Transferable Emissions Permits

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Abstract

This paper introduces the rationale of transferable emissions permits as an instrument in pollution control policies and the applicability of this instrument. Then the issues in implementation of emissions permits system are discussed. The experience of this system in reality is reviewed. In the end, the Pilot Emission Reduction Trading (PERT) Program in Ontario is analyzed and the possible reasons for the low trading activity are explored.

Keywords: Transferable emissions permits, emissions trading, cost-effective, PERT

TRANSFERABLE EMISSION PERMITS

1 INTRODUCITON

Transferable Emissions Permits have been discussed as an economic instrument in pollution control for a long time. To date, most of the practical applications have occurred in the United States. The U.S. Emission Trading Program (ETP), which is based on Emission Reduction Credit (ERC), was introduced in 1975 (see Hahn and Hester, 1989). The U.S. Acid Rain Program (sulfur dioxide allowance trading) was created by Congress in legislation passed in 1990 – called the 1990 Clean Air Act Amendments – and was fully operational by 1995 (see Schmalensee et al., 1998).

In Ontario, Canada, a Pilot Emissions Reduction Trading project (PERT) was initiated in 1995. The trading under this project is rather low. The amount of transferred credits for most pollutants only account for about 5% or less of the aggregate credits created; the remainders have been banked. This paper will explore the possible reasons underlying the low trading activity in PERT. By identifying the possible reasons, it will help to find out the working prerequisites of this economic instrument and make recommendations for the improvement of this particular program.

Specifically, seven possible reasons for the low number of trades in PERT will be examined: 1) learning curve; 2) weak standards; 3) similar abatement costs; 4) location constraints; 5) bilateral negotiation; 6) transaction costs; 7) uncertainty. It will be shown that the most likely causes of the problem are uncertainty, transaction costs, in particular costs associated with bilateral negotiations, location constraints, and learning curve. The huge uncertainty regarding how the future regulation will recognize the credits in the market and high transaction costs from searching for trading partners and bilateral negotiations for price create the disincentive for sources to participate in the trading. Location constraints reduce the number of potential trading partners for buyers. More and more trades happen when sources go along with their learning curves and the uncertainty is reduced by the support from the Ontario government. In contrast, similar abatement costs do not appear to be a plausible cause of the low number of trades, because the possibility is very slim for many sources to have similar marginal abatement costs. Further compliance data is needed to test the possibility of weak standards. Therefore, it would be advisable for the Ontario government to alter PERT in the following manner: 1) clarify the regulations regarding the credits; 2) reduce transaction costs through quick review, clear price signals and early recognition of credits. In order to significantly improve the environmental quality, it is also necessary for the regulator the check the current environmental standards.

The structure of the paper is as following. **Sections 2-4** provide an overview of the environmental economics principles underlying PERT. **Section 5** focuses on the question of the low number of trades. **Section 6** gives some conclusions about the design of a trading system.

2 RATIONALE FOR TRANSFERABLE EMISSIONS PERMITS

2.1 Evaluation of The Environmental Policy

2.1.1 Two Criteria

There are two economic standards to evaluate an environmental policy: one is "efficiency"; the other is "cost-effectiveness" (Tietenberg, 1992, Ch.4).

According to Tietenberg (1992, P93), there are usually two periods in the process of determining an environmental policy: target setting and the choosing of regulatory instrument. In the fist period, where target standards are set, the economic criterion for choice among various standards is *efficiency*. Efficiency means that the net benefits from the standard should be maximized. (Tietenberg, 1992, P22) Since benefit is maximized when the marginal benefit is equal to the marginal cost (Tietenberg, 1992, P28), we need to know the marginal benefit curve and the marginal cost curve. But estimating the benefit and cost is not an easy task, especially when estimating the benefit of nonmarketed environmental resources such as the air. (Cropper and Oates, 1992, IV; Tietenberg, 1992, Ch. 4) So, in practice, the objective standard is usually specified by the political process (Tietenberg, 1992, P93): evidence on the physical consequences of different standards is used to judge the appropriate level, or the criterion is used that assures enough safety for human and ecological health (Tietenberg, 1992, P369).

The other economic criterion is *cost-effectiveness*, which means the policy can minimize the cost of accomplishing the policy objective. If one policy is efficient, it is also cost-effective. But a cost-effective policy is not necessarily efficient unless the policy objective is efficient. This is analogous with the following example: a firm which uses the cheapest method to produce a given output will not maximize its profit unless the given output is the one which maximize its profit; so, profit maximization implies cost minimization, but the converse is not necessarily true.

Therefore, if the policy objective is set through accurate cost-benefit analysis so that the net benefits from the objective are maximized (marginal benefit is equal to marginal abatement cost), the policy is both efficient and cost-effective. There are no separate stages in the policy-making process. But, as we mentioned above, the predetermined objective is usually set politically because of the difficulty to measure benefits and costs accurately. Certainly, the predetermined objective probably is not efficient. So we need to enter the second stage of policy-making: to choose a cost-effective policy to minimize the cost of accomplishing the given objective. (Tietenberg, 1992, P93, P369)

2.1.2 Cost-effective Policy

Then we need to know which pollution control policy is cost-effective. We can use the following simple model to illustrate the character of a cost-effective policy. (Tietenberg, 1992, P370)

Assume there are 2 polluting firms and Q units of emissions needed to be controlled to reach the target standard of environmental quality. The problem is to decide how many units of emissions each firm needs to control, in order to minimize the total control cost.

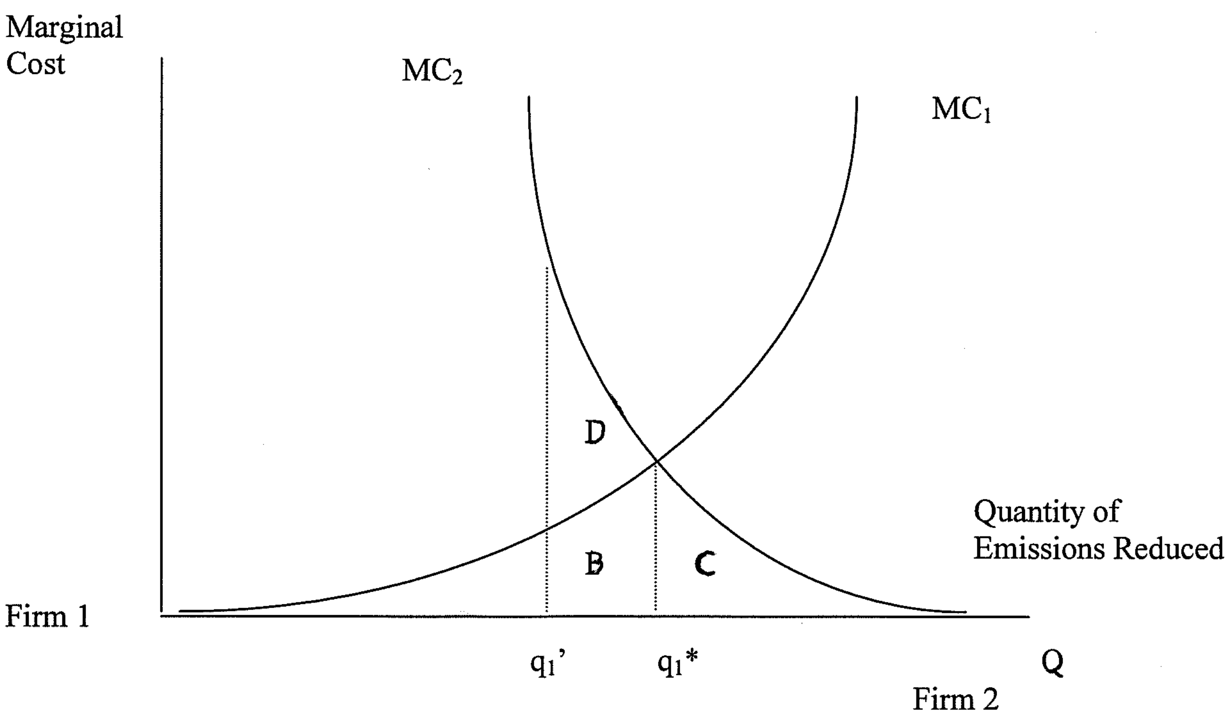
Figure 2-1 consists of two curves of marginal control cost for the two firms. The one starting from the left side of the horizontal axis (MC_1) is for the first firm. The other starting from the right side of the horizontal axis (MC_2) is for the second firm. Notice that every point on the horizontal axis represents a different combination of Q-unit pollution reduction by the two firms.

At the point q_1^* where the corresponding two marginal control cost curves cross, the control cost for the first firm is areas A and B and the control cost for the second firm is area C. The total control cost is (A+B+C). Now the first firm controls q_1^* units of pollution, while the second firm cleans up $(Q - q_1^*)$ units.

Now choose any point other than q_1^* on the horizontal axis, for instance, $q_1^{'}$. The first firm controls q1' units, while the second firm cleans up $(Q - q_1^{'})$ units. The corresponding control cost for the first firm now is area A and the control cost for the second firm is area (B+C+D). The total control cost is (A+B+C+D), which is bigger than the total control cost with point q_1^*. By the same reason, we can conclude that any other point will lead a higher total control cost than the point q_1^*. So q_1^* is the cost-effective allocation of control responsibility.

This illustrates what is a cost-effective pollution control policy. *Under a cost-effective pollution control policy, the marginal control costs are equalized for all polluting firms.* This can be understood by this way: if marginal control cost of one firm is higher than that of another, the total control cost can be lowered by letting the firm with lower marginal control cost reduce one unit of pollution for the firm with the higher one; the total control cost cannot be lowered down if and only if there is no difference among all the marginal control costs.

Figure 2-1



2.1.3 Command And Control (CAC)

We have known what is a cost-effective pollution control policy. Under such a policy, the allocation of pollution control responsibility should let every polluting source face the same marginal control cost. In order to make the cost-effective allocation, we need to know the curves of marginal abatement cost of every polluting source.

In reality, there are usually various ways to control pollution for every firm. The cheapest method differs among different industries and even among firms in the same industry. Every firm knows the information in order to maximize its profit. But the regulatory authority is not able to have so much information. It is also not realistic to let the firm report the accurate information to the regulatory authority, because the firm has the incentive to amplify its control cost in order to receive less burden of pollution reduction. (Tietenberg, 1992, P371)

Traditionally, the control authority uses a legal approach called *technology standard*, under which firms are required to pursue some technology to reduce pollution emissions. For example, the Sikorski/Waxman bill in the US in 1983 proposed to require the installation of scrubbers (flue gas desulfurization equipment) at the fifty dirtiest plants (Burtraw, 1998, P2) Usually, the required technology is thought by the authority to be able to best control pollution. But, in fact, the required technology may not be the cheapest way for some firms. So the total control cost may not be minimized. Technology standards cannot ensure that the marginal abatement costs are equalized for all polluting sources. When time passes by, there may be new methods to control pollution with less cost. But firms are still required to use required technology. So this approach is not a cost-effective one.

Another traditional approach is to impose a separate *emission standard* on each polluting source. (Tietenberg, 1992, P371) An emission standard is a legal limit on the amount of pollutant an individual source is required to reduce. In the example in this section, it is clear that the sum of the two emission standards should be the Q units. But we do not know, without the information on control costs, how the Q units of emission reduction are to be allocated between the two firms. One easy way is to allocate an equal reduction to each firm. From **Figure 2-1**, we can see that this approach will not be cost-effective: firm 1 will have lower marginal cost of control that firm 2. Without knowing the curves of marginal control costs of polluting sources, the regulatory authority can hardly allocate the responsibility for emission reduction in a cost-minimizing way. However, this method offers more flexibility than the technology standard, because it does not specify by which specific act the polluting firms achieve the target standard. So the emission standard is expected to cost less than the technology standard does.

There is also one approach called *input limitations*. Polluting sources are required to use input that has less emission rate, so the amount of total emissions can be controlled. In literature, technology standard, emission standard and input limitations are all refereed as *command and control* strategies. Under them, each polluting unit is required to achieve a certain standard, no matter if it is very expensive to do so. These strategies are hardly cost-effective.

2.2 Transferable Emission Permits

Is it possible to find a cost-effective policy when the regulatory authority has no information on marginal control costs of polluting sources? It is possible if a *transferable emissions permits* system is used to control pollution.

Rationale

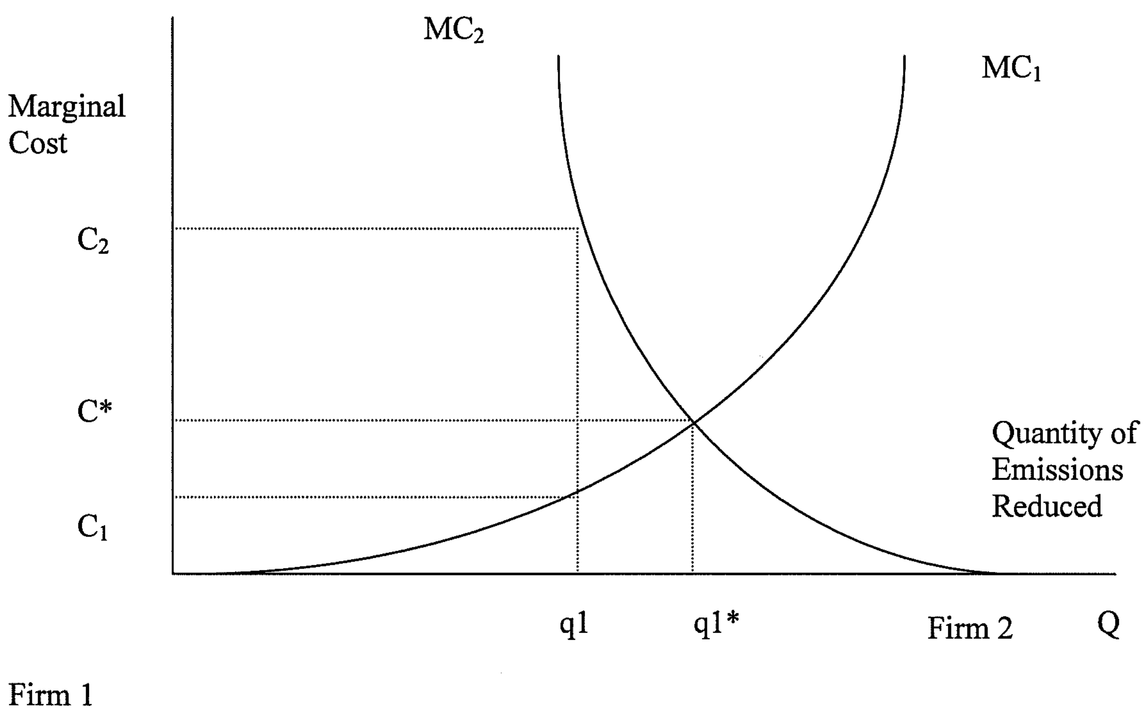
The system of transferable emission permits relies on economic incentives to produce the desired outcome. Under this system, the control authority issues a certain number of emission permits needed to produce the desired emission level at first. Then these emission permits are allocated to firms freely or by an auction. Each permit allows the firm to emit a certain amount of pollution. All polluting sources must have enough permits to cover the pollution they emit. What is important is that the permits are freely tradable: if one firm is able to control the pollution under the amount allowed by the permits it holds, this firm can sell its extra permits to others; if one firm cannot cover its pollution with the allocated permits, it can buy corresponding permits instead of controlling the pollution itself. If one polluting source does not have enough permits to emit pollution, it will face monetary sanctions for the emissions in excess of those allowed by the permits it holds. By this system, the desired quantity of pollution discharge is ensured from the beginning. (Cropper and Oates, 1992, P682; Tietenberg, 1992, P375)

How can this approach lead to a cost-effective allocation of control responsibility? It can be explained with the help of **Figure 2-2**, which is under the same situation of **Figure 2-1**. Besides the emissions allowed by issued emissions permits, there are still Q units to be got rid of. No matter how the emission permits are allocated initially between the two firms, there will be two cases: cost-effective allocation and non-cost-effective allocation.

If the initial allocation is not cost-effective, there will be a difference between the marginal control costs of the two firms. Pick up any point q1 representing this situation on the horizontal axis: the first firm needs to reduce q1 units of emissions, while the second firm needs to control $(Q - q_1)$ units. Now the marginal control cost of the second firm (C_2) is higher than the marginal control cost under cost-effective allocation (C^*), while the marginal cost of the first firm (C_1) is lower than C^*. If the second firm can buy extra emission permits with the price lower than C_2, it will do so instead of controlling the pollution by itself. So it has the demand for emission permits with the price lower than C_2. If the first firm can sell its emission permits with the price higher than C_1, it will choose to reduce more emission and sell the extra emission permits saved. So it can supply emission permits with price higher than C_1. Since C_2 is greater than C_1, the trade will happen. The trade of permits will take place until the marginal control costs of two firms are equal, where a cost-effective allocation is reached.

If the initial allocation is cost-effective or a cost-effective allocation is reached after emission permits trading, there will be no trade. Because now the marginal value of the permit is equal to C* to both firms. Firm 2 pays the same no matter it chooses to control the pollution emission itself or buy extra emission permits; Firm 1 cannot sell its permits with a price higher than its marginal control cost. The permit market then would be in equilibrium.

Figure 2-2



Therefore, the equilibrium of an emission permits market is the cost-effective allocation. Just issue the appropriate number of permits and let the market do the rest; the regulatory authority can reach the predetermined standard by a cost-effective policy without the knowledge of control costs. When there is new entry that emits the same pollutant, the appropriate number of permits for the given standard should not be changed; otherwise, the violation of environmental standards could lead to severe damage. The allocation method of permits between existing and new sources will be discussed in **Section 3.2**.

In essence, a transferable emission permits system utilizes the market mechanism to cost-effectively allocate the control responsibilities among polluting firms. With the price signal in the trading market, less efficient firms in pollution control are given more flexibility (Tietenberg, 1992, P376): they can choose to control pollution emissions themselves or to pay other firms who would like to take extra emission reduction responsibilities. By the flexibility, the more efficient firm who controls pollution emissions with less cost will take more responsibilities to achieve the given target standard. So the total control cost will be lowered.

2.3 Applicability

2.3.1 Uncertainty

Weitzman (1974) has studied under what conditions the instruments of quantities or the instruments of prices should be chosen. Weitzman's study results show that, which instrument should be chosen depends on the *relative* steepness of the marginal benefit and cost curves. Besides the instrument of tradable emission permits, there is another economic instrument that is also popular in environment economics literature---a unit tax on polluting activities. The permit system is one instrument of quantity, while the tax system is an instrument of price. In the presence of uncertainty concerning the costs and benefits of pollution control, which instrument should be preferred? Weitzman's study can offer some implications regarding this question.

Unit Tax On Polluting Activities

A proper unit tax on polluting activities has been shown to be able to give polluting firms economic incentives to reduce pollution emissions to desired level (Cropper & Oates, 1992, II). The following highly simplified functions Cropper and Oates use can basically show the relationships among consumers, producers and pollution:

$$U = U(X, Q) \qquad U_X > 0,\ U_Q < 0 \qquad (1)$$

$$X = X(L, E, Q) \qquad X_L > 0, X_E > 0,\ X_Q < 0 \qquad (2)$$

$$Q = Q(E) \qquad Q_E > 0 \qquad (3)$$

U, the utility of a representative consumer

X, a vector of goods consumed, $(X_1, X_2, \ldots, X_n)$

Q, the level of pollution

L, a vector of conventional inputs

E, the quantity of waste discharges

Here, pollution is viewed as a "bad" commodity in production; pollution is directly produced from waste discharges. The production function (2) considers waste discharge and pollution as factors of production. This can be understood this way: to reduce E needs other inputs, which could be used to produce goods. So reductions in E lead to reduced output. The inclusion of Q is due to the fact that "pollution may have detrimental effects on production (such as soiling the output of the proverbial laundry or reducing agricultural output) as well as producing disutility to consumers" (Cropper and Oates, 1992, P679).

We utilize the following notation: let

$U_j(x_{1j},...,x_{nj},Q_j^c)$ be the utility function of individual j, j = 1, …, m;

$X_i(L_i,E_i,Q_i^p)$ be the production function for product i, whose output is X_i, i = 1, …, n;

x_{ij} be the quantity of X_i consumed by individual j;

$Q_j^c(E_1,...,E_n)$ be the level of pollution faced by individual j and

$Q_i^p(E_1,...,E_n)$ be the level of pollution faced by producer i.

Pareto optimality requires maximization of the utility of any arbitrarily chosen individual, say m, subject to the requirement that there be no less in utility to any of the m-1 other persons. Thus the problem is to maximize

$$U_m(x_{1m},...,x_{nm},Q_m^c)$$

subject to

$$U_j(x_{1j},...,x_{nj},Q_j^c)=k_j \text{ (constant), (j = 1, 2, …, m-1), (i = 1, 2, …, n)}$$

$$\sum_{j=1}^{m} x_{ij} = X_i$$

and the input requirement constraint

$$L_1+L_2+...+L_n=R$$

Then we obtain the Lagrangian

$$L=\sum_{j=1}^{m}\lambda_j[U_j(x_{1j},...,x_{nj},Q_j^c)-k_j]+\sum_{i=1}^{n}\upsilon_i(X_i-\sum_{j=1}^{m}x_{ij})+\mu(R-L_1-L_2-...-L_n)$$

where we take $\lambda_m=1$, $k_m=0$.

Differentiating with respect to the x_{ij} and the E_i, we obtain the first order conditions

$$\frac{\partial L}{\partial x_{ij}}=\lambda_j\frac{\partial U_j}{\partial x_{ij}}-\upsilon_i=0 \tag{4}$$

$$\frac{\partial L}{\partial E_i}=\sum_{j=1}^{m}(\lambda_j\cdot\frac{\partial U_j}{\partial Q_j^c}\cdot\frac{\partial Q_j^c}{\partial E_i})+\upsilon_i[\frac{\partial X_i}{\partial E_i}+\sum_{k=1}^{n}(\frac{\partial X_k}{\partial Q_k^p}\cdot\frac{\partial Q_k^p}{\partial E_i})]=0 \tag{5}$$

From (4), we obtain $\lambda_i=\upsilon_i\Big/\frac{\partial U_j}{\partial Q_j^c}$ and substitute into (5)

$$\sum_{j=1}^{m}(\upsilon_i\cdot\frac{\partial U_j}{\partial Q_j^c}\cdot\frac{\partial Q_j^c}{\partial E_i}\Big/\frac{\partial U_i}{\partial x_{ij}})+\upsilon_i[\frac{\partial X_i}{\partial E_i}+\sum_{k=1}^{n}(\frac{\partial X_k}{\partial Q_k^p}\cdot\frac{\partial Q_k^p}{\partial E_i})]=0$$

$$\sum_{j=1}^{m}(\frac{\partial U_j}{\partial Q_j^c}\cdot\frac{\partial Q_j^c}{\partial E_i}\Big/\frac{\partial U_i}{\partial x_{ij}})+\frac{\partial X_i}{\partial E_i}+\sum_{k=1}^{n}(\frac{\partial X_k}{\partial Q_k^p}\cdot\frac{\partial Q_k^p}{\partial E_i})=0$$

Then we obtain one important condition:

$$\frac{\partial X_i}{\partial E_i}=-\left[\sum_{j=1}^{m}(\frac{\partial U_j}{\partial Q_j^c}\cdot\frac{\partial Q_j^c}{\partial E_i})\Big/\frac{\partial U}{\partial X_i}+\sum_{k=1}^{n}(\frac{\partial X_k}{\partial Q_k^p}\cdot\frac{\partial Q_k^p}{\partial E_i})\right] \tag{6}$$

This first summation in (6) represents the marginal damages that waste charges bring to consumers and the second summation in (6) represents the marginal damages to producers. So equation (6) shows that polluting firms should control their waste discharges to the extent at which the marginal product of these emissions equals the sum of the marginal damages they bring to consumers and producers. Also, the desired amount of waste charges should make marginal abatement cost equal to the marginal benefits from reduced pollution (summed over all individuals and all firms).

Consider the condition characterizing the equilibrium in a competitive market. If the firms have access to free environmental resources, that is, they do not need to pay for their polluting activities, they will engage in those activities till $\frac{\partial X}{\partial E} = 0$ (the marginal return of emissions is 0). Therefore, polluting sources will engage in socially excessive levels of polluting activities if they do not need to pay the external cost imposed on others.

The policy implication drawn from this result is that, in order to reach the desired status, a "price" needs to be imposed on the polluting sources. The price should be equal to the marginal social damage, that is, the expression in equation (6). By the price instrument, the external cost of the polluting activity will be internalised at the margin. The price can be in the form of "Pigouvian tax", a levy on the polluting sources equal to marginal social damage. The tax would be attached directly to the polluting activities. (Cropper & Oates, 1992, P680)

Weitzman's Theorem

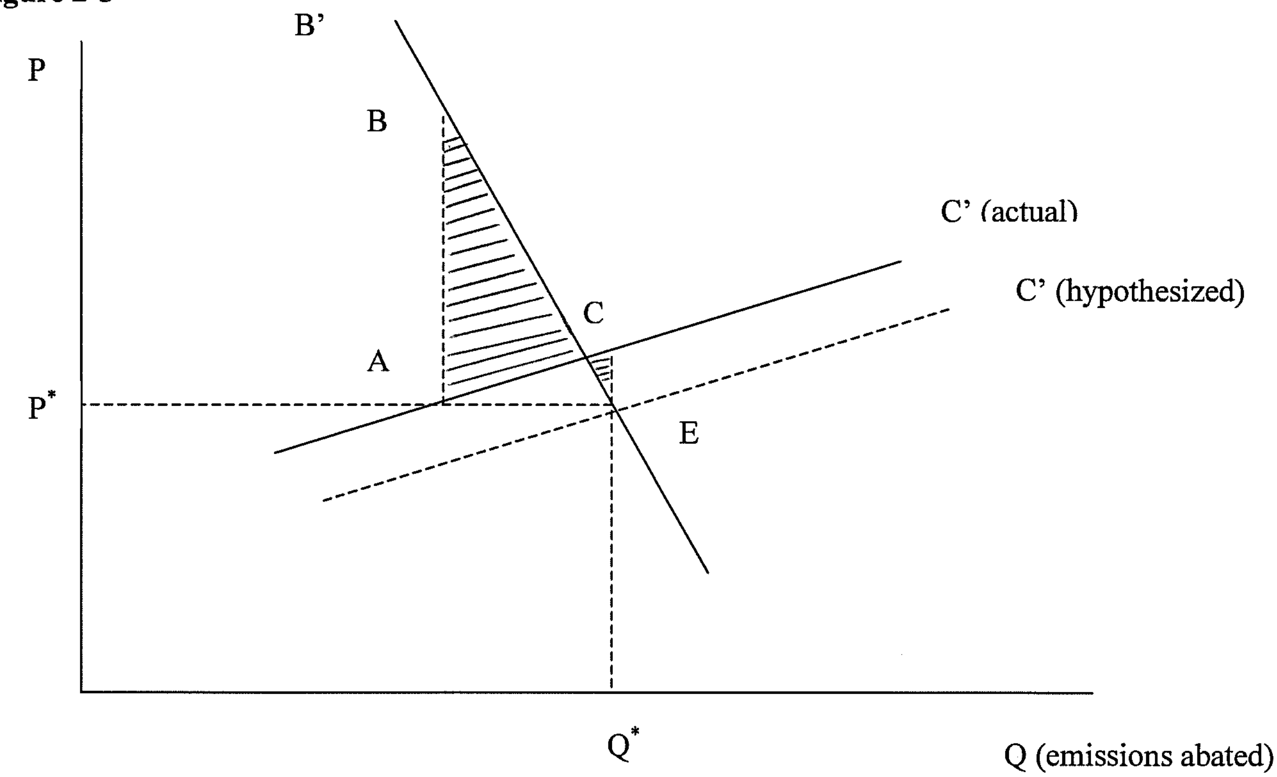
Weitzman, M. (1974) uses a model to study price and quantity instruments and produced a theorem that established the conditions under which the expected welfare gain under a price instrument exceeds, equals or is less than that under a quantity instrument. Among the pollution control policies, the tax system can be deemed as imposing a price on the polluting activity, so it is a price instrument; the permit system can be thought as a quantity instrument because usually it is associated with a fixed supply of permits, which is determined by the desired quantity of total pollution emissions before the implementation of the permits system. Thus, Weitzman's theorem has implications for the choice of pollution control policies.

The model of Weitzman assumes linearity of the marginal benefit and cost functions over the relevant range and also assumes that the error terms enter each function additively. Interestingly, uncertainty in the benefits function does not introduce any asymmetry between the price and quantity instruments. Weitzman finds that which instrument is preferred depends on the curvature of cost and benefit functions around the optimal output level; *when the sum of all other considerations leads to a zero bias toward any system, quantity is the preferred instrument if and only if benefits have more curvature than costs*. The results of Weitzman's study can be generalized as following:

1) *The quantity system is preferred when either the benefit function is more sharply curved or the cost function is closer to being linear.* When marginal costs are very flat and a price instrument is chosen, the smallest miscalculation or change will lead to either too much or too little pollution. So a price instrument could have detrimental consequences. In **Figure 2-3** (Adar & Griffin, 1976), triangle ABC is the welfare loss under the price instrument with the level of P^*, which is calculated with hypothesized marginal cost curve; triangle CDE is the welfare loss under the quantity instrument

with the level of Q^*, which is also obtained with hypothesized marginal cost curve. Apparently, the area of ABC is much bigger than that of CDE. If the benefit function is very sharply curved, by the same reason, a price instrument also could make the benefit reduced too much. Therefore, the permit system is preferred under such circumstances.

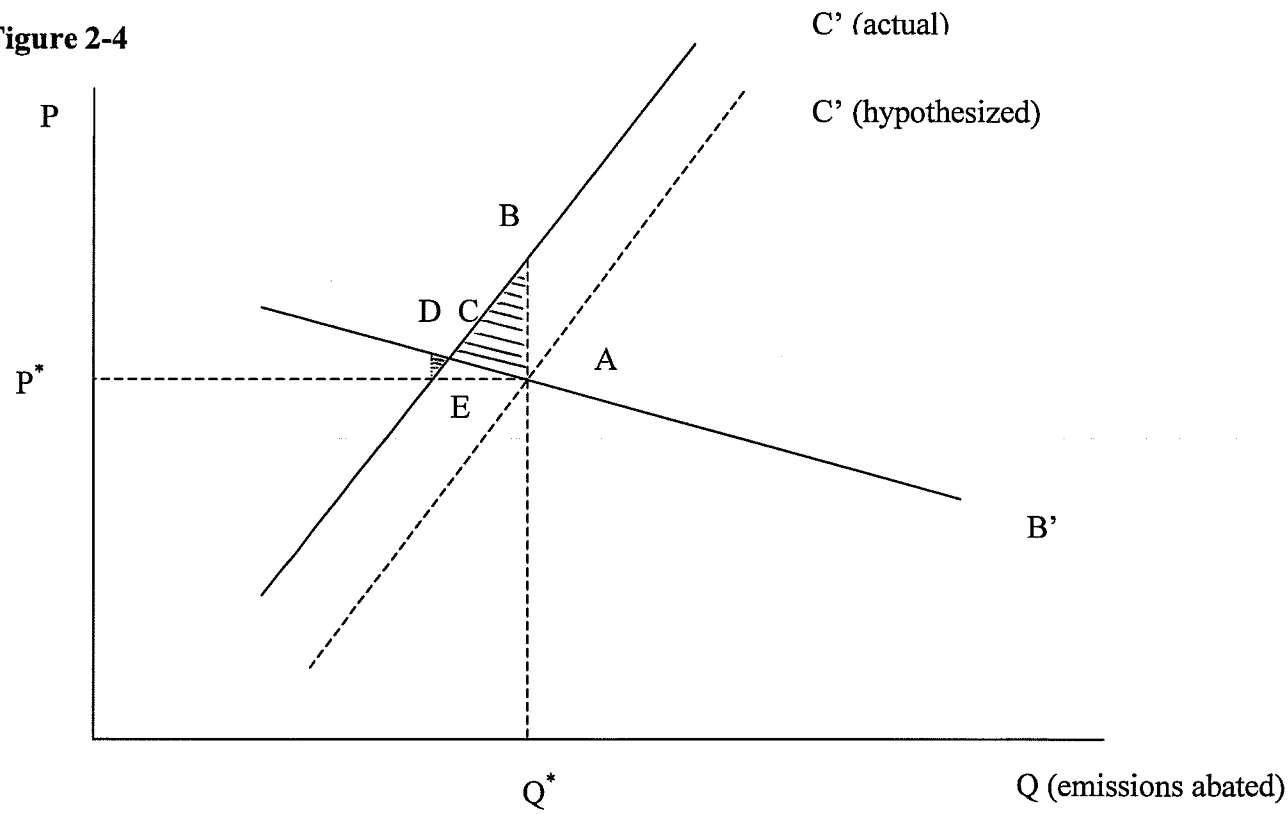
Figure 2-3



2) *The price system is preferred when the benefit function is closer to being linear.* Since the marginal benefit is approximately constant in some range, the price instrument can let the firms eliminate the uncertainty from cost and find the optimal output level themselves. If a quantity instrument is used, the total control cost could go very high

if the authority sets an overly stringent quantity. Under a price instrument, the polluting sources always have the option to pay for the unit tax even when they face high marginal abatement costs. In **Figure 2-4** (Fishelson, 1976), triangle ABC is the welfare loss under the quantity instrument with the level of Q^*, which is calculated with hypothesized marginal cost curve; triangle CDE is the welfare loss under the price instrument with the level of P^*, which is also obtained with hypothesized marginal cost curve. The area of ABC is much bigger than that of CDE.

Figure 2-4



3) *At the point the cost function is highly curved, or we move closer to the perfect certainty case, no one system is preferred to the other.* If marginal costs are very steeply rising around the optimum, "there is not much difference between controlling

by price or quantity instruments because the resulting output will be almost the same with either mode" (Weitzman, 1974, P485)

4) *When the curvatures of cost and benefit functions are imperfectly known, the quantity system is preferred.* Weitzman finds that quantities will absolutely dominate prices if the benefit function is highly curved ($B'' \to -\infty$), the cost function is closer to being linear ($C'' \to 0$) *or* both of the two situations. But the only circumstance in which prices absolutely dominate quantities is when the cost function is closer to being linear ($C'' \to 0$), the benefit function is closer to being linear ($B'' \to 0$) *and* the cost function has more curvature than the benefit function ($C'' > -B''$). Therefore, under such circumstances that the curvatures of cost and benefit functions are imperfectly known, prices have a much bigger probability to be a poor choice than quantities.

An even better outcome can be obtained by combining the price and quantity instruments. Roberts and Spence (1976) have shown that, the regulator can set the quantity of permits at the desired level where expected marginal benefit and marginal cost are equal, then give a subsidy for emission reductions beyond the allowed amounts by permits and a unit tax on the extra emissions. This will lead to a higher expected welfare gain than any instrument alone, because each instrument can protect the failing of the other: permits can be used to avoid extremely high levels of pollution; the unit tax is in case that actual control costs are much higher than anticipated; in addition, the subsidy provides the incentive to control more than the permits required, if the actual control cost is very low.

The economic rationale is the following. The regulatory authority uses permits to limit the quantity of pollution. But if control costs have been so significantly overestimated that the actual marginal abatement costs of sources are lower than the subsidy, sources will have the financial incentive to control more pollution until their marginal abatement costs equal the subsidy. On the other hand, if the actual control cost is so high that the marginal abatement costs are higher than the penalty, sources still can escape from the restriction of permits by paying penalties until their marginal abatement costs are lowered to the level of penalty.

2.3.2 Market Imperfection

We know that, no matter how the emission permits are allocated initially, a cost-effective allocation will be reached by the market mechanism. The final permit price will be reached by the market mechanism. The final permit price will be equal to the equalized marginal control costs for all polluting firms. These desirable properties depend on an important assumption: the permit market is perfectly competitive. If there is market power in the permits market, will the desirable properties of a tradable emission permits system still exist?

Hahn (1984) has studies this question by a static model in which all transactions of permits take place at a single equilibrium price. His finding was that, in the presence of market power, the initial allocation could have an effect on both the final allocation of permits and the permit price. This finding is in contrast to the case of a competitive permit market.

In Hahn's study, permits are allocated to emitters without charges rather than allocated by an auction. It is supposed that there is only one firm with market power. The firms who take the price of permits will choose the amount of permits they hold to minimize the sum of abatement costs and permit costs. The minimization for the price-taking firms occurs when the marginal abatement cost equals the equilibrium price.

The firm with market power has an influence on price, so it will pick a price that will minimize its costs of abatement and permits. Here the chosen price is not necessarily equal to its marginal abatement cost. It is shown that, for the firm with market power, the marginal abatement cost will equal the equilibrium price only when the amount of initial allocated permits exactly equals the amount the firm chooses to use in the clear permits market with market power. Then Hahn found that (Hahn, 1984, P756),

> "Suppose that there is one firm with market power. If it does not receive an amount of permits equal to the number that it holds in equilibrium[1], then the total expenditure on abatement will exceed the cost-minimizing solution".

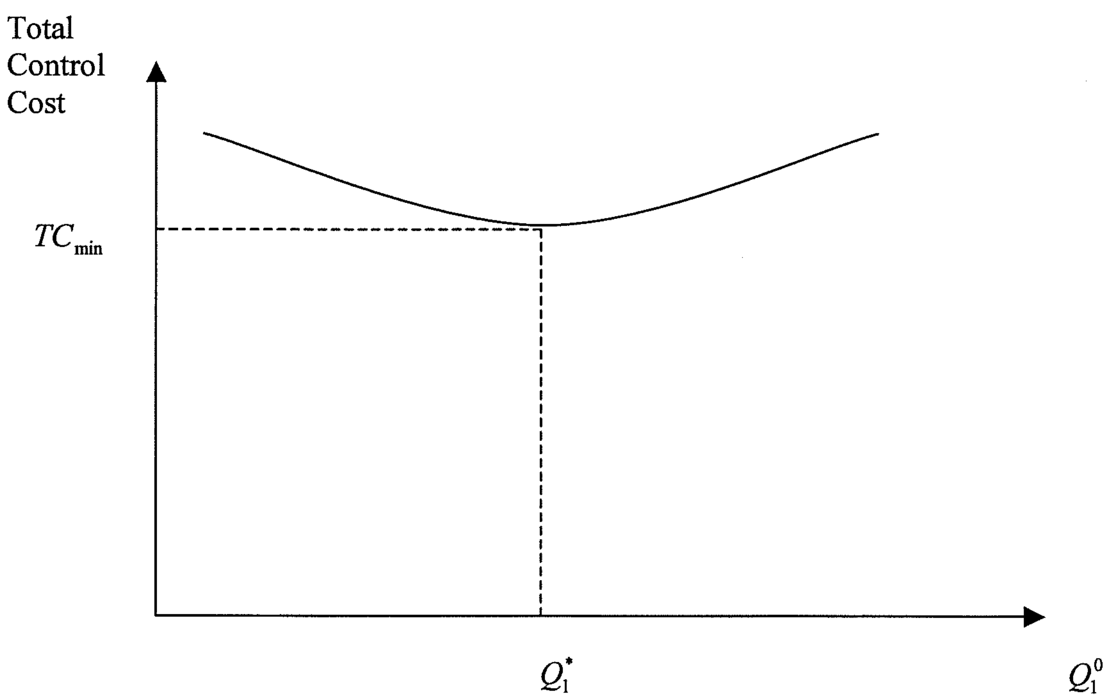
This finding means that, in the presence of market power, the distribution of permits has effects on the cost. The cost-minimization solution cannot be realized automatically unless the permits are appropriately allocated at the beginning. Hahn also found the

[1] The equilibrium Hahn refers here is the one in the permits market with market power.

equilibrium price of permits will increase with the increased amount of permits initially held by the firm with market power.

Hahn also explored the relationship between the distribution of permits to the firm with market power and the degree of ineffectiveness regarding cost-minimization. Here the ineffectiveness is measured by the extent to which the total abatement cost exceeds the minimum cost. Use Q_1^* to denote the amount of permits held by the firm with market power in equilibrium with market power, Q_1^0 to denote the amount of permits initially allocated. Hahn got his another finding that is illustrated with **Figure 2-5**: the ineffectiveness increases both as Q_1^0 increases above Q_1^* and as Q_1^0 decreases below Q_1^* (Hahn, 1984, P757).

Figure 2-5



It is not hard to understand why the initial allocation matters with the presence of market power. A single price-setting source has the incentive to trade when its initial allocation is higher or lower than its cost-effective allocation. When a price-setting source receives fewer permits than its cost-effective allocation, it will exercise power on the buyer's side of the permit market. If it receives more, it would exercise power on the seller's side of the permit market. The farther the initial allocation from the cost-effective allocation, the greater the potential for the price setter to exercise power on the permit market. (Tietenberg, 1992, P411)

2.3.3 Transaction Costs

To apply a transferable emissions permits system, it is necessary to know the information about operating permits and emissions inventories. The regulatory authority needs to monitor the actual emissions and to check if the actual emissions correspond to the permits firms hold. All the costs of these activities are transaction costs. If transaction costs in the trading market are too high relative to the differences of marginal control costs of firms, the cost savings could be diminished greatly. (Tietenberg, 1992, P411)

2.3.4 Spatial Limitation

The system of transferable emissions permits will achieve the least cost with a certain amount of emissions in theory. But this system cannot determine the ultimate distribution of emissions. For some pollutants, the outcome of trading can lead to high emissions amount in a subarea because the firm in this subarea buys a lot of permits. This could lead to damage to this subarea. So in reality, a concentration standard is imposed. Then the emission permits are traded with the limitation that the concentration standard should not be violated. So some potential trades that could lead to the violation of the concentration standard at some subarea would not be allowed, though these potential trades could bring cost savings. Another case is that the environmental quality in a subarea has been very poor and the concentration standard has been violated. The permits trade should not be allowed if the trade will bring more permits to the polluting sources in this subarea. Since the trading of permits is not totally free under such circumstances, such spatial restrictions could reduce the cost savings associated with the transferable emission permits system.

2.4 Product Market, Social Welfare And Permits Market

The previous theory regarding emission permits trading does not consider the product market. If the product market is considered, is there any effect that the permits trading will bring to the product market? If the effect of the permits market is negative, how will the total social welfare change under permits trading? Sartzetakis and McFetridge (1999) have studied the effects of permits trading on the product market and social welfare under different scenarios. Their results will be presented here.

2.4.1 Competitive Permits Market And Competitive Product Market

Sartzetakis and McFetridge (1999) first study the effects of inter-industry emissions permits trading. They find that, when both the permits market and the products markets of industries are competitive, the total abatement cost is minimized and the social welfare is maximized. The permits trading has no effect on the product market.

2.4.2 Competitive Permits Market And Product Market With Market Power

Monopoly Product Market

But when the permits market is competitive[2] and one of the industries is monopolistic, the output of the monopoly industry will be reduced under permits trading while the total abatement cost is minimized. This means that the permits trading aggravates the existing monopoly problem in the product market. Sartzetakis and McFetridge (1999) have given the explanation: before implementing the permits trading with an emission ceiling, there are two distortions --- the product market power and the environmental externality. The product market power makes the monopoly reduce its output, while the environmental externality lets the monopoly increase output. The two distortions offset each other. When only the environmental externality is removed, the product market power may make the result worse.

[2] This is also the inter-industry emissions permits trading.

Oligopoly Product Market

Still with competitive permits market, if the only industry involved is characterized by product market oligopoly[3], there will be a shift in market shares among the oligopolists firms. The direction of shift is from the firms that are more efficient in abatement to firms that are less efficient in abatement, because the firms that are less efficient in abatement can reduce their abatement costs per unit of output by purchasing emission permits.

The industry output may be increased, decreased or unchanged, so the overall effect of permits trading on social welfare is ambiguous. If industry output remains the same, social welfare will increase because the total abatement cost decreases. If industry output increases, there will be a further increase in welfare. If industry output decreases, the effect on welfare will be ambiguous.

2.4.3 Both Permits Market And Product Market With Market Power

Sartzetakis and McFetridge (1999) also study the behaviour of oligopolists both in product market and permits market[4]. Here, both the two markets are imperfectly competitive.

Collusive Behavior

[3] This means that the trading is intra-industry emissions permits trading.

Sartzetakis and McFetridge assume that the regulatory authority allocates a certain amount of permits[5] entirely to the oligopolists and leave no permits to potential entrants[6]. In their Cournot duopoly model, the oligopolists have the incentive to merge to achieve the monopoly output because this will lead to the higher industry profit. The resulting monopoly would be secure against entry since potential entrants have no emission permits.

But the discussion above does not consider the anti-trust legislation, which will challenge the agreement of product and permits between the oligopolists. In addition, a permit allocation method that leaves permits to potential entrants could solve the problem.

Non-cooperative Cost Manipulation

In this section, Sartzetakis and McFetridge examine the case in which one firm can influence the permits price in the permits market, while other firms are price takers; they also use the example of a Cournot duopoly in the product market. According to the analysis of Hahn (1984), when there is market power in the permits market, the leader who has the power will manipulate the permits price in order to maximize its profit; under such manipulation, the abatement cost minimization will not be achieved.

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[4] The product market oligopolists are also the only participants in the permits market.

[5] We suppose the quantity of permits corresponds to the environmental target.

[6] Potential entrants have to buy permits from existing source.

Since permits can be deemed to be an input in the production, the price of the permits has effects on the total abatement cost of a firm and its output. Thus the product market and the permits market are linked. By raising the permits price, the firm that has market power in the permits market can also raise the total abatement cost of its rival and take advantage in the product market. Sartzetakis and McFetridge find that when the leader in the permits market raises the permits price, both firms' marginal costs increase compared to the efficient allocation in the permits market. As a result, the industry output will decrease. However, the increase in the leader's market share is smaller, so that its market share in the product market will increase.

Sartzetakis (1997) also finds that when the leader is more efficient in production and the price-taker is more efficient in abatement, the industry profit will increase. The underlying reason is that: the market power in the permits market leads the price-taker to engage in more abatement activity and leads the leader to more product market share than when the permits market is competitive. When the leader is more efficient in the product market and less efficient in the permits market, the result is that the two firms will utilize their own advantages. Therefore, the industry profit will increase. On the contrary, when the leader is less efficient in production and the price-taker is less efficient in abatement, the industry profit will decrease.

Since the industry output decreases under such a situation, there is a loss in consumer surplus. When the industry profit decreases, or the increase in industry profit is not large enough to outweigh the loss in consumer surplus, the social welfare will decrease. When the increase in industry profit is large enough to outweigh the loss in consumer surplus, the social welfare will increase. Therefore, the change of welfare is ambiguous.

In the whole **Section 2.4**, we find that when there is market power in the permits market and/or the product market, the overall effect of emission trading on social welfare is ambiguous. That is, the introduction of emission trading does not necessarily lead to a welfare-maximizing outcome. But the potential limitation does not imply the superiority of a command and control system. The reason is that the command and control system is more efficient than permits trading only if the regulator has full knowledge of the respective abatement costs of all sources. Therefore, given the limited information, permits trading is generally superior to a command and control system (Sartzetakis & McFetridge, 1999, P63).

3 IMPLEMENTATION OF TRANSFERABLE EMISSIONS PERMITS SYSTEMS

3.1 Determination of Total

3.1.1 Total Amount of Permits

As we see in the previous section, transferable emission permits can achieve a given pollution standard at least cost. Usually, the total amount of permits is determined by the given pollution standard. For example, if the given pollution standard is 1,000,000 kg in a certain area in the year 2000 and one permit allows the emission of 1 kg a year, there will be 1,000,000 permits issued.

Once again, one thing we should note is that the given pollution standard may not be set at an appropriate level. For an appropriate pollution standard, the marginal cost of achieving the standard should be equal to the marginal benefit so that the net benefit can be maximized to achieve the efficiency criteria. But measuring control costs and benefits is not easy, especially measuring the benefits of improved environmental quality, which is not sold in markets. However, environmental economists have made some progress on this issue (Cropper and Oates, 1992, P700): they develop a series of methodologies to measure the nonmarketed good, which will be introduced next. Though the outcome of measurement cannot be precise, it is still helpful to judge if the pollution standard is suitable over some ranges.

3.1.2 Measurement of The Nonmarket Good

The techniques to measure the nonmarket good can be classified into two categories: indirect market methods and direct questioning approach. (Cropper and Oates, 1992, IV)

Indirect Market Methods

Indirect market methods want to get the value of nonmarket goods from people's actual choices, such as choosing where to live, the value people place on environmental goods. There are three indirect methods that rely on observed choices.

1) *The averting behaviour approach.* Since inputs can be used to compensate for the effects of pollution (for example, residents suffering smog pollution can take medicines to relieve itchy eyes), the value of a small change in pollution can be measured by the value of the inputs used to compensate for the change in pollution. For instance, if the number of days of respiratory symptoms can be reduced from 6 to 5, either by an expenditure on medication of $ 20, or by a reduction in one-hour maximum ozone levels from 0.16 parts per million (ppm) to 0.11 ppm, then the value of the ozone reduction is $ 20 (Cropper & Oates, 1992, P703).
2) *The weak complementarity approach.* This approach values changes in environmental quality by making use of the complementarity of environmental quality (e.g. cleaner water) with a purchase good (e.g. visits to a lake). In practice, this approach has been used most often to value recreation sites.

3) *Hedonic Market Methods.* This method uses the concept of hedonic prices---the notion that the price of a house or job can be decomposed into the prices of the attributes that make up the good (such as air quality in the case of house, risk of death in the case of job). It is used to value environmental quality, mortality risks, etc.

Direct Questioning Approaches

When there are no appropriate averting or mitigating behaviours existing, indirect methods cannot be used to estimate the morbidity benefits of reducing air pollution. In addition, there is a category of benefits called *nonuse* values, which refer to benefits from just knowing that a good exists (such as preserving an endangered species). Such benefits cannot be measured by indirect market methods. Direct questioning approaches can measure such benefits by asking people to make tradeoffs between environmental goods and other goods in the survey.

3.2 Method of Allocation

When the permits are allocated, some criterion for allocation is needed to act as the basis. How the permit is distributed initially is important because it affects the amount of costs facing polluting firms. Two commonly discussed allocation methods, auction and free allocation (also called "grandfathering") will be introduced in this section.

Another reason that initial allocation matters is that it may affect the structure of the permits market and the associated cost. If a competitive permits market is formed after initial allocation, a cost-effective allocation of the permit will be reached in the end (Montgomery proved this in 1972). If an initial allocation creates a non-competitive permits market, the final distribution of the permits is not necessarily a cost-effective one unless an initial distribution of permits for the price setter coincides with the cost-effective solution (This is the conclusion from the model of Hahn, 1984. For details, please see the Section 2.3., P15).

3.2.1 Auction

Auctioning lets the polluting firms compete to purchase the transferable emission permits in the auction market. First, the price information in the auction market is helpful to the planning of polluting firms for future trades in the permits trading markets. Second, this is fair to new emitters, because the existing emitters also have to buy the emission permit for the right to pollute (Fromm and Hansjurgens, 1996, P370). So auctioning is preferred by economists.

But the firm does not like the method of auctioning, because the firm has to pay for the right to pollute, besides to undertaking investments in emission reduction. This will lead to high costs for polluting firms, which do not exist before the working of a transferable emissions permits system. So auction is hard to be adopted politically. (Fromm and Hansjurgens, 1996, P371)

Tietenberg also pointed out in 1991 that the overall costs involved in the purchase of auctioned emissions permits could be higher than the cost saving from the adoption of the permit system. The financial burden of a polluting source is an auction permits market consists of control cost and expenditures on permits. The former represents real costs to society, while the latter are only resources transferred from one group to the other. The empirical evidence suggests that, when an auction market is used, the expenditures on permits are usually bigger than the control costs in magnitude (Tietenberg, 1991, P97). Though control costs from a source with a permits system are less than with a command-and-control system, the cost saving is still less than the additional financial burden associated with an auction-market permits system. Since they do not want to pay more, the sources would be against this kind of allocation method.

3.2.2 Free Allocation Based On Emissions

Free allocation seems necessary in order to get political support for a system of transferable emissions permits, because the polluting sources do not need to pay for the costs of permits that are associated with the method of auctioning. Even though permits are allocated freely, some basis of allocation still needs to be determined. One proposed method of initial allocation is to allocate permits according to past emissions of those polluting firms. This method considers the existing status of emission inventory when a system of permits is implemented. But there are several problems associated with this method. (Fromm and Hansjurgens, 1996, P372)

Disadvantage of "Clean" Firms

When the initial allocation is determined by the past emissions, the firm who has done greater effort to reduce pollution will receive less emissions permits than others who did not do so. One firm receives less emissions permits only because it is "cleaner" than others are. This is not fair to the firm who has done more effort to reduce its pollution emissions.

Disadvantage of New Firms

This method is unfair because it gives advantages to existing firms. When the program is implemented, existing firms can get the free emissions permits according to their historical emissions; but new firms have to pay to get necessary permits on the trading market. So new firms need to count the costs of permits into its total costs when planning to enter the existing market. In fact, the costs of necessary permits consist of a barrier of entry to potential entrants. In order to deter potential entrants outside the market, the incumbent firms can collude to use the price strategy ---to raise the price of permits--- to increase the height of the entry barrier. So new firms are at a disadvantage.

3.2.3 Free Allocation Based On Outputs

Another method of free allocation is to allocate according to past outputs of polluting firms. Assume there are two firms who have the same amount of past outputs, then they will receive the same amount of emissions permits. If one of them has made more effort to reduce its pollution more, this firm will get more extra permits after the necessary use of permits to cover its pollution emissions. Then it can gain more by selling extra permits in the trading market. So the "clean" firm will be rewarded by its previous efforts.

This principle has been applied in the Regional Clean Air Incentives Market (RECLAIM) in Southern California, United States. (Fromm and Hansjurgens, 1996, P372) In RECLAIM, each firm is divided into different sources of emissions. For each source, an annual output is determined according to the peak activity level over a certain period; then the output is multiplied by an emission factor, which is derived from legal standard and differentiates between fuel types. This factor provides a standard for each type of abatement technology and reflects the emission-reduction measures which should have been enforced by the existing command-and-control rules. The allowable emission is obtained for each source. A firm's total amount of allowable emissions is determined by adding up all the allowable emissions from all its sources. If the sum of all allocations exceeds the stipulated amount in the legal act, every source will get an identical percentage reduction, in order to meet the given target. This method of allocation admits the emissions reduction efforts taken by firms. The "dirty" firms are not favored over "clean" firms.

How are we to deal with the problem of new firms? New firms can also get free allocation on the basis of their outputs. We can establish such a mechanism that the permits which are valid for one year are allocated annually. New firms need to apply to get free emission permits before their operations, according to their estimated outputs. If the sum of allocations from existing and new firms exceeds the predetermined target, by the same principle as above, every firm will get an identical percentage reduction.

By this mechanism, 1) since the permits are allocated freely, the polluting sources need not pay the costs of permits. This retains the advantage of free allocation and is easy to get political support to implement. 2) News firms are considered in the allocation so they are treated fairly. This mechanism gets rid of the entry barrier brought by emission permits and leads to no obstacle for potential entrants. 3) The fact that the allocation is conducted annually is convenient for the regulatory authority to adjust the total amount of permits when necessary and is helpful for the authority to take new firms into account in time.

3.3 Regions of The Market

3.3.1 Geographic Domain of The Policy Target

Let us first look at the geographic domain of the policy target. It is natural to use the local airshed as the geographic domain of the policy target. (Tietenberg, 1980, P396) Though the boundaries of a local airshed cannot be very clear, it is still necessary to isolate it from other airsheds.

If the geographic domain of the policy target includes several local airsheds and there is no geographic constraint for the trade of permits, it is possible that lots of permits are used in one area so that the environment of that area is damaged badly. Actually, this danger exists even when the geographic domain of the policy target is one local airshed as long as the emission target is an aggregate one, but the danger is amplified when the geographic area of the predetermined target is expanded.

3.3.2 Geographic Region of The Permit Market

The geographic region refers to the area within which polluting firms are required to have emissions permits while those polluting firms outside the area are not required. (Tietenberg, 1980, P397) It should include all the areas within which polluting firms contribute pollutants to the area of the policy target.

The geographic region is different from the area of the policy target, because the polluting firms bringing pollutants to a local airshed may be located outside the area right under the airshed. Some pollutants can be transported rather long distances with wind, so a city may have environmental pollution though there is no polluting source in that city!

3.3.3 Natural Boundaries And Political Boundaries

The geographic region of the permit market may not correspond to the political boundaries in the real world. An ideal geographic region may cover several states in a country or even several countries. Under such circumstances, the coordinates among those regulatory authorities of the states or countries should be pursued at the most possible extent. Otherwise, chances of great cost saving from interregional permits trades cannot be realized.

3.4 Coverage of Emitters

Theoretically, all emitters of pollution should be included in a transferable emissions permits system. This is an equal treatment of all the emitters and a large number of participants make the trading market workable. (Fromm and Hansjurgens, 1996, P369)

In reality, some small sources of pollutants should be excluded from the permits system, because the control and monitoring costs may far outweigh the benefits of pollution reduction from the inclusion of these small emitters. (Tietenberg, 1974, P283) In addition, the costs will especially burden small units and make them lose economic competitiveness (Fromm and Hansjurgens, 1996, P370). For example, RECLAIM applies only to sources emitting at least 4 tons of NO_x and SO_x per year.

If the monitoring and enforcing costs of including small emitters far outweigh those benefits and these small emitters collectively are an important source of pollution in an area, other regulatory designs are needed to explore.

There are also other types of emitters which may be exempted from the permits system. Public institutions usually are not included because they lack control over the necessary expenditure on pollution control, such as universities, hospitals and prisons. They cannot control their cost as easily as private firms. (Fromm and Hansjurgens, 1996, P370) But in RECLAIM, such institutions can voluntarily participate in the program. Some polluting sources also cannot be included if their emissions cannot be quantified (for example, mobile sources, restaurants, dry cleaners); there is no basis to determine how many permits these sources need.

3.5 Duration of The Permit

An emissions permit can be designed to allow emitters to discharge a specified amount of pollution emissions for perpetuity or only for some finite time period. A limited term permit is preferred because it can offer more flexibility to the regulatory authority to control the total amount of pollution emissions with the change of circumstances. (Tietenberg, 1980, P409) In fact, the regulatory authority can also adjust the amount of perpetual permits by acting as a buyer or seller of permits when necessary. But as the amount of desired pollution usually decreases over time, this means that the regulatory authority will pay for the improvement in air quality through the tax system.

One disadvantage of the limited term permit should not be omitted. (Fromm and Hansjurgens, 1996, P375) If all polluting sources submit their expired certificates of emissions permits to the regulatory authority for validation at the same time, permits trading will possibly be concentrated during the period right before the expiration date. If there is a seller market, the price of permits will go high because buyers are eager to buy necessary permits to cover their actual emissions; in the case of buyer market, the price will be very low. So it is very unlikely to produce a reliable and calculable price of permits. Then the polluting sources tend to reserve a large amount of emissions permits in order to protect themselves against the unreliable market price. This will decrease the effectiveness of trading market.

One solution to the problem above is staggered expiration dates. (Fromm and Hansjurgens, 1996, P375) In RECLAIM, the polluting firms are divided into two cycles. Cycle-1 polluting sources get permits on January 1 and the comparison of the annual total emissions and the permits held by polluting sources takes place on December 31. Cycle-2 polluting sources get permits on July 1 and the comparison takes place on June 30 of the next year. Each cycle contains about 50% of the total permits. The expiration dates of the permits match those of the cycles. Each polluting source can buy cycle-1 and cycle-2 permits to cover emissions.

3.6 Coverage of Pollutants

Macintosh (1973, P66-68) suggests to include all the different types of pollutants into a single market by defining the aggregate emissions target in terms of equivalent emissions. This is desirable administratively. The weights of different pollutants can be determined on the basis of some historical contribution to pollution in the target area.

However, this method of fixed weights of pollutants in a single market is not suitable in the long run. Tietenberg (1980, P409) points out that, the costs to reduce different kinds of pollutants will change when time passes by. Then emitters will use permits for pollutants that are relatively more expensive to control. As a result, the air quality standard for less expensive pollutants will be easy to meet, while the standard for more expensive pollutants may be violated. The reason is that the regulatory authority loses the control over the amount of each pollutant.

To avoid this, the regulatory authority can reduce the total amount of permits until the air quality standards will be met for all pollutants. But this possibly will lead to a very expensive and excessive control for some pollutants. Therefore, a separate market for each pollutant is needed.

4 EMPIRICAL STUDIES OF TRANSFERABLE EMISSIONS PERMITS

4.1 Programs In Practice In The Early Stage

There are several programs in the early stage, which apply the idea of transferable emissions permits in the world. They are all implemented in the United States. (Cropper and Oates, 1992, P689) Though these programs in the early stage are not implemented with the mechanism proposed in the textbook, it is still helpful to see how they worked[7].

4.1.1 Wisconsin System of Transferable Discharge Permits (TDP)

In 1981, the Department of Natural Resources in Wisconsin, USA, established the rules in the Wisconsin Administrative Code that allow the transfer of discharge permits among dischargers on the Fox River (Novotny, 1986). These rules have been widely cited as establishing a TDP program/market[8]. The pollutant under this program is biological oxygen demand (BOD[9]). Though there were only about 20 sources, a preliminary study (O'Neil et al. 1983) did indicate large cost savings, about US$7 million per year, from

[7] One of the early programs is the *Emission Trading Program* in the United States, which has developed into the current *SO_2 Program* in 1990s. Because the current SO_2 Program is much closer to what is introduced in the economics textbooks than any other program of emission permits, the early Emission Trading Program and the SO_2 Program will be introduced separately in Section 4.3..

[8] For example, Cropper and Oates (1992, P690); Hahn (1989).

[9] A measure of the demand for dissolved oxygen imposed on a water body by organic effluents (Hahn, 1989, P97).

several potential trades. But according to G. Novotny[10] (personal communication, January 2, 2001), no trading has occurred under those rules until today[11].

Novotny (1986) points out several factors that contribute to the lack of trading. *First, the sources do not have enough incentives to participate in permits trading* (Novotny, 1986, P8-9). The study of O'Neil assumes that new treatment facilities need to be constructed, which constitute a big cost. In contrast, however, treatment plants built in the late 1970's were still in operation in 1980's. One reason probably is that, some plants were designed to meet stricter limits than O'Neil's study assumes, because the "Interim Final" limits set by EPA were stricter than the "Final" limits. The other reason is that the design of treatment plants offered some room to the treatment capacity in case of uncertainty in application, which is a custom in the field of engineering. So, no new treatment facilities were needed. Another reason is the emergence of more efficient equipment that substantially reduces waste; the uncertainty in the abatement technology is an important factor that contributes to the disparity between expectation and reality. In addition, the cost of wastewater treatment only accounts for less than 1% of the product cost, so the paper mills are not enthusiastic about permits trading.

[10] Department of Natural Resources, Wisconsin, USA.

[11] Several papers report that there was one trade in 1980s: a paper mill transferred its rights to a municipal wastewater treatment plant because it shifted its treatment activities to the municipal facility (Cropper and Oates, 1992, P690). But G. Novotny (personal communication, January 8, 2001) does not think this is a trade, because it is not based on the incentive to utilize permits market to reduce abatement costs and "could have occurred without the rules adopted for trading".

Second, there are several rules in the Wisconsin Administrative Code that restrict potential trades and discourage permits transfers. One restriction is that transfers must last for at least 1 year, which eliminates the trade on a short-term basis. There are also restrictions on the eligibility for trades. "Transfers are only allowed for new dischargers, increased production, or treatment plants that cannot meet the required effluent limits despite optimum operation and maintenance" (Novotny, 1986, P8). Trades that only reduce operating expenses are not allowed, which is not reasonable from the perspective of an economist. The most serious problem deemed by Novotny (1986) is the provision that parties to the trade must waive all rights to the transferred permits beyond the permit term. Nobody knows the result of the trading regarding the permits, for the property right is not well defined.

Third, there are huge transaction costs in the permit markets. Any transaction between sources requires modifying or reissuing permits, which is a about 6-month process; this takes time. Each discharger who intends to trade must identify potential trading partner and evaluate the discharge location and river conditions by itself. The situation of effluent trading is complicate because the impact of a discharge on a critical point depends on location, temperature and flow conditions. Therefore, the cost of collecting data is high for a discharger. If transaction costs are too high, the source will not seek the opportunity in the permits market.

Fourth, the size of market is limited by the concentration standard on the Fox River. Any trade should not violate the concentration standard at the critical points[12]. Therefore, the market size is effectively limited to the dischargers affecting a critical point. Naturally, the chance of trades is small. With all the factors above, it is not surprising that the result of this program, which is not carefully designed and not guided by the objective of minimizing abatement cost, is disappointing. Though several things can be done to improve the trading of BOD permits, it seems that Wisconsin has ended the effort on this path (M. A. Lowndes[13], personal communication, January 9, 2001).

4.1.2 Lead Trading Program

Lead Trading Program began in 1982 and ended in 1987 (Hahn, 1989, P102). This program was scheduled to have a fixed life from the beginning. Its purpose was to allow gasoline refiners greater flexibility during a period when the amount of lead in gasoline was being significantly reduced. The permits allowed refiners to trade severely limited rights to lead additives to gasoline. The trading market was active: for example, in 1987, about 50 percent of all lead added to gasoline was obtained through trades of lead rights. Though reliable estimated cost savings are not available, Hahn and Hester (1989) estimated the cost savings could be hundreds of millions of dollars. They pointed out, the success is due to the absence of large transaction costs: refiners were essentially free to trade lead rights and only needed a quarterly report to EPA on their gasoline production

[12] If the water quality standard is met at the critical point, it will be met at all other points (Novotny, 1986, P6).

[13] Department of Natural Resources, Wisconsin, USA.

and lead usage. Moreover, there were well-established markets in refinery products so that refinery managers had plenty of experience in these kinds of transactions.

4.2 Programs To Control Air Pollution In The USA

4.2.1 Emission Trading Program

Emission trading program is the largest one in terms of scope and impact among those programs in the early stage. Pollutants covered under this program include volatile organic compounds (VOC), carbon monoxide (CO), sulfur dioxide (SO_2), particulates, and nitrogen oxides (NO_x) (Hahn & Hester, 1986). There are several major components under this program (Hahn, 1989). "Bubble" provision[14] is considered by EPA to be the centerpiece of emission trading (Hahn, 1989, P99). It dictates an overall emissions limitation to a plant with many sources of emissions of a particular air pollutant. Within the limit, the plant can choose the best control methods and the best distribution of emissions among the sources, rather than comply with specific treatment procedure for each source. "Netting" provision[15], allows new sources to use the amount of reduced emissions from other sources of the pollutant within the same firm. Hahn and Hester (1989) reported that there had been over 100 approved Bubble transactions and at least 5,000 Netting transactions (it is estimated between 5,000 to 12,000). According to Hahn (1989), the cost savings from Bubble transactions are estimated to be US$ 435 million; the estimates of cost savings from Netting transactions exhibit a wide range from US$

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[14] "Bubble" provision is introduced in 1979.

525 million to over US$ 12 billion because of the uncertainty of the number of transactions.

"Offset" provision applies in nonattainment area where the environmental standard is not achieved. It allows new sources to "offset " their new emissions with the reduction of emissions from existing sources. Netting transactions are internal (within plant) trades, while Bubble and Offset transactions can be internal or external trades (Hahn, 1989). Hahn and Hester (1989) indicate that there have been about 2,000 Offset transactions, 90% of which have been internal trades.

On one side, Emission Trading Program brought substantial cost savings. On the other side, there have been further chances of cost savings unrealized since the majority of the trades are internal ones. The main reason seems to be an extensive and complicated set of procedures for external trades that have brought substantial transaction costs. Besides this, this program is grafted onto the previous command-and-control regulations. Many potentially trades have not come because they are prohibited under the command-and-control regulation. (Cropper and Oates, 1992, P690) However, since the Emission Trading Program showed a demonstrable effect on cost savings, the instrument of Transferable Emission Permits is expected to receive more widespread use.

[15] "Netting" provision is introduced in 1974.

4.2.2 Current SO_2 Program

Based on the previous experience from Emission Trading program, Title IV of the 1990 US Clean Air Act Amendments initiates a system of transferable emissions permits that regulates emissions of SO_2 from electric utility facilities. This program is much closer to what is introduced in the economics textbook compared with other programs in early stage. So it offers a good chance to test the idea of transferable emissions permits in reality and deserves more attention.

Overview of The SO2 Program

The annual cap on average aggregate emissions by electric utilities is set in the Title IV of the 1990 US Clean Air Act Amendments: about one half of the amount emitted in 1980. This cap guarantees that emissions will not increase with economic growth. (Burtraw, 1998, P1)

The market area for the permits program of SO2 is the whole nation, so there are a large number of participants in the market. In this permits program, permits are allocated to individual facilities in proportion to fuel consumption multiplied by an emission factor during the 1985-1987 period. About 2.8 percent of the annual permits are auctioned by the Chicago Board of Trade. The revenues from auction are returned to the utilities that were the original owners of permits. One permit allows emissions of one ton of sulfur dioxide (SO2). Besides trading, firms can bank the permits for use in the future. The firms can meet the regulation by whatever means they want. There are no major limitations on trading.

This program is divided into two phases (Carlson at al., 1998, P2-4). During the first phase (1995-2000), each of the 110 dirtiest power plants (with 263 generating units) is to reduce its emissions to an annual tonnage equivalent to 2.5 pounds SO_2 per mmBtu of heat input. During the second phase (beginning in 2000), all fossil fueled power plants larger than 25 megawatts are required to reduce their emissions to an average of 1.2 pounds of SO_2 per mmBtu.

Estimated Cost Savings

There is a series of empirical studies on the estimate of annual cost under the permits program of SO_2 in 2010 when the program is fully implemented. Because the estimate of annual cost will vary with the change of input prices and the technology, only the most recent empirical study which captures the input price and technological changes can give us a relatively more accurate estimate.

In 1998, Carlson et al. built a simulation model based on marginal abatement cost functions derived from an econometrically estimated long-run total cost function for electricity generation. The sample includes over 800 generating units over the period of 1985-1994. The model considers firms' behavioral responses to changes in relative input prices. These behavioral responses refer to the change of proportions of inputs to reduce the sum of two costs: cost of generating electricity and cost of complying with emission reduction requirements. This model can also measure the role of technological change in reducing the abatement cost over time. The advantage of this model is that it can consider the effects of changes in input prices and in technology in calculating the cost savings from trading. So it can more accurately forecast future compliance costs and gains from trade, taking into account future behavioral responses to both changes in relative inputs prices and changes in technology.

Carlson et al. want to estimate a marginal abatement cost function that describes the cost of meeting the actual emission rate, so they express costs as a function of e, the actual emission rate. The cost function to be estimated is

$$C = C(p_k, p_l, p_{ls}, p_{hs}, q, e, t),$$

p, price; k, generating capital; l, labour; ls, low-sulfur coal; hs, high-sulfur coal; q, output; e, actual emission rate; t, time.

The econometric model includes following equations (Carlson et al., 1998, P9):

$$\ln c = \alpha_0 + \sum \lambda_m d_m + \alpha_t t + \sum \alpha_j \ln p_j + \alpha_q \ln q + \alpha_e \ln e$$

$$+ \frac{1}{2} \sum \sum \alpha_{jk} \ln p_j \ln p_k + \sum \alpha_{jq} \ln p_j \ln q + \sum \alpha_{jt} (\ln p_j) t$$

$$+ \sum \alpha_{je} \ln p_j \ln e + \frac{1}{2} \gamma_{qq} (\ln q)^2 + \frac{1}{2} \phi_{ee} (\ln e)^2 + \frac{1}{2} \delta_{tt} t^2$$

$$+ \gamma_{tq} t(\ln q) + \phi_{te} t(\ln e) + \beta_{qe} \ln q \ln e + \varepsilon_c, \qquad (7)$$

$$s_l = \alpha_l + \alpha_{ll} \ln p_l + \alpha_{lfhs} p_{hs} + \alpha_{lfls} p_{ls}$$

$$+\alpha_{lk}p_k+\alpha_{lq}\ln q+\alpha_{lt}t+\alpha_{le}e+\varepsilon_l, \qquad (8)$$

$$s_k=\alpha_k+\alpha_{kk}\ln p_k+\alpha_{lk}p_l+\alpha_{fhsk}p_{hs}$$

$$+\alpha_{flsk}p_{ls}+\alpha_{kq}\ln q+\alpha_{kt}t+\alpha_{ke}e+\varepsilon_k, \qquad (9)$$

$$\ln e=\alpha_e+\alpha_{e^*}\ln e^*+\sum\beta_i m_i+\sum\gamma_i m_i(\ln e^*)$$

$$+\delta_i v+\delta_t t+\sum\lambda_i\ln p_i+\delta_t t+\varepsilon_e.$$

(10)

Equation (7) is the cost function in a translog form, with added dummy variables for each plant to measure fixed effects that vary among plants. Fuel type (high-sulfur and low-sulfur coal), labour and generating capital are treated as fully variable inputs in the cost function. A quadratic function of time is used to capture technical change. Equations (8) & (9) are input share equations that specify the share of total costs attributed to capital and labour. Equation (10) is to predict the firm's mean annual emission rate as a function of the emission standard and other exogenous variables. e^* represents the emission standard, typically stated as an emission rate averaged over a specified time interval. For p_i, $i=l,k,ls,hs$. Linear time trends enter these three equations. Dummy variables are included to indicate the type of emission standard the plant faces (m_i) and the time period over which emissions are averaged (v).

The marginal abatement cost functions are obtained by calculating $\frac{\partial c}{\partial e}$ and converting the emission rate into the amounts of SO_2 emissions.

After estimating marginal abatement cost functions, Carlson et al. compute the least cost solution to achieve the cap on SO_2 emissions. The difference between the least cost solution and the cost under the command and control policy (here the command and control approach is uniform emission rate standard) represents the potential cost savings from permits trading. In order to calculate the lest cost solution, Carlson et al. adjust the allocation of the total SO_2 emissions among the sources to the point where their marginal abatement costs are equal to each other. The adjusting of emissions is based on an assumption that a source can change its emissions for a given output. This is true for firms who switch their input from high-sulfur coal to low-sulfur coal, while not true for firms who use scrubbers. Scrubbers will make the emission meet the criteria for any input and the emissions from firms using scrubbers cannot change for a given output.

Table 4-1 presents several estimates using this model, with different assumptions of fuel prices and technological changes. The columns in the table represent, after 2010 when the permits program is fully implemented, the annual cost of a command-and-control policy, the annual cost of efficient trading, its associated marginal abatement cost and the potential gains from trades.

The first row in the table above indicates costs for a benchmark scenario with the following assumptions: relative fuel prices remain stable at 1989 levels; technology including the utilization rate of scrubbers is at 1989 levels; the method for measuring emissions is the historic one based on sampling of coals and engineering formula and so on. The second row presents the estimated costs with fuel prices at 1995 levels and technology also at 1995 levels.

Table 4-1 Cost savings with different prices and technologies

Scenario	Command and control (annual cost)	Efficient trading (annual cost)	MAC	Potential gains from trade
1989 price 1989 technology	2,670	1,900	560	770
1995 price 1995 technology	2,230	1,510	436	720
1995 price 2010 technology	1,820	1,040	291	780
unit	Million 1995 US$	Million 1995 US$	1995 US$	Million 1995 US$

From: Burtraw, 1998, P5

The last row presents the Carlson et al. (1998) preferred estimates. Compared to the benchmark, this scenario adopts 1995 prices and 2010 technology. Other assumptions include: utilization rates and performance of in-place scrubbers continue to improve; retirement rate of coal-fired facilities is slower; half of retired facilities are replaced by gas; continuous emissions monitoring systems replace the historic measure of emissions. Burtraw (1998, P6) points out that these studies all do not consider the influence of other regulations, such as those on NO_x emissions, particulate or global warming gas.

According to the figures above, we can estimate that the cost savings from efficient application of permits trading are about 780 million US$ annually, about 42% of the costs under command and control (uniform emission rate standard).

If compared with a command and control policy represented by technology standard, the cost saving from permits trading will be greater. The technology standard offers individual firms less flexibility to achieve the emission standard; the firm under a technology standard cannot take advantage of the low price of low-sulfur coal. For instance, the 1978 Clean Air Act regulation of sulfur emissions dictates scrubbing as the only technological choice and the use of low-sulfur coal cannot avoid the strict technological standard (Burtraw, 1998, P6) Therefore, the technological standard will cost substantially more.

In summary, permits trading is expected to result in a substantial cost saving relative to a command and control approach when the program is fully implemented by the year 2010.

Performance of The Program

How is the performance of the permits trading program to date? Did it reach the desired result?

First, we can check if the actual annual cost approximates the estimated annual cost under efficient trading. Second, we can look at if the marginal control costs among firms are the same in the current period (Burtraw, 1998, P8). According to the theory, the approximate equality of marginal control costs will indicate an efficient market.

Carlson et al. (1998) study the control costs in 1995. Their results are reported in **Table 4-2**. In theory, the cost of efficient trading is estimated to be 552 million US$, with a marginal cost for fuel switching activities of 101 US$. Compared with the cost of 802 million US$ under a command and control emission rate standard, this represents a saving of 30 percent. By using observed emissions at individual polluting sources, they estimate the actual cost is 832 million US$ in 1995. Ellerman et al. (1997) also estimate the actual cost of 1995, which is 726 million US$.

Table 4-2

Estimated Compliance Cost in 1995

Study	Annual cost	Marginal cost per ton SO2	Average cost per ton SO2
Carlson et al. (1998) Efficient trading	552	101	194
Carlson et al. (1998) Actual emissions	832	180 (weighted marginal cost)	291
Ellerman et al. (1997)	726	153 (average cost)	210
unit	Million 1995 US$	1995 US$	1995 US$

From Burtraw, 1998, P8

Carlson et al. calculate the marginal cost of each polluting source, weigh them by their portions of total generation and sum to get an estimated marginal cost for the industry of 180 US$. Ellerman et al. do not report the marginal cost, but they find an average cost from fuel switching activities of 153 US$[16]. But both of the two studies do not report the

[16] This number is only the average cost of sources that use the method of fuel switching to comply with regulations. There are also other firms that install scrubbers, whose emissions will meet the regulations for

distribution of the marginal abatement costs among those polluters. Thus we do not know to what extent the marginal abatement costs are equal to each other.

The results of Carlson et al. and Ellerman et al. are approximate by equal to each other. We can see that there is a big difference between the actual cost and the ideal cost under efficient trading. The observed price of permits in the market in 1995 is around 90 US$, but the estimated actual marginal control cost is in the range from 150 to 180 US$. This evidence indicates that there were potential gains unrealized in the first year of the program. The program was not mature and did not reach the desired result in 1995.

Burtraw (1998, P7-8) also evaluates the performance of the permits market from the third dimension. This is an intertemporal one --- to compare the market price of permits and the discounted present value of marginal abatement cost in the future. If the trading market works well in this dimension, they should be equal to each other.

In **Section 2**, we know that the transferable emissions permits system is cost-effective and that the marginal control costs of different firms will be equalized when the market reaches its equilibrium. The price of permits at equilibrium is exactly equal to the value of equalized marginal control cost at equilibrium. As long as there is a difference between the marginal control costs of two firms, the firm with higher marginal control cost will have an incentive to buy permits with price below its marginal control cost and

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any kind of fuel. When including the sources using scrubbers, Carlson et al. (1998) get the average cost per ton SO_2 of 210, as shown in the last column of **Table 4-2**.

the firm with lower one intends to sell permits with price higher than its marginal control cost. Trading will occur until the marginal control costs are equalized and the price of permits is stable with the value equal to the equalized marginal control costs.

With the provision of banking, by a similar reasoning, the relationship between the prices of permits at different times is also the case: the price of permits at any given year is equal to the discounted present value of marginal abatement cost in the future. If the price at present is less than the discounted present value of its marginal control cost in the future, the firm can buy permits now and bank them to use in the future, saving its cost. Otherwise, the firm can sell permits now and control the pollution emissions in the future by itself. Trading will occur until the discounted present values of marginal control costs in the future are equalized to the level of the price of permits at present.

From **Table 4-1** we get that the long-run marginal cost, also the price of permits, in 2010 is 291 US$. Burtraw uses a discount rate of 8% reflecting the opportunity cost of capital for firms in the industry. The discounted value in 1997 is about 95 US$. The prices in the trading market in 1997 lied in the range of 100 US$ to 110 US$. This indicates that the market and the banking provision worked to an important degree from the intertemporal dimension. Part of the difference can be explained by the omission of other regulatory actions on NO_x and CO_2 in the model.

Analysis And Further Expectation

In 1995, there are different patterns of compliance behavior in the industry. Some firms utilized the flexibility of emissions control offered by the permit program. But some others just took advantage of the new program within the firm, and did not trade permits with other firms in the industry. (Bohi and Burtraw, 1997) The majority of trades that are recorded have been transfers within firms for accounting convenience or other reasons. (Burtraw, 1998, P9)

This difference between expectation and actual performance in the beginning can be due to some of the reasons following (Burtraw, 1998, P9). It would take some time for an industry that has been subject to cost recovery rules in a regulated setting to adjust to a new economic-incentive-based system of regulation. Some firms seemed risk averse to the use of permits; they want to make sure to comply with the regulation with their own effort.

The performance of the market at the beginning cannot indicate well the performance in the long run. We should note that the trading activity is increasing. The number of trades between independent firms has doubled each year through 1997 (Burtraw, 1998, P9). Since the weighted average cost in 1995 is much higher than the permit price, we can expect that more and more firms should turn to the permit market to utilize this new instrument in the future. In addition, the competition in the electricity industry has just begun; the pressure of competition will force the firm to reduce costs by utilizing the chance in the permits market.

4.3 Empirical Studies Regarding Cost Savings

4.3.1 Empirical Studies Regarding Cost Savings of Various Pollutants

We know that in theory transferable emissions permits can reach a given environmental standard with the least cost while traditional command and control cannot be the cost-effective method. Before we reform regulation into the method of transferable emissions permits, we had better know how much space for cost savings there is to transform from command-and-control to transferable emissions permits. If the cost under command and control approximates the least cost, there is no need to reform. To answer this, empirical study is needed. We hope we can draw some generalizations from various empirical studies.

Tietenberg (1992, P403) presents some empirical studies of air pollution control that compare the cost under traditional command-and-control and the least cost (**Table 4-3**). Here the least cost refers to the total control cost when it is cost-effective, that is, when all the polluting sources face the same equalized marginal abatement cost. The nine comparisons cover different pollutants and different areas.

Atkinson and Lewis (1974) classify the major sources according to different types and consider the applicability of control measures to each source. The control measures include devices and input changes. The total annual cost of each device includes annualized capital and installation cost as well as operating and maintenance costs.

Annualized capital and installation costs are principally a function of the source's size, interest rate and the life of the device. Operating and maintenance costs are based on the quantity of power, labor, the availability, costs and ash contents of fuel, and the cost for disposal of the collected pollutant. The reduction in pollutant-collection efficiency of control devices over time has also been considered.

Hahn and Noll (1982) derive the estimated cost functions by a combination of engineering cost estimate (based on history data and regulations) and survey. The information initially obtained was the cost of using a particular method to achieve a specific emissions rate for a particular source at some historical date. Then the information was combined to produce an abatement cost function for representative facilities based on 1977 regulations. The results were submitted to the relevant firms for comments. They find that the total annual abatement cost varies both as a function of the "cleaner" fuel (natural gas) supply and the air quality target. In their analysis, production and energy use at sources were assumed to be independent of emissions control.

Krupnick (1983) and Seskin et al. (1983) use the same approach and computer software. They use discrete abatement cost functions of different technologies for different types of emissions sources. Though they do no give the details of the abatement cost functions, we know from the papers that the abatement cost is a function of controlled emissions and control technology.

Maloney and Yandle (1984) use a function of $C = \gamma_0 P^{\gamma_1} F^{\gamma_2} R^{\gamma_3} \beta^{\gamma_4}$ to express the abatement cost for each source. P is the initial pollution level; F is air flow; R is peak emission rate measured as opposed to the base P (if the peak emission rate is the same as the average, R is equivalent to P); β is the percentage reduction for the source. [17]

We can find that in most cases, the cost under command-and-control approach is much higher than the least cost. In the Chicago study, the CAC costs are 14 times the least cost; in the Lower Delaware Valley study of particulate, the CAC costs are 22 times the least cost. Except in one case, the CAC approach costs at least 78% more than the least-cost allocation.

The exception is the study of Los Angeles, which shows the CAC was close to a cost-effective approach. Tietenberg (1992, P404) concludes the reason is as follows:

> "In effect, virtually every source is forced to control as much as is economically feasible. Because the menu of options in essence consists of a single feasible allocation, all policies must ultimately arrive at this allocation. "

Is the divergence between CAC approach and the least-cost allocation related to the stringency of the environmental standard? The study of Atkinson and Lewis (1974) finds that it is so. In the most stringent range of control, the relative divergence between the CAC and least-cost allocations declines when the objective standard becomes tougher to

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[17] Only part of the cost functions in these studies is presented here because of limited information.

Table 4-3 **Empirical Studies of Air Pollution Control**

Study	Pollutants	Geographic area	CAC benchmark	Ratio of CAC cost to least cost
Atkinson and Lewis (1974)	Particulates	St. Louis Metropolitan Area	SIP regulations	6.00
Roach et al. (1981)	Sulfur dioxide	Four Corners in Utah, Colorado, Arizona and New Mexico	SIP regulations	4.25
Hahn and Noll (1982)	Sulfates	Los Angeles	California emission standards	1.07
Krupnick (1983)	Nitrogen dioxide	Baltimore	Proposed RACT regulations	5.96
Seskin, Anderson and Reid (1983)	Nitrogen dioxide	Chicago	Proposed RACT regulations	14.40
McGartland (1984)	Particulates	Baltimore	SIP regulations	4.18
Spofford (1984)	Sulfur dioxide	Lower Delaware Valley	Uniform percentage reduction	1.78
	Particulates	Lower Delaware Valley	Uniform percentage reduction	22.00
Maloney and Yandle (1984)	Hydrocarbons	All domestic DuPont plants	Uniform percentage reduction	4.15

Note:
SIP = State implementation plan
RACT = reasonably available control technologies, a set of standards imposed on existing sources in nonttainment areas
Least cost = the cost-effective total control cost when all polluting sources face the same equalized marginal abatement cost.

From: Tietenberg, 1992, P403

meet. This is confirmed for hydrocarbon control by Maloney and Yandle (1984). The CAC policy will approximate the least-cost allocation only when the degree of control is sufficiently high, because at this time any flexibility is effectively eliminated. For instance, in the study of Los Angeles above by Hahn and Noll, the degree of control is very high, because the sulfate is a big problem there; the result of CAC is close to cost-effective. This can be understood this way: the great cost savings brought by a system of tradable emission permits come from the great difference of marginal abatement costs. As the environment goal is tightened, that is, the degree of control is high, the marginal abatement costs of all sources are less disparate. The cost savings by a permit system then decrease. In other words, the CAC policy under such degree of control is close to a cost-effective policy.

4.3.2 Recent Empirical Studies Regarding Cost Savings In The SO_2 Program

Burtraw (1998) also summarizes a series of recent empirical studies regarding the cost savings in the SO_2 program in the USA, which are presented in **Table 4-4**. This table presents the cost savings from the permits trading system as a percentage of the CAC benchmark. There are also two studies of SO_2 control in **Table 4-3**: in one case, a least-cost market-based approach can bring savings up to 76% relative to State Implementation Plan regulations (the ration of CAC cost to least cost is 4.25); in the other case, a least-cost market-based approach can bring savings of 45% relative to a standard of uniform percentage reduction (the ration of CAC cost to least cost is 1.78).

Table 4-4

Empirical Studies Regarding Cost Savings in the SO2 Program

Study	Ratio of the Cost Savings to CAC cost	
	CAC Benchmark	
	Installation of Scrubbers $7.9 - 11.5 billion[18] per year	Average Emission Rate for Each Utility Company $3.4 - 7.5 billion per year
ICF (1990) [EPA]	30%-85%	0%-75%
Van Horn Consulting et al. (1993) [EPRI]	60%-80%	3%-68%
GAO (1994)	60%-80%	3%-70%
White et al. (1995) [EPRI]	64%-88%	15%-82%
ICF (1995)	70%-80%	32%-70%
Burtraw et al. (1997)	89%-92%	74%-88%
Carlson et al. (1998)	87%-91%	71%-87%

Source: Burtraw, 1998, P2-3

From all these studies of SO_2, we can find:

(1) The percentage of savings relative to technology standards (installation of scrubbers) is higher than that relative to emission standards (average emission rate for each utility company). The reason is that emission standards usually offer more flexibility to sources than technology standards so that the total control cost is less under emission standards than under technology standards.

(2) The 2nd and 3rd columns also reflect that the percentage of cost savings increases over time. There are several reasons for the decline of estimated cost over time. First, the decrease of low-sulfur coal in fuel markets brings a lower emission rate. Second, the technological change also plays a role to reduce control costs. Recall in **Section 4.2**, Carlson et al.'s model isolates the effects of fuel prices and technological change and forecasts that the percentage of cost savings in 2010

relative to a uniform emission rate standard will be about 42%. This number approximates the number of 45% in the case cited in **Table 4-3** in which the benchmark is also uniform percentage reduction.

4.4 Uncertainty

When choosing a regulatory instrument to control pollution emissions, we can apply Weitman's theorem to deal with the uncertainty. If the cost function and benefit function are available to the regulator[19], it is a fact that these functions are only estimates or approximations. There are many uncertain factors unobserved or unknown at the present time. For cost functions, even the engineers who are most familiar with the production cannot precisely tell the cheapest abatement method in advance given various hypothetical output levels; one uncertain factor is the technology, which will change rapidly in the fast growing world. The benefits may be also unsure at a given output level since they depend on other things such as the weather. It seems that usually we do not have enough information regarding the curvature of cost and benefits functions around the optimal output level. When a decision needs to make, according to the Weitzman theorem discussed in **Section 2.3.1**, we have the impression that there will be many circumstances where the more conservative quantity method will be preferred[20]. Therefore, the regulator had better choose the quantity method because it will have a greater probability of avoiding bad mistakes.

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[18] All the units of the numbers in this table are 1995 US$.

[19] Sometime these are not available at all, while a decision regarding the control instrument must be made.

[20] Please see Weitzman theorem (4).

4.5 Market Imperfection

What is the degree to which market imperfection could undermine the desirable properties of a tradable emission permits system? Is this problem a serious one in the permit market? Empirical studies are needed to answer these questions. Hahn (1984) conducted a study simulating the particulate sulfates market in the Los Angeles area. The amount of emissions allowed by total permits was 149 tons/day. The study shows that, the minimization of total annual abatement cost is reached at about 490 million US$ when the permits of 36 tons/day are initially allocated to the firm with market power. The total annual abatement cost remains rather stable (around 490 million US$) when the market power firm receives the initial distribution of permits under 60 tons/day. If the initial distribution of permits is in the range of 60-70 tons/day, the market power firm is able to exert some market power and the total annual abatement cost will increase from 490 million US$ to around 550 million US$. When the market power firm receives the initial distribution of permits in excess of 70 tons/day, the solution is not unique. It seems that market power is not a serious problem in this market unless the price-setting firm receives sufficient permits which can make it a monopoly seller. The implication is that the policymaker should try to avoid a situation where the firm with market power can act as a monopolist and lead the price-quantity equilibrium too far away from the competitive equilibrium.

Maloney and Yandle (1984) studied the effects of cartelization of plants on the permit market. Their study involved 52 plants and 548 sources of hydrocarbons. Their analysis allows collusion to take place separately among buyers and sellers, and allows the number of colluding plants to vary from 10% to 90% of the total number of plants buying or selling. Their results show that the total cost will not increase substantially until the cartelization reached a high degree, but large cost savings are still present with the high degree of cartelization. In their study, the cost saving in a competitive market can reach 76% compared with command and control regulation. If the cartel controls 90% of all permits sold, the cost saving is still as high as 66%, though total control costs increase nearly 40%. It seems that the presence of market power does not negatively affect the cost saving very much. (Tietenberg, 1992, P412)

4.6 About Measurement of Cost

4.6.1 In A Dynamic Perspective

The measurement of cost savings above is calculated within the context of the same control technologies under different control approaches. But from a more dynamic perspective, transferable emissions permits can encourage the polluting sources to develop more effective and cheaper control technologies relative to command-and-control approaches, because emission reduction with the cost below permits price in the market can make the polluting sources gain. So the firm has a greater incentive to conduct R&D efforts. (Cropper and Oates, 1992, P686; Tietenberg, 1992)

4.6.2 Overcontrol of CAC

Empirical studies usually compare the costs under different control instruments to achieve a given environmental standard; here achieving the standard usually means the pollution at any point in the area does not exceed the maximum level allowed under the given standard. But standards do not represent the exact measurement of environmental quality. Standards are just ceilings on allowable levels of pollution. We should distinguish the concept of environmental quality from standards, because the benefit from an environmental policy depends on the actual environmental quality. If different pollution control instruments lead to different environmental qualities (though the objective is the same standard), we should consider the benefits from higher environment qualities when computing cost savings.

Atkinson and Tietenberg (1982) have noticed that, command-and-control systems usually result in overcontrol compared to the system of tradable emission permits. That is, the environmental quality under CAC systems is higher. Under command-and-control systems, if the emissions are below the allowed amount, the firm cannot utilize the space between actual emissions and allowed emissions. But under a tradable emissions permits system, the firm can sell this part of pollution rights to other firms to get financial gains. Then the firm decreases its control cost by giving up the space for emission.

For example, there are 2 firms (**Table 4-4**): firm 1 emits 8 units of pollution annually and firm 2 emits 12 units annually. Suppose they face the same limit of 10 units per year according to the predetermined standard. Firm 1 cannot utilize its space of 2 units pollution under CAC system. Under permit system, firm 1 can sell the 2 units to firm 2, but the total amount of pollution exceeds that under CAC system.

Table 4-5 The Environmental Qualities under CAC and Permit System

Scenario	Firm 1	Firm 2	Total
Previous Emission	8 units	12 units	20 units
Command and Control	8 units	10 units	18 units
Permit System	10 units	10 units	20 units

In essence, the permit system realizes cost savings with some expense of environmental quality. So, we should take into account the improved environmental quality beyond the standard under a CAC system when comparing CAC and tradable emissions permits systems. (Reduced cost - relative reduced benefit) is the actual cost saving from a tradable emissions permits system.

4.6.3 Rough Measurement

We know that the estimated cost of pollution control cannot be a precise one. No one expects to get an exact estimate. But at least we can get a rough estimate of the cost involved. The object should be to make a measurement as best we can. (Cropper and Oates, 1992, P730) The roughly estimated costs are still quite helpful in evaluating the cost-effectiveness of different policy instruments. And comparing estimated magical benefit and marginal cost of pollution control would help us to evaluate the efficiency of the targeted environmental standard.

4.6.4 Enlightened CAC

Another thing we should note is that there are still different pollution control instruments under the name of command-and-control. The control costs under them are still different. Try to imagine an instrument that specifies the amount of emissions for a particular polluting source but allows the polluting source to choose the form of compliance (without trading); the cost of this instrument will be greatly below that under the instrument which establishes the specific treatment procedures because of more flexibility. With a complicated design, the control cost under command-and-control may not be as high as some suppose. On the other hand, the transferable emissions permits system usually cannot reach the least cost in theory either. This is possibly due to transaction cost, market imperfection and other constraints imposed on trading considering the need in reality. So the cost savings we find in actual programs are not as big as people imagine from the early studies. But empirical studies have shown the cost savings are still substantial when the program is well designed; this gives us an optimistic attitude toward further application of this new control instrument.

5 PILOT EMISSION REDUCTION TRADING PROJECT IN ONTARIO, CANADA

Now in Ontario, Canada, there is a Pilot Emission Reduction Trading (PERT) Project which has applied the idea of transferable emissions permits. This project is used to test if a system applying transferable emissions permits can help control the pollution problem in this area economically. (Pilot Emission Reduction Trading [PERT]a, 1999a) The objectives of this section are:

1) to introduce and analyze the institution of PERT;

2) to present and analyze the result of PERT;

3) to discuss the alternative explanations on why the trading activity is low;

4) to make some recommendations for the improvement of PERT.

5.1 Overview of PERT

In 1990, the Canadian Council of Ministers of Environment proposed a NO_x and VOC (two determinants of ground-level ozone, or smog) Management Plan. In the plan, it was recognized that transferable emissions permits could make a significant contribution to control NO_x and VOC (IERTWG, 1995, P1). PERT was formed by the industry in August 1995 to control emissions of NO_x and VOCs in Ontario (PERTa, 1999-6, P1). In 1997, PERT was expanded to include SO_2, CO and CO_2 (PERTa, 1999a, P10). The aim of PERT is to develop a working example of an emissions reduction trading program

(PERTa, 1999a). This project is not an initiative of the Ontario government but rather a cooperative effort undertaken by participating firms.

The instrument PERT uses is called *Emission Reduction Trading* (ERT), which in essence uses the rationale of transferable emission permits. If a source successfully controls its emissions below its *Baseline Emission Rate* (BER), which is equal to or less than the emission rate specified by environmental regulations, the source will create and own the *Emission Reduction Credits* (ERCs). One ERC represents the right to emit a certain amount of a particular pollutant. Different from allowance that is used in the U.S. Acid Rain Program with the unit of tonne/year, ERC is a stock concept with the unit of tonne and the right it represents can last until the credit is used. Though not officially recognized by the Ontario government yet, those credits that have been reviewed and registered by PERT can be transferred to anyone who wants them. The owners of ERCs can have emissions in excess of regulated standards with the amount corresponding to the credits. The creation and transaction of ERCs are voluntary. What sources need to comply with are still current environmental regulations. The institution of the ERT project is grafted onto existing regulations.

BERs are used to calculate the number of created ERCs, so the concept of BERs only exists for creators of ERCs. For other polluting sources, including buyers of ERCs, they do not have the limits of BERs; they just need to comply with all existing environmental regulations. A firm's BER is defined as the lower of its actual historical emission rate, its projected emission rate (where sufficient historical data is not avaliable), and its allowable emissions rate given by regulations (PERTa, 1999-5-1, 2.7)

Banking is allowed in PERT. The credits created and banked now can be used to comply with regulations in the future.

ERCs can be used to comply with environmental regulations. There is no duration of these credits: banked credits are valid until they are used. Each ERC can only be used once: the ERC cannot be used or transferred any more and will be automatically "retired" from the trading market.

In order to improve the environment quality, 10% of ERCs must be permanently retired right after they are created. This means these 10% ERCs cannot be traded and exit from the market of emission reduction trading (PERTa, 1999-2).

PERT has members from both Canada and the United States (PERTb, Resources, News). The current members include both trading members, which engage in trading emission reduction credits, and non-trading members (PERTb, Membership, How to Join). The trading members consist of both small and large companies, as well as trading brokers. The non-trading members include energy, engineering, management and environmental consultants, environmental non-governmental organizations, government, and professional organizations such as legal, accounting and finance firms.

5.2 Summary of ERCs under PERT until March 01, 2001

According to the report of *PERT ERC Creations* (PERT Technical Advisory Committee, 2001), there are 43 applications of ERC creations that have been reviewed and registered by PERT until 2001. These applications are from 26 sources, because some sources have several applications for different emissions reduction activities. These applications cover an aggregate amount of 45,932.25 tonnes of ozone NO_x, 38,181.48 tonnes of non-ozone NO_x, 10,465.75 tonnes of SO_2, 28.99 tonnes of VOC, 124.62 tonnes of CO, and 14,615,009.80 tonnes of CO_2. Until March 01, 2001, there were also 8 applications of ERC creations that had been reviewed but not registered, which cover 392.57 tonnes of ozone NO_x, 212.02 tonnes of non-ozone NO_x, 2,640.30 tonnes of SO_2, 14.13 tonnes of VOC, and 904,385.00 tonnes of CO_2, and 13 applications that are under review, which cover 4,950.15 tonnes of ozone NO_x, 5,263.49 tonnes of non-ozone NO_x, 19,348.82 tonnes of SO_2, and 2,612,793.00 tonnes of CO_2.

Until May 2001, the transferred ERCs include 677.09 tonnes of ozone NO_x, 61.69 tonnes of non-ozone NO_x, 7.24 tonnes of SO_2, 19.62 tonnes of VOC, 124.62 tonnes of CO, and 880,895.64 tonnes of CO_2 (PERT Registry). The percentages of traded ERCs to created ERC that are reviewed and registered are respectively 1.47%, 0.16%, 0.07%, 67.68%, 100%, and 6.03%.

There are few credits of VOC and CO created and the traded percentages for these two credits are high. It seems that it is not easy for sources to control the VOC and CO emissions below their respective BERs. On the contrary, there are lots of credits of NO_x, SO_2 and CO_2 created and the traded percentages are much lower.

The only two buyers of ERCs are *Ontario Power Generation* (OPG) and *EPCOR Utilities Inc.*. Most of the traded ERCs were purchased by OPG. EPCOR, which is located at Edmonton, Canada only bought 20,000 tonnes of CO_2.

According to PERT Registry, there are only 46.7 tonnes of ozone NO_x ERCs that have been used by OPG, which only account for 0.1% of all the ozone NO_x ERCs that are reviewed and registered. The remainders have all been banked.

5.3 Why Little Demand of ERCs

What we have observed is that, there are few ERCs traded in the market relative to the supply of ERCs and few sources that purchased ERCs. In order to realize the benefits of emissions trading, it is necessary that trading take place. Therefore, it is worthwhile to explore why there is relatively little demand of ERCs up to today. **Section 5.3** will consider the following seven possible reasons for the low trading activity.

5.3.1 Learning Curve

At the beginning of implementing a new instrument, sources may not know its existence, or know how to use it, or may not yet have the staff to manage it, or need some time to adjust their operations to utilize this instrument, just like what happened in the SO_2

program in the States (Burtraw, 1998, P9). All the potential buyers of ERCs may be at the starting ends of their learning curves.

5.3.2 Weak Standards

One possible reason could be that most of the firms do not need the ERCs at all. This means they can comply with existing regulations without too high marginal control costs, so they do not need to utilize external methods such as buying ERCs. The deep reason behind it probably is that the environmental standards are not very strict. Nobody needs the ERCs, although some create the supply. Compliance data of sources are necessary to check this possible reason.

5.3.3 Similar Abatement Costs

Another possibility is that there is no big difference in the marginal control costs of polluting sources. Since the price of ERCs will be between the marginal abatement costs of two trading sources, there will be not many gains from the trading if the two sources have similar marginal abatement costs.

5.3.4 Location Constraints

Trading of ERCs under PERT is subject to location constraints in order to avoid the problem of "directionality". On hot summer days, it is estimated that half of NOx and VOC emissions in Ontario are carried by prevailing winds from the United States (PERTa, 1999-2). PERT has developed corresponding restrictions as a preventive measure against this problem (PERTa, 1999-5-3). Trading of NO_x and VOC in a single ozone season (April to September) may only follow the prevailing seasonal downwind pattern (PERTa, 1999-5-3, pollutant schedule). The reason for this type of restriction is that the downwind area is burdened with the emissions brought by the wind. These restrictions themselves do not affect the level of BERs.

Besides the constraints in case of directionality, the ambient air quality standards also must be complied with. Ambient standards are set for non-uniformly mixed pollutants to avoid "hot spot", an area where the concentration level of pollution is very high. Permits trading does not alter the aggregate amount of emissions, but could result in high concentration of emissions at the area where the buyer is located. Complying with ambient standards is a protection of local air quality, but this could inhibit potential trades (Tietenberg, 1996). Buyers usually need to design complex diffusion models in order to make sure the compliance of local ambient standards when considering the trading of non-uniformly mixed pollutants credits with sources that are far apart, while trading between proximate sources do not have much effect on ambient air quality. The designing of such models is usually costly because the information of climatology and emission transport is necessary. The cost of such modeling creates the disincentive especially for the potential trading partners that are far apart (Tietenberg, 1995). In the U.S. Emission Trading Program, most trades of non-uniformly mixed pollutants credits did happen between sources in close proximity to each other (Tietenberg, 1996). It is reasonable to expect such a bias toward trades among proximate sources under PERT with ambient standards. All the location constraints may prohibit potential trades of ERCs that could bring cost savings.

5.3.5 Bilateral Negotiation

Prices for ERCs are arrived at through bilateral negotiations between the buyer and sellers. Whether prices for ERCs in transactions should be publicly disclosed is still in debate (PERTa, 1999-5-1, 4.8). Only some transactions show the prices in the trading on the PERT Registry. The reliability of market price information is important for an operating trading market, because sources rely on the availability of price information to conduct cost-benefit analysis (Fromm & Hansjungens, 1996, P374). There is also a question of efficiency. A single and uniform price leads to efficient trades, while differentiated and confidential prices leads to inefficiency. The lack of public price signals and resulted bilateral negotiations will lead more costs to the potential buyers and sellers.

5.3.6 Transaction Costs

Transactions costs are also an important factor considered by firms when they decide whether to participate in ERC trading. As we mentioned, sources need to conduct bilateral negotiations to learn all the price information under PERT. If sources do not collect all the prices information before they make the decision to abate emissions themselves or purchase ERCs from a given seller, there is a risk that the profit is not maximized. If sources do collect all the prices information, the transaction cost of searching for trading partners will be high, especially in the absence of a centralized trading market; but there is no guarantee that sources will find the trading partners with suitable ERCs. The cost of searching for trading partners and the unpredictable search result create disincentive for firms to participate in the trading.

Another issue is the verification of ERCs. The onus of verifying ERCs to the Ontario Ministry of Environment now is totally on the user. That means before the transaction is made, the buyer need to assume all the possible measures to make sure the ERCs are satisfactory.

5.3.7 Uncertainty

The most important reason probably is that there is huge uncertainty regarding PERT. Firms do not know what the future environmental regulations in Ontario will be and whether the purchased ERCs will be recognized or not in the future regulatory regimes. The uncertainty of property rights reduces a firm's incentive to buy ERCs.

In the creation of ERCs, the creator faces the uncertainty in anticipating how the regulator will determine the BER level and how much emissions reductions will be recognized as ERCs by the regulator. In the trade of ERCs, all the uncertainty will be brought to the buyer. The buyer must know if the potential seller really has made necessary emission reductions to own the ERCs and whether the regulator will officially recognize the ERCs to the buyer.

In order to reduce the concerns on uncertainty of the ERCs, in July 1998, the Ontario Ministry of the Environment and PERT reached agreement in a letter of understanding that emission reductions created or transacted under PERT will be recognized as early progress toward future requirements or voluntary commitments. This means, the actions under the pilot project can be used to meet future regulatory obligations (Haites, 1998). In April of 1999, the Letter of Understanding was extended until March 31, 2001 (PERTa, 1999-6, P2). It would appear that this letter of understanding has been effective in reducing the uncertainty surrounding ERCs, since there were only 3 trades before the letter while there have been 14 trades after it (PERT Registry, 2001).

5.4 Proposed Improvements

5.4.1 Clarify Environmental Regulations Regarding ERCs

Clearly recognize the ERC

The most severe problem now is that sources do not know how the credits will be recognized in the future regulations. The regulator should enact the corresponding regulations that clearly specify how the credits are recognized. This will clear the ambiguity over the property right. It is better to have a permanent framework design for credits, so the value of ERCs held by sources will not fluctuate with regulatory shifts.

Clarify baselines for sources

Now the definition of BER is still ambiguous. The source that intends to create credits are not sure what BER will be determined by the regulator. Thus there is also uncertainty of the amount of ERCs recognized by the regulator. By clarifying the BERs for those sources, it reduces the uncertainty of the ERCs to which sources may be entitled.

5.4.2 Reduce Transaction Costs

Expedite review of applications

Transaction cost is also incurred by the process of application review. If the process is lengthy and complicated, the high transaction cost gives sources the disincentive to participate in the creation or transfer activity. Therefore, the future regulation should let the regulator finish reviewing application in a short time.

Make price signals clear

Every source that would like to sell credits should list the price offered on the registry with the description of those credits. The prices of the successful credits transactions should also be made public on the registry. These will give potential trading partners clear price information make the cost-benefit calculation. The regulator can also organize auctions where potential trading partners negotiate together. The auction mechanism is adopted in the U.S. Acid Rain Program in order to establish a public price (Schmalensee et al., 1998). Clear price signals and efficient auctions help to reduce transaction costs caused by searching for sellers or buyers.

Recognize ERCs early

The regulator should decide how many credits are officially recognized after the review of credit creation application. Only the officially recognized credits are allowed to be listed on the registry. This makes sure that buyers will not buy unqualified ERCs. This avoids the verification responsibility for the user of credits. The cost of verification and the risk of unusable credits are eliminated for buyers.

5.4.3 Check Environmental Standards

The instrument of transferable emission permits is used to reduce cost in achieving a given environmental standard, but this economic instrument cannot significantly improve environmental quality itself. If the actual air quality is not satisfactory, it is necessary to check the suitability of existing environmental standards and try to find the appropriate level.

For the implementation of a trading system, it is also necessary to check the environmental standards. If almost all the sources can comply with existing environmental standards easily when a trading system is introduced, there will be not much incentive for sources to utilize the trading instrument and a trading market will not be formed.

5.4.4 Determine the emission baselines

Currently, it is the lower of allowable emission rate or historical emission rate that acts as the baseline. Since the historical emissions are considered in determining the baseline, it is possible that clean sources that have taken actions to abate emissions before the initiation of the trading system face more stringent baselines than dirty sources. This is an unfair treatment because clean sources are discriminated against dirty sources that have not done the same abatement efforts.

It seems better to determine the emission baselines according to the projected production activity calculated on the basis of relevant data of the sources. By this way, two sources that have the same production activity will have the same emission baseline. For the same production activity, a source with better or more abatement technology will have less pollutants emissions. Thus the cleaner source will have more credits. The early emission reduction efforts clean sources have taken therefore are considered.

6 CONCLUSION

The development of PERT is still at its early stage and this program is not an official one yet. Its experience to date indicates that sources prefer certainty when considering different emission compliance options. It is reasonable to believe that more sources will be involved in this program when corresponding environmental regulations are set. Transaction costs and bilateral negotiations for price are big obstacles to trading. In the future system design, the regulator should assume more responsibilities such as verification of credits and organizing public auctions to reduce the costs for sources to participate in trading. Location constraints are also an important factor to consider in order to protect local environmental quality; this usually makes the trading system more complex. Finally, the environmental standards need to be checked, because the trading system is not likely to have much effect if most sources can easily comply with those standards.

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