Trading of Emission Discharge Permits in a Common Pool Market (A Gross Pool Formulation)

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Abstract - The modern-day version of a property right system for environmental quality is the cap and trade policy where the property right traded is an environmental discharge permit (EDP). Trading EDPs can become problematic with the occurrence of "hot spots," but this is easily resolved by using a trading framework that combines regulatory tiering with a common pool permit trading market. In this paper we design and implement a common pool market trading model with regulatory tiering. This framework is an optimization-based system which is used to compute EDP trading solutions and the actual calculation of permit trades based on a linear programming model. The property right traded is an EDP and the regulatory tiering component is introduced in the common pool market model constraint set as a set of regional pollution constraints. The key feature of the permit trade is modeling system is that all EDP trades are within a common pool and no bilateral trades are allowed to occur. The actual trading model is formulated as a gross pool, where the decision variables are the number of EDPs each market participant desires to hold and the market manager calculates net trades after the market is solved, given participants' initial EDP holdings. The linear programming model is used to develop a set of numerical simulations demonstrating the functioning of the common pool market model formulated as a gross pool. The numerical exercise also demonstrates the model usefulness for dealing with the specific environmental problems from the policy perspective.

***Keywords**:* environmental pollution policies; air pollution; permit trading; regulatory tiering; common pool market; gross pool market

JEL: Q50, Q53, Q58

1. INTRODUCTION

Designing air quality policies on the basis of a property rights system has a long history in economics. For example, Coase (1960) advocated the need to make property rights for environmental assets explicit and transferable so that they could be valued in a market setting. Dales (1968) and Crocker (1966) developed practical applications of Coase's argument for water and air quality, respectively.

The modern day version of Coase's proposal is the cap and trade policy (Tietenberg, 2006). The property right traded in this system is an emission discharge permit (EDP) and the market process for this is an emission discharge permit system (EDPS) (Atkinson, 1983; Atkinson and

Tietenberg, 1991; and Tietenberg, 2006). Every emitter in the EDPS receives the same entitlement and trades are carried out on a one-to-one basis. It is assumed with the EDP that the spatial distribution of emitters is unimportant. But using this property right becomes problematic if the spatial distribution of emissions becomes important, given the characteristics of the particular pollutant under consideration. The issue in this case is that the damages from the emission sources become location specific and the receptor locations become important, since the environmental policy targets are set with respect to particular locations. These target levels are frequently expressed in terms of ambient concentration levels at the target levels, but can also be expressed in terms of deposition amounts of pollutants such as sulfur dioxide emissions (Batterman and Amman, 1991; Ellis, et al, 1985). Basing the cap and trade policy on an EDP property right can lead to the regional air quality targets being violated. These regional violations are called "hot spot" problems and are frequently addressed with different types of trading rules that are added to an emission discharge permit system (EDPS). The trading rules impose restrictions on EDP trades, complicate the trading process and add significant transaction costs (Tietenberg, 2006).

In theory, the market-clearing price in an EDP system is equal to the cost-effective solution shadow price associated with the cap imposed on emissions. The actual process for solving an EDPS for market-clearing prices remains problematic. Hanley et al (2007) argue that actual trades are bilateral and sequential where traders are typically not fully informed about the minimum compensation demanded (supply price) and the maximum willingness to pay (demand price) of likely trading partners. This trading system incurs large transaction costs.

The EDPS transaction costs can be reduced if the permit market becomes a dynamic process. Ermoliev et al (2000) have demonstrated that if the market structure allows the price formation process between buyers and sellers to be separated in time from the process of finalizing trading contracts, a bilateral sequential trading process could yield reduced transaction costs. The trading process in this case is formulated as a Walrasian auction that could be used to determine a set of ambient and discharge prices in a centrally controlled permit market. The inherent problem with this process is that the price adjustments do not lead to an equilibrium quickly or monotonically.

Trading permits in a cap and trade policy where the property right being traded is an EDP and "hot spots" are appropriately addressed can be done in a cost-effective manner by using a framework that combines regulatory tiering with permit trading in a common permit trading market pool. The common market pool is also known as a "computer-assisted smart market" (McCabe, et al, 1991). The permit market in this application is designed as an optimization problem that is used to compute permit trading solutions. The actual calculation of permit prices and trades can be done with a linear programming model. The model objective function is generally defined as the aggregate net benefit function for the market traders subject to an appropriately defined constraint set. All EDP trades are with the common market pool and no bilateral trades are allowed to occur. The "hot spot" problem is resolved by adding a set of regional constraints to the common market model constraint set. This model bears some resemblance to the U.S. Sulfur Allowance Program (Tietenberg, 2006). Willett et al (2014) present a discussion of previous applications of common pool market trading models.

The purpose of this paper is to design and demonstrate a common pool permit trading market with regulatory tiering. An EDP is the property right traded and the regulatory tiering component is a set of regional pollutant constraints in the model constraint set. The trading model is formulated as a gross pool where the decision variables are the number of EDPs each market participant desires to hold and the market manager calculates net trades after the market model is solved, based on participants' initial EDP holdings. The formal model structure is a linear programming model.

The contributions of our paper are the following. First, we show that a better alternative to bilateral pollution permit trading is to have the permit trading activity take place through a common market pool. This does not require that permit traders be matched up since all EDP trades take place through the common market pool which is coordinated by a market manager. The prices in our system are based on key shadow prices reflecting each trader's impact on the environmental capacity. Our second contribution is the inclusion of regional pollutant constraints at key receptor locations. Inclusion of these constraints allows us to have a cost-effective method to minimize the "hot spot" problem and continue to take advantage of the benefit of permit trading. The third contribution is formulated as the common pool permit market as a gross pool.

The remainder of the paper is organized as follows. The next section introduces the common pool permit trading model formulated as a gross pool. The basic idea of the gross pool formulation is explained in detail and it is compared to the net pool formulation. The process of solving the gross pool formulation and the trading process are explained in detail. The specific model structure is presented and the permit prices which are based on key shadow prices from the model constraint are shown. The third section presents a numerical example of the common pool permit trading model and demonstrates the potential use of this framework in an environmental policy setting. The last section of this paper presents a set of conclusions.

2. INSTITUTIONAL STRUCTURE OF THECOMMON POOL PERMIT MARKET

The basic institutional structural components for our model are presented in this section. Consider first the rationale an individual firm or emitter entering EDPS market uses to determine its valuation of an EDP. In this situation the firm is assumed to make a tradeoff between undertaking more emissions abatement and releasing more untreated emissions. The latter decision requires the firm to have the appropriate number of EDPs under a cap and trade policy. The tradeoff between more abatement of emissions and holding more EDPs suggests that the firm's demand schedule for EDPs is its marginal abatement cost function. Atkinson (1983) shows the development of such a demand function for EDPs that is widely used. The decision problem for the firm in an EDPS is equivalent to minimizing the cost of emission control plus the net value of EDP trades. We assume that such a demand function is used by each firm to determine its value of EDPs and becomes the firm's EDP bid function. Throughout our discussions we assume that each firm truthfully reveals its emission abatement cost function. Our main objective is to illustrate how a common pool permit trading market for an EDPS works. Introducing incentive compatible bidding mechanisms is beyond the scope of this paper and the subject of future research.

We now turn our attention to the common pool permit trading market formulated as a gross pool. In the following paragraphs we describe in some detail the property right traded, the role of a market manager, participant impacts on regional environmental quality, the participant bidding process and the market-clearing process.

In a previous section we noted that the property right traded is an EDP. The EDP entitles a property right holder to discharge one unit of emission (measured as one ton or one kilogram). Each market participant receives the same entitlement and trades between market participants are on a one-to-one basis. Trading activity can have an impact on the regional receptor locations as will be explained in more detail below.

An important component of the market design is a central market manager who oversees the market operations. The manager is responsible for defining the target pollution levels for the regional receptor locations as well as determining the number of EDPs to be issued in the market. The manager accepts bids from market participants and clears the market using an optimization model after the bidding closes. No bilateral trades are allowed in our version of a permit market. All participants in this market buy from and sell to the market manager through a common pool market. The market manager is responsible for completing all financial settlements and permit trades after the market is cleared with an optimization model.

The market manager is also responsible for developing the relationships that link market participant abatement and emission release decisions to the receptor monitoring locations. An air dispersion model such as the one described in Batterman and Amman (1991) and also Ellis et al (1985) can be used to develop impact or transfer coefficients that establish the relationship between market participant emission releases and the corresponding impacts at the different receptor locations. These relationships are incorporated into the common pool optimization model constraint set as is shown in the model section.

The market manager is also responsible for the bidding process used in the gross pool formulation. At the beginning of an auction, each participant has a known initial allocation of EDPs. Each participant in the market may want to buy or sell existing permits. We assume all market participants express their willingness to trade through their bids in a monotonic manner. The combination of an initial holding of permits, an offer curve for selling permits, and a buy curve for permits defines a demand curve for a market participant for various quantities of EDPs to be held and the corresponding prices the participant is willing to pay for each of these quantities. This allows us to use a gross pool formulation similar to those used in electricity markets (Hogan, et al, 1996). Raffensperger (2009) provides an extensive discussion on a net pool formulation versus a gross pool formulation.

An important characteristic of the gross pool formulation is that all market participants bid their entire demand schedules for EDPs and their initial holdings are temporarily ignored until after the market equilibrium is computed as previously described. It has been argued that a market equilibrium can be achieved independently of an initial allocation of EDPs and independent of re-distributional effects if transaction costs are insignificant (Montgomery, 1972; Stavins, 1995). Once the optimal market solution is found, the market manager proceeds to determine net trades on the basis of each participant's initial allocation of permits. The market manager also completes all financial settlements at this stage of the trading process. Each market participant making a trade, pays or receives a marginal cost price (instead of "price-as-bid),which is constructed on the basis of shadow prices from the market model constraint set (Willett et al, 2014).

The institutional structure of the EDP common pool trading market also includes a set of rules for conducting EDP trading activity. The process begins by having the market manager call out proposed EDP prices and asking the market participants to state their respective quantities demand for EDPs at each stated price. The market manager closes the bidding process when there are no further responses from market participants. The market model which is formulated as a linear programming problem is solved to find the market equilibrium and net trades are calculated on the basis of each market participant's initial holding of EDPs. All trades occur at this particular equilibrium outcome. No market participant has an incentive to withhold EDPs in the bidding process for the purpose of trying to manipulate the market outcome. Ando and Ramirez-Harrington (2006) argue that this aspect of the market design lowers the prospect of strategic behavior occurring in this system.

3. COMMON POOL TRADING MODEL A GROSS POOL FORMULATION

Now we present the common pool permit trading market model represented as a gross pool formulation. The actual gross pool model is setup as a linear programming problem. First, the bid function for each emitter is represented as a discrete function where each step is called a tranche. The index for the bidding firm's tranche is denoted by the index $(n = 1, \dots, N)$. Trading activities are assumed to take into account the possibility of hot spots occurring spatially, so regional air quality standards are specified for a variety of receptor points in the model. We simplify our model presentation by assuming that there is one pollutant with multiple receptor points.[1] Let $\bar{Q}_j$ represent the ambient concentration level at receptor location j, B_{in} the size (quantity) of the bid tranche n submitted by firm i, P_{in}^b the price specified in bid tranche n submitted by bidding firm i, and l_{in}^b the quantity of EDPs accepted from bid tranche n by firm i. The gross pool linear program formulation is

$$Max\ R = \sum_{i=1}^{I} \sum_{n=1}^{N} P_{in}^b l_{in}^b \qquad (1)$$

Subject to

$$\sum_{n=1}^{N} l_{in}^b = l_i \qquad (2)\ (\pi_i)$$

$$(i = 1, \dots, N)$$

$$l_{in}^b \le B_{in} \qquad (3)\ (\theta_{in})$$

$$(n = 1, \dots, N)$$

$$(i = 1, \dots, I)$$

$$-l_{in}^b \le 0 \qquad (4)\ (\phi_{in})$$

$$(n = 1, \dots, N)$$

$$(i = 1, \dots, I)$$

$$\sum_{i=1}^{I} l_i \le \bar{l} \qquad (5)\ (\psi)$$

[1] Our analytical results in this research can be easily generalized to include multiple pollutants with multiple receptor locations.

$$\sum_{i=1}^{I} d_{ij}\, l_i \leq \bar{Q}_j \qquad (6)\ \mu_j$$

$$(j = 1, \dots, J)$$

The variables in parentheses to the right of equations $(1) - (6)$ are Lagrangean multipliers.

The objective function equation (1) is the joint economic benefit for all market participants to hold EDPs assuming the market constraint on the number of EDPs and the constraints on the regional air quality standards at all specified receptor locations are satisfied. The solution of the linear programming model yields the optimal quantities of EDPs and the respective permit prices for each bidder.

The coefficient P_{in}^{b} in the objective function equation (1) indicates the marginal value the $i - th$ firm places on the block of EDPs or quantity of permits in the $n - th$ tranche. Constraint (3) places an upper bound on each tranche and constraint (4) indicates that the quantity of bids accepted in each tranche cannot be negative. Equation (3) is an allocation constraint, which shows the quantity of EDPs accepted and the final permit positions for each firm i. Constraint (5) shows that the total number of EDPs traded cannot exceed the total number of such permits issued by the central market manager. Constraints (6) are spatial constraints, which represent capacity restrictions on the market because they restrict the tradable resource capacities. In other words, these constraints are the air quality standards that must be met at different receptor points, when EDP trades take place.

The structure of the optimal EDP prices is constructed using the shadow prices from the smart market model constraint set similar to Willett et al. (2015). At first, suppose that none of the ambient concentration constraints (6) are binding. Also assume that constraint (5) is binding. We can conclude that

$$\pi_i = \psi \qquad (7)$$

for all i $(i = 1, \dots, I)$. The shadow price for the EDP constraint (5) shows the reduction in emission control costs if the market manager were to add one additional EDP to the total number of permits $\bar{l}$ in the market. This shadow price is the market-clearing price for the EDP market and all firms in the EDP market pay the same price if none of the regional air quality constraints are binding. We assume in the remaining discussions that all of the EDPs are fully allocated.

In the second case we assume that all of the regional air quality constraints (6) are binding. The price of an EDP for the $i - th$ firm then is

$$\pi_i = \psi + \sum_{j=1}^{J} \mu_j\, d_{ij} \qquad (8)$$

\Each firm pays a multipart price for an EDP. The first term in equation (8) is the market price for an EDP, which is addressed by equation (7). The remaining components reflect the economic value of the impact each firm has on different receptor points. The shadow price μ_j for the air quality standard at receptor location j shows the reduction in emission control costs if all firms are allowed to violate the air quality standard at point j by one unit. The d_{ij} is a transfer coefficient that shows the impact of emission releases from source or firm i on the level of air quality at monitoring point j. Firms can be restrained from violating the air quality standard at this location if they are charged μ_j per unit increase in the amount of the pollution level. Emission control decisions by firm i are measured in units of emissions, so the actual price a firm i would be charged for its impact on the air quality standard at receptor point j is $d_{ij}\,\mu_j$.

A third possibility for the smart market optimal solution is that the regional pollutant constraints (6) are binding, but the EDP constraint (5) is not binding. This means there is a surplus of EDPs in the constraint (5) and the constraint shadow price ψ becomes zero. The price of an EDP for the $i - th$ firm for this case is

$$\pi_i = \sum_{j=1}^{J} \mu_j\, d_{ij} \qquad (9)$$

The price each firm pays for an EDP is based on the opportunity cost of the impact each firm has on the receptor points.

The shadow price associated with the allocation constraint (5) provides us with the information on how much the objective function equation (1) is going to increase if the $i - th$ firm were given one additional EDP. The π_i is indexed to particular firms and can be called “participation prices.” Each firm i should pay the value of π_i for EDP purchased. It is highly probable that each firm will be charged or paid a difference price (Willett et al., 2014). This follows from the fact that all trades by firms are with the common pool and traders are not matched up. In other words, none of the trades taking place in this model are bilateral.

Let π_i^* represent the optimal marginal opportunity cost price for firm i. Also, let l_i^* represent the optimal number of EDPs demanded by firm i, when the gross pool model is solved and let $\hat{l}_i$ the initial allocation of EDPs for firm i. If $l_i^* > \hat{l}_i$, firm i is a net purchaser of EDPs. The payment due from firm i for this purchase of EDPs is

$$\Gamma_i = \pi^*\left(l_i^* - \hat{l}_i\right) \qquad (10)$$

If $l_i^* < \hat{l}_i$, firm i is a net seller of EDPs. The payment due to firm i is

$$\Gamma_i = \pi^*\left(\hat{l}_i - l_i^*\right) \qquad (11)$$

If $l_i^* = \hat{l}_i$, firm i is neither buying or selling EDPs.

4. NUMERICAL SIMULATIONS OF THE GROSS POOL FORMULATION

In this section a set of empirical simulations is presented, which is designed to illustrate the empirical implications of the gross pool formulation for trading EDPs in a regulatory tiered framework. We assume that there is one pollutant, which impacts in two monitoring or receptor locations. These constraints are called regional pollutant constraints throughout the analysis in this section.

The numerical experiments shown in this section are of two types. The first set of experiments assumes that there are six firms with emission discharges, which seek to purchase EDPs. These firms are assumed to purchase their initial allocation of EDPs from the central market manager. The regional pollution constraints are assumed to be nonbinding, when the initial allocation of EDPs are acquired by the firms. The regional pollution constraints are then put into place and the gross pool model is resolved.

The formulation for trading the regional pollutant constraints in place is as follows. First, the starting point for each firm is based on the initial purchases of EDPs, which is assumed to correspond to the initial allocation of EDPs. The first set of limits for the regional receptor locations are put in place and the smart market is solved. The allocation of EDPs is determined by comparing the market solution outcome with the previous holdings of EDPs. Equations (10) and (11) are used to facilitate these calculations.

The basic data inputs used to construct the gross pool model in a regulatory tiered framework are shown in Tables 1 and 2. The data used to construct the individual firm inverse EDP demand functions shown in Table 1 is taken from Ando and Ramirez-Harrington (2006). We have chosen to use these formulations since they have the suitable mathematical properties for our exercise. We assume that the maximum number of EDPs issued by the common pool market is 9,000 EDPs.

Table 1: Individual Firm Inverse EDP Demand Functions

Firm 1	$P^e = 4{,}000 - 2l_1$
Firm 2	$P^e = 8{,}000 - 4l_2$
Firm 3	$P^e = 10{,}000 - 5l_3$
Firm 4	$P^e = 4{,}000 - l_4$
Firm 5	$P^e = 8{,}000 - 2l_5$
Firm 6	$P^e = 10{,}000 - 2.5l_6$

Note: l_i represents one EDP measured as one ton of emission releases

Table 2: Pollution Transfer Coefficients

	RECEPTOR LOCATION 1	RECEPTOR LOCATION 2
Firm 1	$d_{11} = 1.20$	$d_{12} = 2.00$
Firm 2	$d_{21} = 1.50$	$d_{22} = 1.8$
Firm 3	$d_{31} = 2.10$	$d_{32} = 1.60$
Firm 4	$d_{41} = 0.50$	$d_{42} = 1.75$
Firm 5	$d_{51} = 0.80$	$d_{52} = 2.20$
Firm 6	$d_{61} = 0.75$	$d_{62} = 2.20$

The method used to provide an initial allocation of EDPs to each trader in the market is arbitrary. In our experiment, we assume that the initial allocation of EDPs for each firm must be purchased from the common pool market manager. The outcome of these purchases is shown in Table 3. We have assumed with the initial purchase of EDPs that constraint (5) is binding, but constraint set (6) is not binding.

Table 3: Initial Permit Purchases with EDP Limit of 9,000 for 6 Firms

Firm Number	INITIAL UNTREATED RELEASES (TONS)	INITIAL PERMITS PURCHASED	PERMIT PRICE ($)	TOTAL PERMIT EXPENDITURES ($)
1	2,000	600	2,400	1,440,000
2	2,000	1,200	2,400	2,880,000
3	2,000	1,400	2,400	3,360,000
4	4,000	1,600	2,400	3,840,000
5	4,000	1,800	2,400	4,320,000
6	4,000	2,400	2,400	5,760,000
TOTAL	**18,000**	**9,000**	**-**	**21,600,000**

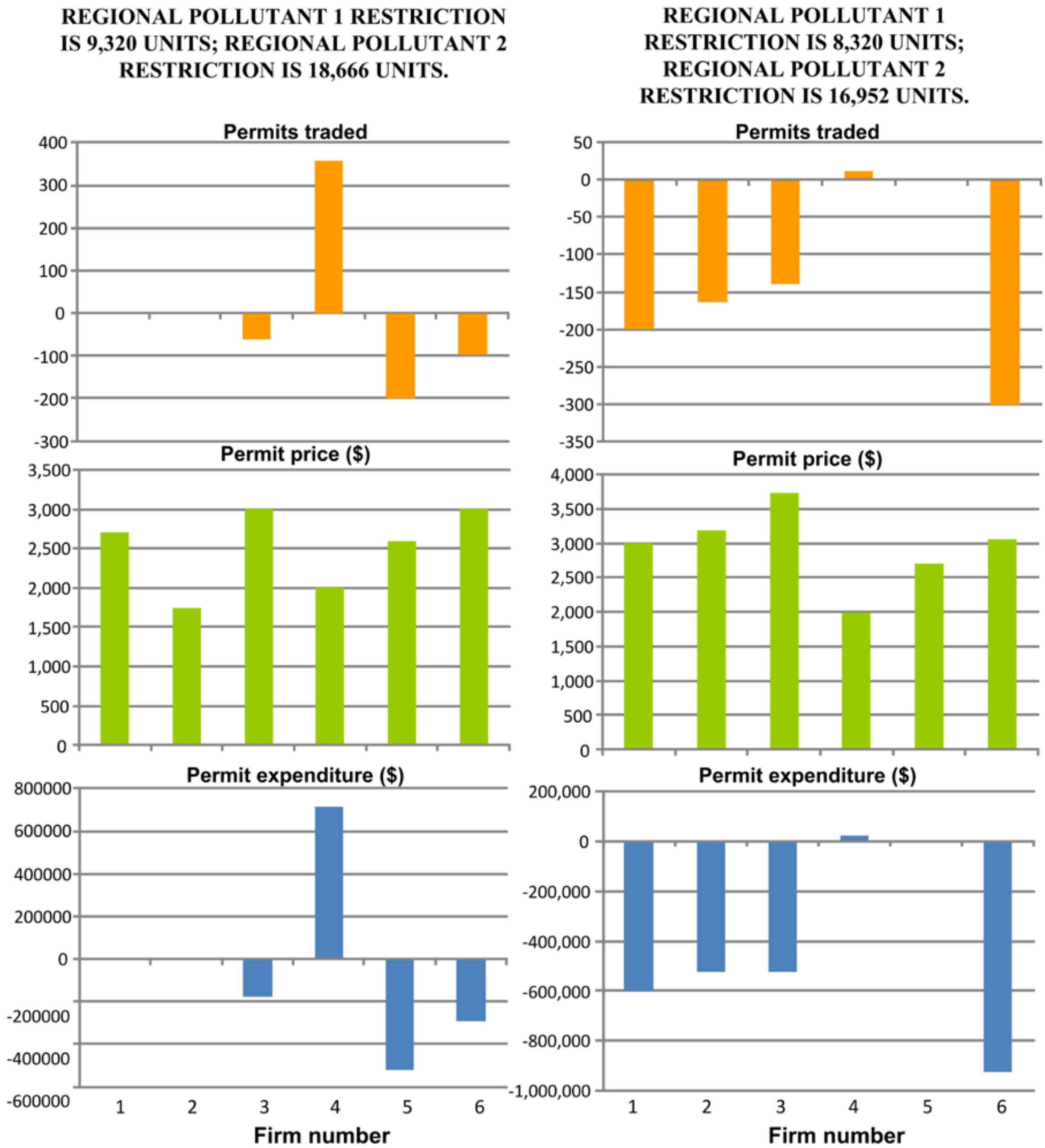
Table 4: Permit Trading Activity with Regional Ambient Standards EDP Standard 9,000 for 6 Firms

FIRM NUMBER	REGIONAL POLLUTANT 1 RESTRICTION IS 9,320 UNITS; REGIONAL POLLUTANT 2 RESTRICTION IS 18,666 UNITS.			REGIONAL POLLUTANT 1 RESTRICTION IS 8,320 UNITS; REGIONAL POLLUTANT 2 RESTRICTION IS 16,952 UNITS.		
	Permits Traded	Permit Price ($)	Permit Expenditure ($)	Permits Traded	Price ($)	Expenditure ($)
1	0	2,711	0	-200	3,014	-602,800
2	0	1,750	0	-163	3,200	-521,600
3	-60	3,000	-180,000	-140	3,733	-522,620
4	358	2,000	716,000	11	2,000	22,000
5	-200	2,602	-520,400	0	2,713	0
6	-98	3,000	-294,000	-302	3,061	-924,422
TOTAL	**0**	**-**	**-278,400**	**-794**	**-**	**-2,549,442**

The permit trading activity when the regional pollution constraints are binding is shown in Table 4 and Figure 1. Consider first the situation, when the pollutant limit at receptor location 1 is 9,320 units and the limit at receptor location is 18,666 units. The starting point for permit holdings is based on the initial permit holdings shown for each firm in table 3. We see that firms 1 and 2 have zero values for the permits traded, which means that they will retain the initial level of permits shown in Table 3. Next, we see negative entries for firms 3, 5 and 6. The negative values mean that each of these three firms finds it optimal to reduce the number of initial permits acquired and sell them to the common market manager. Firm 4 will purchase additional permits to add to the initial value of holdings shown in Table 3. We also see that the total value of permits traded is zero. This means that the regional pollutant constraints (6) are binding and so is the EDP constraint (5).

The next simulation assumes that the pollutant target value at receptor location 1 is reduced to 8,320 units and the target level at receptor location 2 is reduced to 16,952 units. Trading activity now begins with the permit holdings that each firm had after trading activity ended when the regional 1 pollutant restriction was 9,320 and the regional pollutant 2 restriction was 18,666 units. The negative values for permit trades for firms 1, 2, 3, and 6 represent the number of permits each of these firms will sell to the common market pool. In contrast, firm 4 will purchase 11 additional EDPs and firm 5 makes no purchases. The value -794 means that there are excess EDPs that are sold back to the common market manager. This outcome occurs because the value of pollutants at two receptor locations is restrictive enough to prevent the use of all of the EDPs initially allocated.

Figure 1: Permit trading (ambient standard 9000)



5. SUMMARY AND CONCLUSIONS

The decision to base environmental policies on a property right system is an old idea that has received much attention from economists and policy makers alike in recent years. The idea of course is to make the property rights for environmental assets explicit and transferable so they can be fully valued in a market setting.

The cap and trade program used for pollutants such as sulfur dioxide represents an example of an environmental policy that is based on a property rights system. Every firm that is a potential source of emissions discharge in this system receives the same entitlement and all of the trades are on a one-to-one basis. It is typically assumed in such a system that the spatial distribution of emissions is unimportant. The stated advantage of the EDP property right is lower transaction costs because of the one-to-one trading of permits.

The EDPS becomes problematic if the spatial distribution of emission sources is important, given the characteristics of the particular pollutant being managed. The issue of concern is that the damages from the emission sources become location specific and the receptor locations become important. Since the environmental policy targets are expressed in terms of the ambient concentration or deposition policy levels at these locations. Using the EDPS with one-to-one permit trading can contribute to "hot spot" problems when permit trades take place. The recommended solution to this problem is to add different sorts of trading rules or restrictions to the trades, but these rules tend to complicate the trading process and add significant transaction costs to the trading regimes.

In this paper, we have shown that trading permits in a cap and trade policy with an EDP as the property right and "hot spots" are easily addressed in a cost-effective manner with a permit trading regime that combines regulatory tiering with permit trading in a common pool permit trading market. An EDP is the property right traded and the regulatory tiering component of the common pool market structure is a set of regional pollutant constraints in the model constraint set. The trading model is formulated as a gross pool where the decision variables are the number of EDPs each market participant desires to hold and the market manager calculates net trades after the model is solved, based on each participant's initial EDP holdings. The formal model structure solved is a linear programming model.

Our research yielded the following findings. We derived a set of marginal cost pricing relationships that take three different forms, depending on the combination of constraints that are binding. If the regional pollutant constraints are not binding, but EDP constraint is binding, then the shadow price of the EDP constraint becomes the EDP price and each firm pays the same price for an EDP. In the situation where the EDP constraint as well as the regional pollutant constraints are binding, each firm pays a multipart marginal cost price that includes a component corresponding to the shadow price for the EDP constraint. In this case the marginal cost price for each firm is different because the permit traders are not matched up since all trades are within the common pool.

Next we have examined the case where the EDP constraint is not binding, but the regional pollutant constraints are binding. We have shown that the EDP shadow price is zero because there are excess EDPs in this situation due to the nature of the binding regional pollutant constraints preventing the use of all of the existing EDPs. The marginal cost price each firm faces in this situation is based solely on the shadow prices of the binding regional pollutant constraints. Our numerical simulations verify our expectations related to the marginal price rules for the different cases.

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