcome the free-rider problem and exert influence on, say, the magnitude of the permit endowment. Thus there is no a priori reason to rule out significant participation in the permit market. Rather, citizen interest groups face a resource allocation problem. Should they influence (through lobbying) the endowment of permits, or influence (by purchasing permits) the effective level of pollution, or do some of both?

[1] Ahlheim and Schneider (2002), Boyd and Conley (1997), Shrestha (1998), Smith and Yates (2003) consider permit markets in which citizens may retire permits.

Recent anecdotal evidence suggests that citizens are beginning to notice that purchasing permits is a valuable alternative to traditional lobbying.[2] In this paper, we formally analyze the trade-off between lobbying and permit purchases. We delineate situations in which citizens choose not to purchase permits and situations in which they may choose to purchase them.

Our model is comprised of a lobbying stage and a market stage. There is an interest group for citizens and an interest group for firms. The lobbying stage borrows from the rent-seeking literature.[3] The interest groups exert lobbying expenditures to influence the endowment of permits (instead of influencing the probability of winning a prize as is the case in traditional rent-seeking). In the market stage, we consider cases in which citizens are and are not allowed to purchase permits. This enables us to analyze the effects of allowing citizens to participate in the permit market on both the lobbying and market outcomes as well as analyze whether citizens will actually purchase permits when the are allowed to do so.

For the initial analysis, we utilize a set of simplifying assumptions. Under these assumptions, citizens choose not to purchase permits in the market. They only expend resources to influence the endowment of permits. We also show that firms exert *fewer* resources on lobbying when citizens are allowed to purchase permits. The effect on citizens lobbying effort is ambiguous. They may increase or decrease lobbying expenditures. Our initial assumptions may not accurately reflect conditions that exist in many real permit markets. If relax any of them, citizens may indeed choose to purchase permits. We give examples in which citizens expend resources on both lobbying and permit purchases. We also give an example in which citizens only purchase permits.

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[2] How the West Was Auctioned, Christian Science Monitor, June 2, 2003.

[3] Tullock (1980) is the classic reference. For a recent survey see Tollison (1997).

2 Model

The model is comprised of firms and citizens. Firms generate pollution as a by-product of production. They have an interest group that lobbies the government for favorable environmental policy. Each individual firm's abatement cost is common knowledge within the interest group. The economic interest of the firm group is therefore represented by an (aggregate) marginal abatement cost function. Let $\bar{e}$ be emissions of pollution. The marginal abatement cost as a function of emissions is $\alpha - \alpha\bar{e}$. We interpret $\bar{e} = 1$ as the "business as usual level of emissions", i.e. the level of emissions that would result in the absence of environmental regulation. Citizens suffer damage from pollution. They also have an interest group that lobbies the government. Each individual citizen's damage is common knowledge within the group. The citizen group's economic interest is therefore represented by an (aggregate) marginal damage function. The marginal damage as a function of emissions is $\gamma\bar{e}$.

Both the firm and the citizen interest group face a collective action problem. We assume that firms are better able to solve this problem than the citizens. Firms may, for example, belong to an industry trade association that lowers the costs of organizing the group. The firm interest group represents most, if not all, the firms that generate pollution. In contrast, the citizen group is most likely not collectively exhaustive. Some of those hurt by pollution may not be members of the group and these citizen's damage is not included in the citizen group's marginal damage. Because of this, the intersection of marginal abatement cost and marginal damage does not necessarily represent the efficient level of pollution. Nevertheless, the intersection plays an important role in our analysis and so we refer to it as the "efficacious" level of emissions $e^* = \frac{\alpha}{\alpha+\gamma}$. As we shall see, the marginal abatement cost defines the market price of permits, so we let $p^* = \alpha - \alpha e^*$ be the price that corresponds to the efficacious level of emissions.

We use a rent-seeking model to analyze the effect of interest group lobbying. The firm and citizen groups exert lobbying effort f and c respectively. The endowment of permits $e(f, c)$ is a function of these efforts. Our assumptions on $e(f, c)$ reflect basic insights from the rent-seeking literature. First, the effort of an individual group has decreasing returns. This implies the familiar restrictions on the first and second derivatives ($e_f > 0, e_{ff} < 0, e_c < 0, e_{cc} < 0$). Second, an increase in effort by one group that is matched by a proportionate increase in effort by the other group leads to a complete waste of effort— the outcome is unchanged. This implies e is homogeneous of degree zero (for any $t > 0$ we have $e(tf, tc) = e(f, c)$). It will be useful to "invert" $e(f, c)$ to yield combinations of f and c that determine a given e. Because $e(f, c)$ is homogeneous of degree zero, this can be written as a linear equation $f = m(e)c$ for some function $m(e)$.

We analyze a two stage game in which a lobbying stage occurs first and is followed by a market stage. In the lobbying stage, the interest groups account for the effect of lobbying on the endowment of permits as well as the effect of the endowment of permits on the subsequent market stage equilibrium. The market stage itself is competitive, however, as neither group can manipulate the market price once the permit endowment has been determined. For firms, this is because permits are purchases on an individual basis, not as an organized interest group. Even though the citizens act in concert as a single environmental group, they still must compete with many firms for permits and the price taking assumption is appropriate for them as well.

We solve the game by identifying a Nash equilibrium. First we analyze the market stage equilibrium given arbitrary values for e and the price of permits p. Firms purchase permits and abate pollution. Let $\mathcal{F}$ be the cost of the market stage to firms. Citizens suffer damage from pollution and may purchase permits. Let $\mathcal{C}$ be the cost of this stage to citizens. Before turning to the lobbying stage, we determine the equilibrium price and quantity. Substituting this information into $\mathcal{F}$ and $\mathcal{C}$ yeilds the costs of the market stage that are relevant for the lobbying stage decisions. We denote these costs by $\mathcal{F}(e)$ and $\mathcal{C}(e)$ respectively. This procedure of first determining, say, $\mathcal{C}$

and then $\mathcal{C}(e)$ may initially seem cumbersome, but helps reinforce the structure of model.

Our initial simplifying assumptions are (i) firms and citizens have perfect information about each others economic interest— marginal abatement and marginal damage are common knowledge; (ii) the citizens' group budget constraint is not binding; and (iii) all permits are auctioned by the government. In subsequent sections, we consider the effects of relaxing each of these assumptions.

3 No Citizen Trading

Suppose at first that citizens are not allowed to purchase permits. This enables us to introduce many features of the model and determine a benchmark from which we can compare the effect of opening the market to citizens. Because citizens do not participate in the market, emissions are equal to the permit endowment.

In the market stage, given the price of permits, firms minimize the sum of permit expenditures and abatement costs. A picture of the market stage is shown in Figure 1. Let x be the amount of permits purchased. Permit expenditures equal to the sum of areas 1-4 (a rectangle with sides p and x) and abatement cost is given by area 5 (a triangle with sides $(\alpha - \alpha x)$ and $(1 - x)$). The firms' behavior in the market stage can be summarized by the following problem.

$$\mathcal{F} = \min_{x} \quad xp + \frac{1}{2}(\alpha - \alpha x)(1 - x). \tag{1}$$

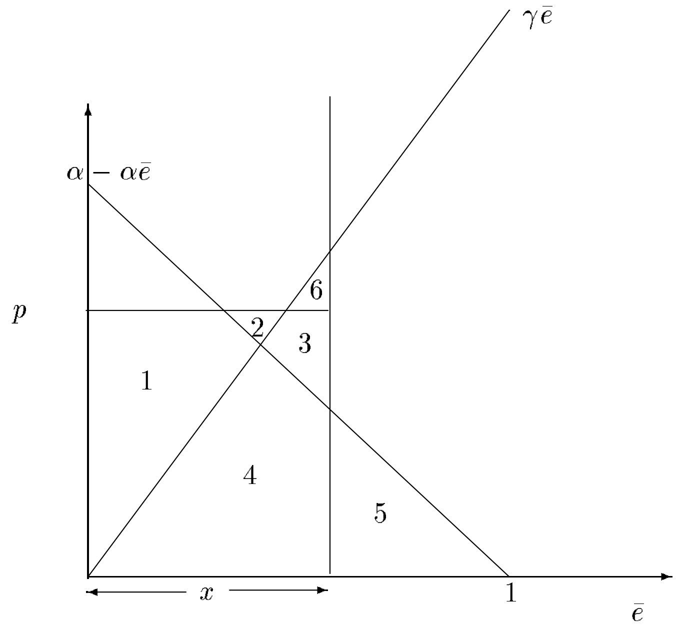
The solution to this problem is

$$p = \alpha - \alpha x. \tag{2}$$

This yields the well-known result that price is equal to the marginal abatement cost.

Now consider citizens. In the market stage, they do not participate and hence suffer damages as a function of the purchases by firms. In Figure 1, the cost to citizens in the market stage is given

Figure 1: Market Stage



by the sum of areas 3, 4, and 6 (a triangle with sides x and γx). We have

$$\mathcal{C} = \frac{1}{2}\gamma x^2.$$

Before solving the lobbying stage, we must incorporate equilibrium information. In other words, we must convert $\mathcal{F}$ into $\mathcal{F}(e)$ and $\mathcal{C}$ into $\mathcal{C}(e)$. The quanity of permits purchased by firms in equilibrium will be equal to the permit endowment. So the x that solves (1) must also be equal to e. Combining this with (2) yields $p(e) = \alpha - \alpha e$. The cost to fimrms of the market stage is then

$$\mathcal{F}(e) = p(e)e + \frac{1}{2}p(e)[1 - e].$$

Now, at the lobbying stage, the total cost to the firms is the sum of lobbying effort and the value of subsequent market stage. Thus the firms select f to minimize

$$f + \mathcal{F}(e) = f + \frac{\alpha}{2}(1 - e^2).$$

The first order condition is

$$1 - \alpha e[e_f] = 0. \tag{3}$$

For citizens, using the equilibrium relationship $x = e$ yields

$$\mathcal{C}(e) = \frac{1}{2}\gamma e^2.$$

The total cost to citizens of the lobbying stage is the sum of lobbying effort and the value of the subsequent market stage. Thus citizens select c to minimize

$$c + \mathcal{C}(e) = c + \frac{1}{2}\gamma e^2.$$

The first order condition is

$$1 + \gamma e[e_c] = 0. \tag{4}$$

Using a superscript to denote that *no* citizen trading is allowed, we identify a Nash equilibrium as a pair (f^n, c^n) that solves (3) and (4). Setting these equations equal to each other yields

$$-\alpha e[e_f] = \gamma e[e_c].$$

Thus

$$-\frac{\alpha}{\gamma} = \frac{e_c}{e_f} = -\frac{f^n}{c^n},$$

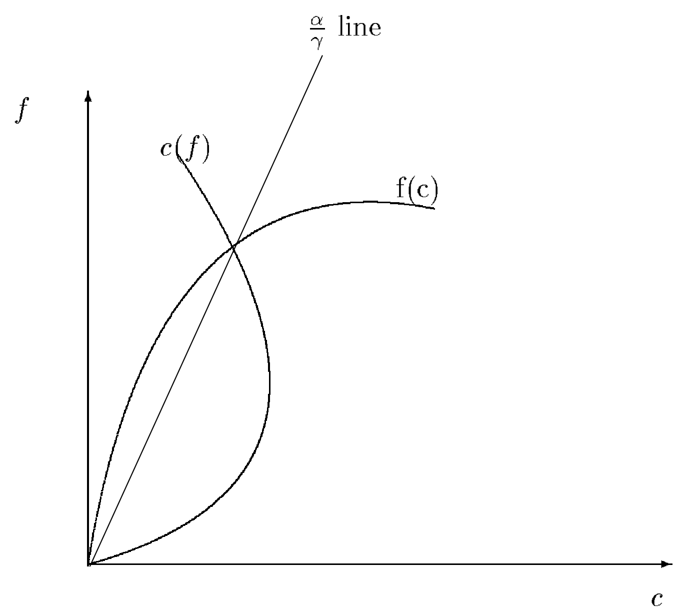
where the second equality follows because e is homogeneous of degree zero.[4] It follows that

$$f^n = \frac{\alpha}{\gamma} c^n. \tag{5}$$

[4]For proof of this result and a further exposition of homogeneous functions, see Simon and Blume (1994, chapter 20).

The equilibrium has a simple geometric interpretation. It lies on a line in the (f, c) plane whose slope is equal to the ratio of the slope of marginal abatement cost to the slope of marginal damage. In Figure 2 we illustrate the equilibrium by sketching the reaction functions for firms and citizens. These curves intersect at a point on the "$\frac{\alpha}{\gamma}$ line".

Figure 2: No Citizen Trading Equilibrium



The equilibrium (f^n, c^n) is determined explicitly by substituting (5) into (3) and (4). For firms we have

$$1 - \frac{\alpha}{2} e(f^n, \frac{\gamma}{\alpha} f^n) e_f(f^n, \frac{\gamma}{\alpha} f^n) = 0.$$

Because e is homogeneous of degree zero, e_f is homogeneous of degree negative one.[5] So we can re-write this as

$$1 - \frac{\alpha}{2} e(1, \frac{\gamma}{\alpha}) \frac{1}{f^n} e_f(1, \frac{\gamma}{\alpha}) = 0.$$

Solving for f^n yields

$$f^n = \frac{\alpha}{2} e(1, \frac{\gamma}{\alpha}) e_f(1, \frac{\gamma}{\alpha}). \tag{6}$$

Similarly,

$$c^n = -\frac{\gamma}{2} e(\frac{\alpha}{\gamma}, 1) e_c(\frac{\alpha}{\gamma}, 1). \tag{7}$$

These equations describe the equilibrium lobbying contributions as a function of the slopes of the marginal abatement cost and the marginal damage.

4 Citizen Trading

Now suppose that citizens are allowed to purchase permits. This complicates the analysis because we must consider two cases. In the first case, which we denote by ℓ, the endowment of permits is *less* than e^*. If this occurs, citizens will be priced out of the market, because marginal abatement cost is greater than marginal damage at the permit endowment. In the second case, denoted by g, the endowment of permits is *greater* than or equal to e^*. In this case, citizens will actually participate in the market, because marginal damages are greater than marginal abatement cost at the permit endowment. Of course, the endowment of permits is endogenous, and determined by c and f. Thus to determine the reaction function for, say, firms, we must account for the fact that the choice of f determines whether case ℓ or case g holds.

To build intuition, consider the firms' reaction function. For a given c, firms decide their lobbying effort. Suppose they drive the endowment of permits greater than e^* and so case g holds.

[5] That is, if e is homogeneous of degree zero, then for any $t > 0$ we have $e_f(tf, tc) = t^{-1} e_f(f, c)$.

In the market stage, citizens will purchase $(e - e^*)$ permits (after that they will be priced out of the market by firms). Thus firms end up back at e^*. They could have attained the same outcome with less lobbying effort by only driving the endowment of permits to e^* in the first place. So firms will not drive the endowment of permits past e^*. Given a "small" value of c, the firms' best response is to drive the endowment of permits to e^*. Given a "large" value of c, it is too costly to obtain e^*. The intuition for citizens is similar. Given a small f, the citizens will drive the endowment of permits below e^* and then not purchase any permits in the market stage. Given a large f, it is too costly to obtain e^* and they will allow the endowment to be greater than e^*. They will then purchase $(e - e^*)$ permits in the market stage.

This intuition suggests that combinations of f and g that lead to e^* will play an important role in the analysis. These combinations are determined by the linear relationship

$$f = m(e^*)c.$$

Thus it is appropriate to refer to them as the "e^* line". Case ℓ occurs when $f < m(e^*)c$ and case g occurs when $f \geq m(e^*)c$.

To describe the reaction functions in more detail, we must first determine the solution to the market stage.

4.1 Market Stage

The market stage depends on the cases ℓ and g. Consider case g first. Here citizens purchase permits. For citizens, the important variable is the actual amount of pollution emitted, z, which of course will be less than or equal to the permit endowment. Citizens determine z through their permit purchases. Citizens minimize the sum of permit expenditures and damages from emissions. Given the endowment of permits e and the market price p, the citizens problem is

$$\mathcal{C} = \min_z \ (e - z)p + \frac{1}{2}\gamma z^2.$$

The solution is $z = \frac{p}{\gamma}$. For firms, the market stage is the same as before— firms solve (1). It is useful to write the solution in this instance as $x = \frac{\alpha - p}{\alpha}$.

Intuition suggests that purchase permits such that emissions are equal to e^*. To see this is indeed the case, we analyze the market equilibrium. In equilibrium, $z = x$ (the actual amount of emissions is equal to the amount of permits held by firms). This implies

$$\frac{p}{\gamma} = \frac{\alpha - p}{\alpha}.$$

Solving for p yields $p = p^*$. It follows that $z = x = e^*$.

The solution to the market stage in case ℓ is the same as in the no citizen trading market stage.

4.2 Firms' Reaction Function

Now consider the lobbying stage. For a given c, if the firm selects an f such that $f < m(e^*)c$, then we have case ℓ. The firms know that citizens will not participate in the market and the market price will be determined by the marginal abatement cost function. Thus their reaction function is identical to that part of the no citizen trading reaction function that satisfies $f < m(e^*)c$.

On the other hand, if the firm selects an f such that $f \geq m(e^*)c$, then we have case g. As we have seen, the subsequent market equilibrium has price of p^* and the firms purchase e^* permits. So

$$\mathcal{F}(e) = e^* p^* + \frac{1}{2} p^* (1 - e^*)$$

and the firms objective is

$$f + \mathcal{F}(e) = f + p^* e^* + \frac{1}{2} p^* (1 - e^*).$$

Given that we remain in case g, the best option for firms is to select f such that e is equal to e^*. So we have $f = m(e^*)c$ and hence the firms' reaction function follows the e^* line.

The boundary between the two cases occurs when the optimal f in case ℓ intersects the e^* line. This will occur at a critical value of c which we denote by $\tilde{c}$. We have

$$f = m(e^*)\tilde{c}.$$

and we solve for $\tilde{c}$ by using the first order condition (3). Substituting in $m(e^*)\tilde{c}$ for f and $\tilde{c}$ for c yields

$$1 - \alpha e(m(e^*)\tilde{c}, \tilde{c}) e_f(m(e^*)\tilde{c}, \tilde{c}) = 0.$$

By definition $m(e)$ we have $e(m(e^*)\tilde{c}, \tilde{c}) = e^*$. Because e_f is homogeneous of degree negative one, we can solve for $\tilde{c}$. We have

$$\tilde{c} = \alpha e^* e_f(m(e^*), 1).$$

Figure 3 illustrates the firms' reaction function. We have reproduced the reaction function $f(c)$ from Figure 2. For points to the right of $\tilde{c}$, we have case ℓ, and the reaction function with citizen trading is equal to the reaction function with no citizen trading. For points to the left of $\tilde{c}$, we have case g, and the reaction function maps the e^* line.

4.3 Citizens Reaction Function

The analysis for citizens is similar for that of firms. There is a critical value of f that forms the boundary between case ℓ and case g. For case ℓ, the citizens reaction function is the same as when there is no citizen trading. So for $c > \frac{1}{m(e^*)} f$, the optimal c is the solution to (4).

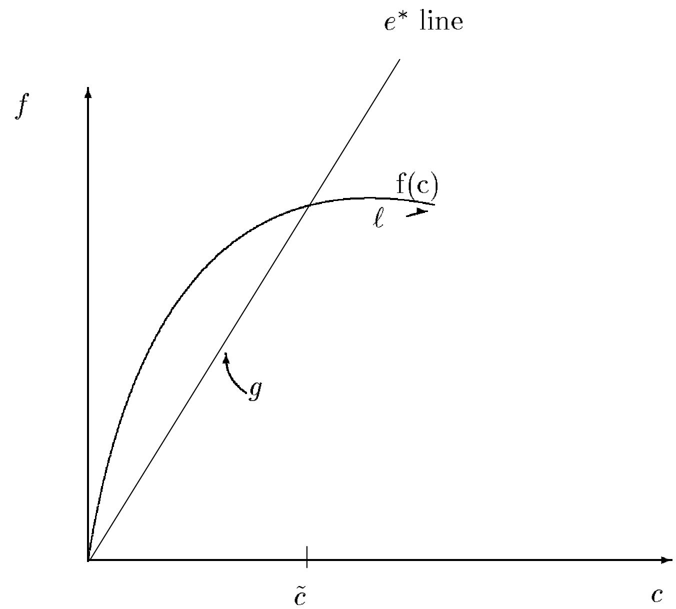
For case g, we have $c < \frac{1}{m(e^*)} f$ and the permit endowment is greater than e^*. In the market stage, as we have seen, citizens purchase permits such that $z = e^*$. The market price is p^* and thus

$$\mathcal{C}(e) = (e - e^*)p^* + \frac{1}{2}\gamma(e^*)^2$$

The citizens objective in the lobbying stage is

$$c + \mathcal{C}(e) = c + (e - e^*)p^* + \frac{1}{2}\gamma(e^*)^2. \tag{8}$$

Figure 3: Firms' Reaction Function



The optimal c, and hence the citizens reaction function, is the solution to

$$1 + p^* e_c = 1 + \gamma e^* e_c = 0. \tag{9}$$

The boundary between the two cases occurs for some $\tilde{f}$ such that the optimal c from (4) or (9) leads to a permit endowment of exactly e^*. Thus $c = \frac{1}{m(e^*)}\tilde{f}$. From either (4) or (9), we see that $\tilde{f}$ can be found from

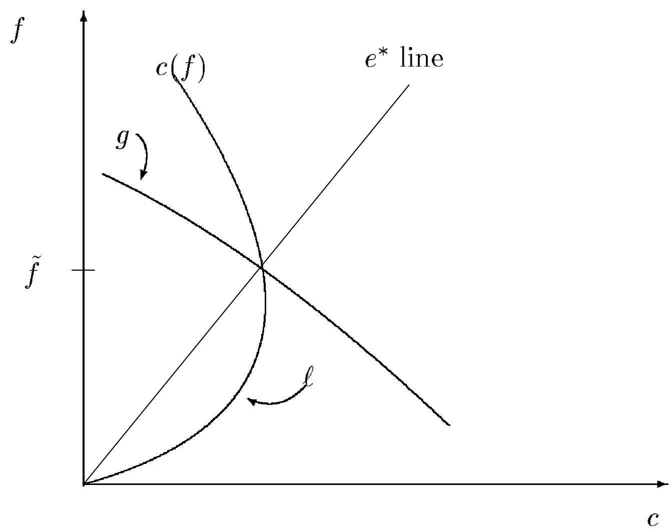
$$1 + \gamma e^* e_c(\tilde{f}, \frac{1}{m(e^*)} f) = 0,$$

from which it follows that

$$\tilde{f} = -\gamma e^* e_c(1, \frac{1}{m(e^*)}).$$

Figure 4 illustrates the citizens reaction function. We have reproduced the reaction function $c(f)$ from Figure 2. For points below $\tilde{f}$, we have case ℓ, and the reaction function with citizen trading is equal to the reaction function with no citizen trading. For points above $\tilde{f}$, we have case g, and the reaction function takes a new form. The boundary between the two cases occurs when the no trading reaction function $c(f)$ intersect the e^* line.

Figure 4: Citizens' Reaction Function



4.4 Lobbying Equilibrium

A Nash Equilibrium for the lobbying stage occurs at the intersection of the two reaction functions. Considering Figures 2-4 we see that the properties of an equilibrium are determined by the relationship between the e^* line and the $\frac{\alpha}{\gamma}$ line. It should not come as a surprise that the $\frac{\alpha}{\gamma}$ line plays an important role in the results. The relative slope of the marginal abatement cost and marginal damage is frequently a critical parameter environmental economic models. The e^* line incorporates both the relative slope (through e^*) as well as the nature of the political influences of the interest groups. The key observation is that allowing trading only effects the citizens' reaction function above the e^* line. If the e^* line lies above the $\frac{\alpha}{\gamma}$ line, then allowing citizen trading has no effect on the equilibrium of the lobbying game. The reaction functions $c(f)$ and $f(c)$ intersect at point (f^n, c^n) on the $\frac{\alpha}{\gamma}$ line whether citizens are allowed to trade or not.

On the other hand, if the e^* line is below the $\frac{\alpha}{\gamma}$ line, the the equilibrium with citizen trading will be different from the equilibrium with no citizen trading. This is illustrated in Figure (5). The equilibrium with citizen trading (f^t, c^t), occurs at the point labeled t. This is the intersection of the citizens' no trading reaction function $c(f)$ and the e^* line. Thus

$$[f^t, c^t] = [\tilde{f}, \frac{1}{m(e^*)}\tilde{f}],$$

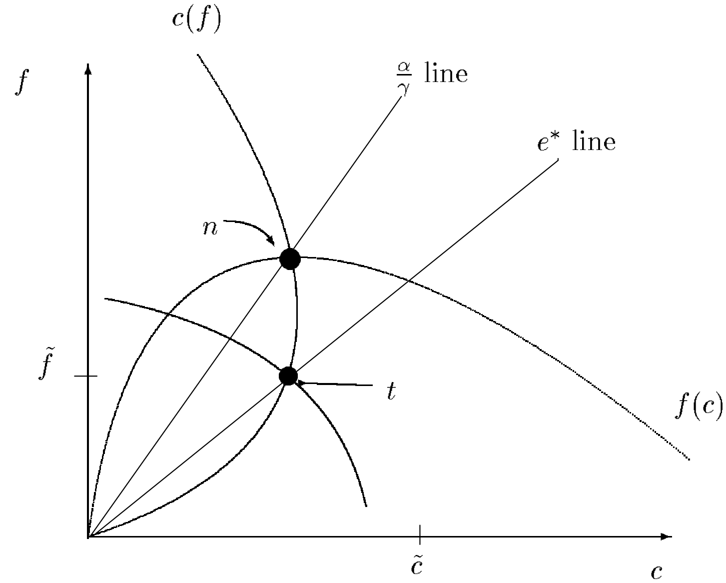
from which it follows that

$$f^t = -\gamma e^* e_c(1, \frac{1}{m(e^*)}) \tag{10}$$

$$c^t = -\gamma e^* e_c(m(e^*), 1). \tag{11}$$

The main conclusion of the equilibrium with citizen trading is that citizens do not actually purchase permits in equilibrium, even though they are permitted to do so. The threat they might indeed purchase permits, though, keeps firms from driving the endowment past e^*. In subsequent

Figure 5: Citizen Trading (t) and No Citizen Trading (n) Equilibria



sections, we see this conclusion depends critically on our initial assumptions. If we relax any of them, can find examples in which citizens purchase permits in equilibrium.

Of secondary interest is the effect of allowing citizen trading on lobbying behavior. From Figure 5, it appears that $f^t \leq f^n$. Intuitively, firms will not lobby past e^* when citizen trading is allowed and thus will exert less effort than when citizen trading is not allowed. Indeed it can be shown that this intuition is correct. More interestingly, the relationship between c^t and c^n is ambiguous. For example, suppose that

$$e(f,c) = (\frac{f}{f+c})^{1/2}.$$

In this case, the sign of $c^n - c^t$ is determined by

$$\gamma^2 - \alpha^2 + \gamma\alpha.$$

Clearly this could be positive or negative, depending on the relative slope of the marginal abatement cost and marginal damage.

5 Extensions

5.1 Citizens Budget Constraint

In many situations, it may not be reasonable to assume that the financial resources of the citizen group are comparable to those of the firm group. Suppose the citizen group has a budget B. The cases ℓ and g each have two sub-cases, depending on whether or not the budget constraint is binding. A systematic analysis of is quite complicated. For example, when analyzing the citizen reaction function, the cases (and sub-cases) do not necessarily occur as a monotonic function of f.

To get a flavor of the analysis, consider case g and suppose the budget constraint is binding. In the market stage, we can no longer assume that the citizens will drive the price to p^*, as they might not have enough money to do so. Rather, citizens solve the following constrained problem

$$\begin{aligned} \mathcal{C} &= \min_z \ (e-z)p + \frac{1}{2}\gamma z^2 \\ & \quad \text{s.t. } (e-z)p \leq B - c \end{aligned}$$

Because we have assumed the budget constraint is binding, the optimal z is

$$z = e - \frac{B-c}{p}.$$

The citizens' budget constraint does not have an effect on the firms market problem. As before, firms solve (1) and the optimal x is given by $x = \frac{\alpha - p}{\alpha}$. Now, in equilibrium, $x = z$ and thus

$$\frac{\alpha - p}{\alpha} = e - \frac{B-c}{p}.$$

This equation is quadratic in p, so we express the solution for p in reduced form as $p(e, B-c) = p(\cdot)$. Likewise we have $z(e, B-c) = z(\cdot)$ and $x(e, B-c) = x(\cdot)$. For citizens, the value of the market stage as a function of e is

$$\mathcal{C}(e, B-c) = [e - z(\cdot)]p(\cdot) + \frac{1}{2}\gamma z(\cdot)^2,$$

and for firms

$$\mathcal{F}(e, B-c) = x(\cdot)p(\cdot) + \frac{1}{2}p(\cdot)[1 - x(\cdot)].$$

In the lobbying stage, the citizens objective is

$$c + \mathcal{C}(e, B-c) = c + [e - z(\cdot)]p(\cdot) + \frac{1}{2}\gamma z(\cdot)^2 = B + \frac{1}{2}\gamma z(\cdot)^2,$$

where the second equality comes from the fact that the budget constraint is binding. The firms objective is

$$f + \mathcal{F}(e, B-c) = f + x(\cdot)p(\cdot) + \frac{1}{2}p(\cdot)[1 - x(\cdot)].$$

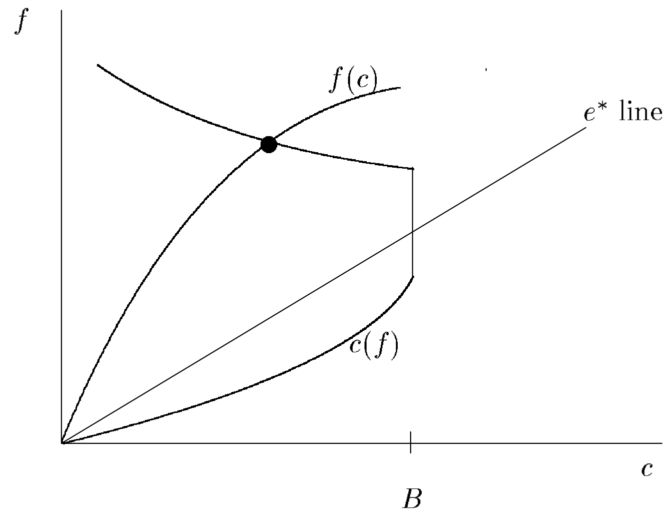
To show the overall effects of the budget constraint on the lobbying equilibrium, we focus two examples with specific lobbying functions. Using these examples, we sketch the reaction functions and show that citizens may indeed purchase permits in equilibrium.

Consider the lobbying function

$$e(f, c) = (\frac{f}{f+c})^{1/2}.$$

This function is biased toward firms. Also assume $\alpha = \gamma = 1$. Firms are willing to drive e past e^* because they know that citizens do not have the resources to retire permits back to e^*. Thus the firms reaction function lies above e^* line. Citizens respond to increases in f by putting in more c until they hit the budget constraint. For very large f's, they cut back on c and then use the remaining funds to purchase permits. The reaction functions and the corresponding equilibrium shown in Figure 6.

Figure 6: Equilbrium with Citizen Budget Constraint



For the second example, consider a lobbying function

$$e(f, c) = \frac{f^{1/2}}{f^{1/2} + c^{1/2}}.$$

This function is symmetric, but we now allow asymmetry in the slopes of the marginal abatement cost and the marginal damage. Let $\alpha = 1$ and $\gamma = 2$, so that marginal damage is more severe than marginal abatement cost. The picture of the equilibrium has the same qualitative features as Figure 6. In particular, citizens purchase permits in equilibrium.

5.2 Imperfect Information

In this section, we relax the assumption that the slope of the marginal marginal damage is common knowledge. We consider a game with imperfect information and we use a Bayesian Equilibrium to solve it. Consider the lobbying function $e(f,c) = \frac{f}{f+c}$. Let $\alpha = 1$ and let γ be described by a two point probability distribution. We have

$$\Pr(\gamma = 1) = \lambda$$

$$\Pr(\gamma = \bar{\gamma}) = 1 - \lambda,$$

where $\lambda \in [0, 1]$ and $\bar{\gamma} > 0$. We first solve the special case of $\lambda = 1$. We then argue that the properties of the solution will hold, by continuity, when λ is close to 1.

The firm assigns probability 1 to $\gamma = 1$, so the firms' strategy is just as in the associated full information case. To solve for citizens' strategy, we must specify a strategy when "nature" reveals that citizens have $\gamma = 1$ or $\gamma = \bar{\gamma}$ (even though the second outcome has zero probability.) When $\gamma = 1$, the citizens act just as if they were in the full-info game. For this e, it turns out the $\frac{\alpha}{\gamma}$ line and the e^* line coincide. Thus the trading and no trading equilibria coincide and the equlbrium can be found from, say, (6) and (7). It is easily verified that the equilibrium contributions are $(f, c) = (1/8, 1/8)$.

When $\gamma = \bar{\gamma}$, citizens face the following situation. They know the firm will contribute $f = 1/8$. We determine the optimal value of c, parameterized by $\bar{\gamma}$, by following the delevopment of the citizens' reaction function in Section 4. This yields

$$c = \begin{cases} \frac{2\sqrt{2\gamma} - \sqrt{(1+\gamma)}}{8\sqrt{(1+\gamma)}} & \text{if } \bar{\gamma} > 1; \quad e > e^* \text{ and consumers will retire permits} \\ \frac{2\bar{\gamma}^{1/3} - 1}{8} & \text{if } \sqrt{5} - 2 \leq \bar{\gamma} \leq 1; \quad e \leq e^* \text{ and citizens will not retire permits} \\ \frac{2\sqrt{2\gamma} - \sqrt{(1+\gamma)}}{8\sqrt{(1+\gamma)}} & \text{if } 1/7 < \bar{\gamma} < \sqrt{5} - 2; \quad e > e^* \text{ and citizens will retire permits} \\ 0 & \text{if } \bar{\gamma} < 1/7; \quad e = 1 > e^* \text{ and citizens will retire permits.} \end{cases}$$

There is an interesting range of possibilities, depending on the value of $\bar{\gamma}$. If $\bar{\gamma}$ is big, or not too small, then citizens will purchase permits in equilibrium. For moderate values of $\bar{\gamma}$, citizens will not purchase permits in equilbrium. Finally, if $\bar{\gamma}$ is small, citiens exert zero effort on lobbying and expend all their efforts purchasing permits.

Now suppose that λ is slightly less than one. Firms now have "real" uncertainty about the citizens damages, but by continuity, the qualitative properties of the equilibrium will be as above. For certain parameter restrictions, citizens will purchase permits when $\gamma = \bar{\gamma}$.

5.3 Grandfathered Permits

It is common for the government to give a large percentage of the permit endowment directly to the firms, rather than auctioning them. For simplicity, we assume here that firms are given the entire endowment.

Once again consider two cases, depending on whether e is greater or less than e^*. For ℓ, the cost to firms of the market stage is equal to the area 5 in Figure 1. At the lobby stage, the firms' objective is

$$f + \frac{1}{2}(\alpha - \alpha e)(1 - e).$$

For case g, the firms may indeed want to drive e strictly greater than e^*, because they generate revenue on subsequent permit sales to citizens. Citizens, of course, will purchase permits until emissions are equal to e^*, and so the permit market equilibrium will have price p^*. At the lobby stage, the firms objective is

$$f + \frac{1}{2}p^*(1 - e^*) - p^*(e - e^*),$$

where the last term is revenue from permit sales.

The intuition for the effect of grandfathered permits on the lobbying equilibrium is fairly straightforward. Because firms may now want to drive e past e^*, citizens may purchase permits in equilibrium. As before, we consider several examples and verify that this intuition is correct. In fact, using the same examples employed in the budget constraint section reveals that citizens do indeed purchase permits in equilibrium.

6 Conclusion

Our results show there are a variety of situations in which citizens' welfare is increased by splitting their resources between lobbying and purchasing permits. Given these results, we would not be surprised to see increased citizen participation in future pollution permit markets.

Acknowledgements

References

M. Ahlheim and F. Schneider (2002), Allowing for Household Preferences in Emission Trading, *Environmental and Resource Economics* **21** , 317-342.

J. Boyd and J. Conley (1997), Fundamental nonconvexities in Arrovian markets and a Coasian solution to the problem of externalities, *Journal Economic Theory* **72**, 388-407.

R. Shrestha (1998), Uncertainty and the Choice of Policy Instruments: A Note on Baumol and Oates Propositions, *Environmental and Resource Economics.* **12**, 497-505.

Simon, C. and Blume, L. (1994), *Mathematics for Economists*, New York: W. W. Norton.

S. Smith and A. Yates (2003), Optimal Pollution Permit Endowments in Markets with Endogenous Emissions, *Journal of Environmental Economics and Management.* **46** , 425-445.

R. Tollison (1997), Rent-seeking, In D. Mueller (Ed.), *Perspectives on Public Choice,* Cambridge: Cambridge University Press, 506-525.

Tullock, G. (1980), Efficient rent-seeking, In J. Buchanan, R. Tollison, and G. Tullock (Eds.), *Toward a theory of the rent-seeking society,* College Station: Texas A&M University Press, 97–112.