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Tradable Environmental Pollution Credits: A New Financial Asset

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Abstract

A new financial asset (Allotment Trading Unit or ATU) that allows a firm to pollute was issued to a number of Chicago firms in 2000 as part of a cap-and-trade model to reduce emissions in the Chicago area. A model of this market was developed to enable us to: 1.) Estimate equilibrium tradable credit prices and quantities and calculate compliance costs for comparison with traditional environmental regulation; 2.) Estimate the consequences for prices and quantities of introducing changing emitter costs; and 3.) Estimate the impacts on prices and quantities of changing market features such as auctioning tradable credits instead of a free allocation, introducing spatial constraints, and changing the emissions cap. The model's results on the price determination of this new financial asset are of interest to accountants and financial analysts. A dated bankable ATU credit has a one-year life expectancy, but future tradable credits can be bought or sold for use at the appropriate future date. It is an intangible asset that should be disclosed, measured and valued. The valuation to place on this asset is an important research topic in finance and accounting and various valuation approaches are discussed to handle the short-term and long-term price paths.

Key Words

Pricing of Environmental Financial Asset, Cap-and-Trade Market, Illinois EPA, Tradable permits, Allotment Trading Unit, Volatile Organic Compounds, Disclosure Issues.

1. Introduction.

While traditional regulation controls the rate of emissions, cap-and-trade regulation sets an aggregate cap lower than historical emissions and allots tradable credits to emitters, which they can buy, sell, or bank. These credits, a new form of financial asset, can be held in portfolios not only by polluters, but also by investors. This study explains and explores the market properties, including price determination, of this asset.

These tradable pollution credits would seem to be of little interest to accountants and financial analysts because such credits are perceived as limited in quantity and unlikely to be included in portfolios of financial assets. These perceptions, however, are changing rapidly due to the recent marked success of the cap-and-trade market to reduce emissions of sulfur dioxide (SO_2), a cause of acid rain. Not only has the program helped alleviate the harms of acid rain, it has also developed into a rich market offering options and futures. Extensions of this innovative regulation to other pollutants are now underway or planned. As an instructive example of the growing importance of this new financial asset, this study will evaluate and analyze the use of a cap-and-trade market in the Chicago region to reduce stationary-source emissions of volatile organic compounds, among the precursors of urban ozone. The objective is to identify the determinants of the market value of these tradable credits and to indicate their place among other financial assets. Valuation of tradable pollution credits differs from the valuation of a stock because the credit does not provide a future income stream directly. It is similar to a stock in that fundamental economic determinants of credit, price, and price changes are at play as we shall explain.

Economists have long touted the desirability of decentralized incentive-based environmental regulation (Tietenberg 1995). This approach was not attempted, however, until the growing costs of traditional regulation led the U.S. Congress in the Clean Air Act of 1990 to pass, by a narrow margin, Title IV mandating a cap-and-trade market for reducing SO_2 emissions of electric utilities. Criticism came from all sides: some businesses were concerned that the program was too new, too costly, and wouldn't work, and some environmental groups were concerned that direct controls of emissions were now in the invisible hands of an autonomous market (Stavins 2001).

The SO_2 program, to the surprise of many, has worked very well. Emissions have been cut roughly in half from the 1980s by issuing to electric utilities about 10 million free tradable allowances each good for one ton of the pollutant. Roughly 5 million tradable credits worth about \$200 each have been exchanged in a recent year. After a preliminary learning period, utilities are trading and banking allowances, and brokers and other traders are engaging in a functioning market that offers futures and options of various kinds (Ellerman et al 2000). Tradable credits resemble non-interest paying assets that may be held in a diversified portfolio. The risks of the price fluctuations in these credits would seem to be largely independent of many stock and bond yield fluctuations since they depend in large part on changes in emitter marginal pollution control costs and on changes in public policy.

The opposition to the use of market incentives in environmental regulation has been muted due to the success of the SO_2 program. Stakeholders of varied political persuasions are now joined in calling for more applications of market-based regulation. A Republican administration in the While House has proposed a "Clear Skies Initiative" that would reduce the SO_2 cap significantly in the future and extend to more states a cap-and-trade market for nitrogen oxide (NO_x) emissions. NO_x emissions are both a source of acid rain and a precursor of urban ozone. An international scheme to reduce carbon dioxide emissions, currently running at about 6 billion tons per year globally, through use of a cap-and-trade market, is also currently being considered. As these programs develop, a wide range of tradable pollution credits is likely to become available to portfolio managers. Therefore, managers, accountants, and analysts will want to know more about the pricing and risks of these new financial assets and how best to disclose them on corporation balance sheets.

This study investigates this new financial asset in the case of a pioneering application of a cap-and-trade market approach designed to contribute to the reduction of volatile organic compound (VOC) emissions, a precursor to ozone, in the Chicago region. This region continues to be a severe non-attainment area with respect to nationally established ozone standards, which means that Chicago's air has not met the national standard during prior summer seasons. The market covers the almost 200 stationary–source emitters, accounting for about 20% of all volatile organic compound emissions, while traditional regulation continues to apply to mobile sources such as cars and small area sources such as lawnmowers (Illinois EPA 1995).

Our method of investigation is to model the cost-minimizing responses of stationary source emitters to market incentives. The model is developed based upon existing rules of the cap-and-trade market and incorporates estimates of individual emitter marginal control costs. The model then simulates or predicts transactions and prices based upon the assumption of cost minimizing behavior of well-informed emitters in an ideal market setting. The central idea is that low cost emitters will have an incentive to reduce emissions and sell surplus tradable credits to high cost emitters. Emitters also have an incentive to develop or use new emission reduction technologies. The community benefits if emissions are reduced at less cost than under traditional regulation.

Our model enables us to:

- Estimate equilibrium tradable credit prices and quantities and calculate compliance costs for comparison with traditional environmental regulation; where traditional regulation is defined as the government specification of the rate of emissions per unit of production activity, usually calling for the same control technology for all emitters. This is often termed command-and-control regulation.
- Estimate the consequences for prices and quantities of introducing changing emitter costs; and finally,
- Estimate the impacts on prices and quantities of changes in market features such as auctioning tradable credits instead of a free allocation, introducing spatial constraints, and changing the emissions cap.

It must be emphasized that our model is based on estimated marginal control costs for individual emitters and on forward-looking well-informed expectations. That is, our model simulates a well functioning market at equilibrium. Early results from the actual operations of the market during the years 2000 and 2001 indicate that the market is not yet at equilibrium. For example, in the first year 1,643 tradable credits were exchanged and in the second, 3,702 (Illinois EPA 2000 & 2001). Similarly tradable credit prices were an average of about $76 in the first year and $52 in the second. Our model predicts that 3,771 credits would be exchanged when the cap is a 12% reduction from baseline. This prediction assumes emitters compare their marginal control costs to the market price of the credit in the first year. These early observed results of lower prices and trades than expected in the Chicago market are very similar to the observed results in the early phases of the sulfur dioxide market. In this market, public utilities were on a learning curve and frequently over-controlled in the first year or two because of their concerns about this new market and their compliance. After three years the sulfur dioxide market approached the estimated equilibrium (Ellerman et al 2000).

We believe that it will be valuable to have the results of this modeling effort available to compare predictions of the model against future observed values in order to evaluate the performance of the market. The efficiency of the market could be affected by factors such as information gaps that are closed over time as new pollution technology and market know-how diffuses among emitters, varying concerns about public acceptance of pollutant trading, unusual transactions costs, and other slippages (Tolley 1993). A carefully prepared framework for market analysis can advance future study of these issues as was discovered in the sulfur dioxide trading program. We also will indicate how this framework could be extended to consider important issues of spatially distinct neighborhood environmental damages and equity (Mendelsohn 1986) and how such a policy change could affect tradable credit valuation.

We now proceed to a brief presentation of the results achieved, then to a description of the features of this innovative market incentive scheme, and next to an explanation of the specification of the model. This is followed by a description of the key databases, an account of the quantitative methods used to obtain empirical results, a more detailed explanation of the results, and finally a discussion of further research opened up by this study.

2. Overview of Findings.

We first assume emissions are uniformly mixed concentrations over an unconstrained urban market area with resulting uniform harms to the population. Our first finding is that the present program with an equilibrium tradable credit price of $76 per 200 pounds of emissions could save about a third of a million dollars per year compared with traditional regulation. These cost savings free resources for alternative uses by the private sector or government. Our model assumes cost-minimizing behavior on the part of emitters, flexibility of choice about control options, full information about control and trading opportunities, no uncertainty about trades and their public reception, and no transactions costs. This model forecast provides a benchmark for appraising future market prices and transactions. The valuation of tradable credits now and in the future depends fundamentally upon government policy, the marginal cost of various pollution control technologies, and the effectiveness of market incentives to lower these costs by innovation and diffusion.

We simulated the effects of emission control cost and policy changes on the market. We first introduced a simple form of transactions costs into the model to estimate their impact on market variables. Higher transactions costs increase tradable credit prices, reduce trading, and reduce cost savings. We also find that free-allocation and allocation by auction lead to the same credit price, quantities traded, and cost-savings in the static case as predicted by the Coase theorem. The primary difference between the two methods of allocation is the transfer of wealth that goes to emitters under free allocation and to the government under auction. To show the flexibility of the model, we reduced the government policy cap on allowable emissions. In this case, we find that at the new equilibriums there is an increase in tradable credit prices, volumes traded, and cost savings. Concerns have been expressed about increases in neighborhood concentrations of emissions that could result from trading. To examine one aspect of this issue we imposed spatial constraints on the market, simulating a change in government policy, and find that trading restrictions lead to reduced credit prices and cost savings.

3. How the ERMS Cap-and-Trade Market Works.

In 2000, the Illinois EPA launched the Emissions Market Reduction System, (ERMS), based on a cap-and-trade variant of emissions trading. This program was applicable to major stationary sources of volatile organic compound emissions in the Chicago severe non-attainment region. Under this new regulatory program both the government and emitter firms share key regulatory decisions; the government sets the cap and the emitter chooses to control or trade. The program target was an aggregate reduction of 12% from benchmark or historical emissions determined by the 1994-1996 period. Some production processes of an emitter were reduced by less than 12% because they were already controlled by the maximum achievable control technology, whereas other processes were reduced by the full percentage. The difference in aggregate reduction caused by these special cases is not large and the effect on prices is believed to be small or nonexistent because emitters will equate marginal costs to market prices for those processes that are subject to reduction under the trading program. The cap is an important determinant of the tradable credit valuation: the tighter the cap the more scarce the allotment of credits to emitters and the higher the price, as we shall demonstrate.

The Illinois EPA devised regulations for the market in cooperation with emitter firms and environmental groups. The financial instrument or tradable credit was defined as a dated Allotment Trading Unit (ATU) good for 200 pounds of seasonal volatile organic compound emissions. A properly dated credit must be returned to the Illinois EPA for every 200 pounds of actual emissions during the specific five-month ozone season. Allocation of credits to individual emitters are based on a 12% reduction from the emitter's historical emissions, meaning that if no trading occurred emissions would still fall by 12%. Tradable credits are bankable for one year in order to prevent buildups of unused credits that could lead to seasonal spikes in emissions in future years. They are also transferable one-for-one anywhere in the region, meaning that there are no spatial constraints on the market. Lastly, the Illinois EPA established record keeping, monitoring, and enforcement procedures in order to prevent against "cheating" under this decentralized form of regulation. After devising these regulations, the Illinois EPA left all other key implementation decisions to the regulated community (Illinois EPA 1995).

Emitters were expected to minimize control costs by trading, reducing emissions, or both. Those emitters with the lowest control costs were expected to reduce emissions by more than 12% and sell credits to those emitters with higher costs until marginal control costs were equal to credit prices across all emitters, thus achieving savings compared to traditional regulation.

Stationary sources in this cap-and-trade market range over 24 SIC classifications, including painting, plating, refining, manufacturing, publishing, and other industries. These industries vary widely in the magnitude of their seasonal emissions and the emission control options available. Control measures could include changing the output level, the product, inputs into processes, or installing control equipment such as catalytic incinerators or other afterburners of various types (DePriest 2000). Such diversity in the industry of emitters and in control options suggests variation between marginal control costs, which augurs well for cost savings from trading.

It is important to note that existing traditional regulation of emissions remain in force acting as a ceiling to the rate of emissions. Stationary source emitters cannot exceed existing traditional regulation levels because only the 12% reduction from those levels is subject to trading opportunities. It has been recognized by the Illinois EPA that a further tightening of the cap might be required in order to achieve national standards by the targeted year of 2007 (Illinois EPA 1995).

4. Modeling the Cap-and-Trade Market.

Emitter firms with their allocated portfolio of dated credits are assumed to know their marginal control costs and those of others in the market. Knowing these costs, their endowments of credits, and the exogenous credit price, the firm's objective is to make joint cost-minimizing decisions about the degree of trading and reduction of emissions by control measures. We shall assume perfect and symmetric information in the regulated and regulating communities in the model's simulations, although tests against observed values of variables will require a future study of market imperfections.

Because of the fundamental rule that a credit must be returned to the government for every 200 pounds of emissions during the season by an emitter, the following identity holds for n emitters:

$$h_i = q_i + r_i + t_i \qquad i = 1,...n. \tag{1}$$

h_i refers to the historical or benchmark emissions of the ith firm, q_i is the allocation of currently dated permits for the i^{th} firm, r_i is the reduction in emissions during the season for the i^{th} firm, and t_i is the number of credits bought (if positive) or sold (if negative) during the season for the i^{th} firm. We shall consider credits that are banked for one year as a self-sale and include them in t_i. Credits may not be bought or borrowed from the future for current use. All variables are measured in 200-pound units of emissions.

Under traditional regulation, $t_i \equiv 0$ and equation (1) reduces to $r_i = h_i - q_i$ where all values of the variables are determined by the government. Under emissions trading, equation (1) holds where r_i and t_i are now decision variables of the firm. We show later that the optimal value of one determines the optimal value of the other.

The emitter's objective function under trading is to minimize reduction or control costs and trading costs, knowing the control cost function, $c_{ri}(r_i)$, which is increasing in r and differentiable, and the trading cost function, $c_{ti}(t_i)$, or

$$Min\, c_{ri}(r_i) + c_{ti}(t_i), \tag{2}$$

$$Subject\ to\ r_i \geq 0.0. \tag{3}$$

Knowing that $c_{ti}(t_i) = pt_i$ because p is the exogenous credit price, and also knowing that $\partial t_i / \partial r_i = -1$ because of (1), we can write the equilibrium conditions as

$$\partial c_{ri}(r_i) / \partial r_i - p \geq 0, \tag{4}$$

$$r_i[\partial c_{ri}(r_i) / \partial r_i - p] = 0, \tag{5}$$

$$r_i \geq 0. \tag{6}$$

The solution to (4), (5), and (6) yields the firm's optimal reduction, r_i^*, and therefore the optimal trades, t_i^*. Note that r_i^* could be zero or equal to h_i, and t_i^* could be positive, negative, or zero. In order to minimize aggregate control costs, marginal control costs are equated to p for every firm deciding to reduce emissions. That is, the marginal cost of trading must equal the marginal cost of emissions reduction.

The optimal values for the firm's reductions and trades may be used to obtain a measure, S, of the aggregate cost savings of trading compared with traditional regulation. We may estimate S as the difference in aggregate control costs between regulatory regimes, or

$$S = \sum_{i=1}^{m} c_i(h_i - q_i) - \sum_{i=1}^{m} c_{ri}(r_i^*) - \sum_{i=1}^{m} c_{ti}(t_i^*) \tag{7}$$

The first term is aggregate control costs under traditional regulation, the middle term is aggregate control costs under trading, and the last term is the sum of equilibrium purchases and sales of tradable credits. Except in the unusual case of equal marginal control cost functions and equal historical emissions for all firms, S is expected to be positive; meaning that emissions trading leads to cost savings. We also hypothesize that the greater the variance of control cost functions, the greater the aggregate cost savings.

Demand and supply curves for credits may be derived from the marginal control cost schedules of firms. Since we know the marginal cost functions of the emitter firms, we may simulate demand and supply in the market under the cap by trying out varying prices until sales equal purchases, or, equivalently, until the last term in (7) is zero. This approach may also be used to determine equilibrium permit prices when model constraints, parameters, and emissions targets are changed. A geometric description of this procedure is provided in the next section.

An implication of emissions trading theory in a competitive market is that any change in the allocation to individual emitters will not affect the permit price or cost savings in the static case (Montgomery 1975). Under the current program, the firm's allocation, free of charge, is determined by the equation $q_i = (1-\lambda)h_i$ where lambda is the fraction reduction (.12) of the firm's historical emissions. One interesting alternative allocation would be an auction of the same number of tradable credits as were allocated free. When we simulated such an auction we find the credit price, quantity of trades, and cost savings to be the same as under free allocation. The difference is that under the free allocation, emitter firms receive a significant transfer of wealth, whereas under the auction the government receives the wealth in the form of revenues. These results hold for the cap based on a 12% reduction as well as for other hypothetically tightened caps. Recent research, however, has indicated that auctioning of credits can induce more innovations in the dynamic or evolutionary case than a free allocation (Milliman and Prince 1989; Jung et al. 1996).

In Figure 1 we illustrate our method of estimating the equilibrium price of credits and calculating the cost savings from emissions trading. The increasing and linear approximation to the marginal cost schedules of two emitter firms, *i* and *j*, are drawn under the assumption that $0\,r$, measured in 200-pound units, reflects the total possible reductions of both. For ease of visualization, we assume the government allocates $r\,r_0$ credits to both firms, resulting in a 40% cap on emissions. Under traditional regulation each firm would reduce by $0r_0$ with total control costs measured by the triangles $\Delta 0r_0b + \Delta 0r_0a$.

Allowing the firms to trade opens up new possibilities. At the equilibrium price in the market the number of credits desired to be bought equals the number desired to be sold. At all other prices trading will not occur. Given marginal control cost schedules for both firms and cost minimizing behavior, a unique equilibrium price of $0p_i$ exists. Emitter *j* sells $r_0r_j^*$ credits and reduces by the amount $0r_j^*$. Emitter *i* buys the amount $r_0r_i^*$ where $r_0r_i^* = r_0r_j^*$, and reduces by $0r_i^*$. Total control costs under trading are measured by the triangles $\Delta 0r_i^*d + \Delta 0r_j^*c$ and net savings compared with CAC regulation are $r_i^*r_0bd - r_0r_j^*ca$, clearly a positive number measured by *dfb+fac*. The argument generalizes to more than two firms and to integrals under nonlinear cost functions. Thus, credit valuation depends upon the marginal pollution control cost functions given the policy-determined cap. Banking for one year introduces expectations of next year's cost functions. Since future dated credits may be bought or

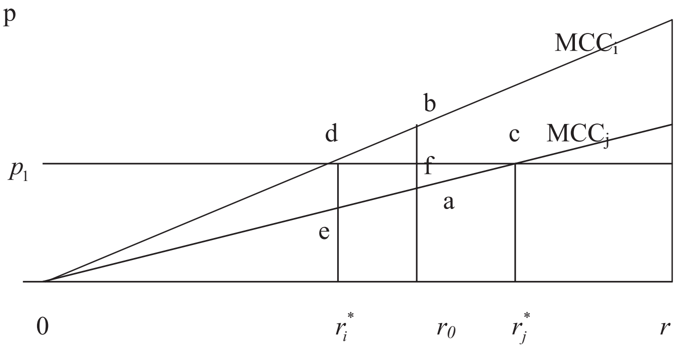

Figure 1.
Price determination and cost savings with a homogenous pollutant. p = \$ per 200 pounds of emissions. r = reduction in 200 lb of emissions units. MCC_i and MCC_j are marginal control costs for firms i and j respectively. In this figure the assumed firm cap is about 40% given by r_0r.

sold, but not used until that future date, expectations of future changes in control cost affect credit valuations and prices. For example, expectations of future reductions in costs will lead well-informed emitters to use or acquire current credits and raise current prices because it will be cheaper to buy now and control later.

5. Empirical Implementation of the Model.

To measure the variables we have described requires detailed information on individual emitter marginal control costs, tradable credit allocations and trades, and actual emissions before and after trading. We describe the data used in this study, all of which can be made available to researchers on request.

To obtain the critical information on marginal control costs, we rely on a large study carried out by the Illinois EPA that surveyed the numerous control measures for emission reduction available to participants in the market (Illinois EPA 1996). The survey estimated the costs at about the 12% emission reduction level for a number of emitters. The survey estimated these marginal control costs by making use of engineering data and U.S. EPA estimates of the costs of Reasonably Available Control Technologies. These estimates were then extended to other emitters in the same SIC classification. Capital and operating costs were estimated in the study in present value terms. We have adjusted these costs to allow for technological change by using the observed market price to estimate improvements in pollution control technology since 1996.

The model of this study makes use of actual credit allocations and prices for the first year of the program available from the Illinois EPA (2000 & 2001). As explained earlier, actual trades and prices were below values expected by most observers, and as predicted by our model due to start-up costs such as learning behavior. Actual trades in the second year approached the model predictions and are consistent with a movement toward equilibrium.

The underlying structural relationships of the model are the marginal control cost curves that were fitted for each firm by passing the curve through the origin and the 12% emission reduction cost value. These costs may be viewed as incremental to the control costs necessitated by prior traditional regulations that remain in effect. They are understood to be linear approximations of marginal costs over the relevant range. Based on these structural relationships, estimates of credit equilibrium prices and control costs under trading and traditional regulation at equilibrium output levels were obtained by use of a specially written optimization program that was built using the B34S® **matrix** programming language (Stokes 1997).

Basic to the approach was the specification of the excess demand functions. These depend upon the desired targeted level of reduction, which was 12% in the case of current program. Summing the excess demand functions for all the firms and selecting the price that made this sum equal to zero determined the equilibrium price. In other words, at equilibrium the number of credits sold must equal the number of credits bought as demonstrated in Figure 1. Using the **matrix** command, the price was restricted to be greater than or equal to zero in the model specification and an optimization routine determined the equilibrium price where the sum of excess demands was zero. An advantage of the optimization approach is that it allows the user to easily change constraints, parameters, and emissions targets or caps in the model and observe the results.

Some observers have expressed concern about “hot spots” in the market where some sub-areas could experience increases in emissions over baseline despite the reduction in aggregate emissions. One possibility for simulation of a public policy change is the inclusion of spatial constraints in the optimization model. For example, it is possible to restrict purchases of tradable credits within a certain zip code, or group of them. The model enables us to gauge the effects of such proposed changes on both credit prices and the distribution of pollution. Mapping of these emission patterns provides a means of evaluating these changes in distribution. The optimization approach also enables us to highlight the flexibility of the model by changing the emissions reduction targets and reporting the consequences. A more explicit account of these implementation methodologies is given in the Appendix.

6. An Investigation of the Cap-and-Trade Market By Means of Simulations.

Establishing the cap or emissions-reduction target may be viewed as the government acting as the citizen’s purchasing agent for air quality. The cap or target may change from time to time as new information comes to light or new citizen pressure comes to bear on air quality. Similarly, the choice of a regulatory instrument may be viewed as the purchasing agent’s efforts to obtain the desired air quality in the most cost-effective way. Our model presents a methodology to evaluate the agent’s policy options and their consequences for the valuation of tradable credits.

In Table 1 we present the equilibrium credit price, volume of credits traded, the control costs under emissions trading compared with traditional regulation, and the cost savings to be realized by using market incentives for the present program reduction rate of 12% from the historical benchmark. We present additional simulation results for hypothetically increased reduction rates up to 36%, both as a test of the model and as a relevant exercise in view of the current policy debate on reducing acceptable urban ozone levels. The results are as expected from emissions trading theory. As the reduction in emissions increases from 12% to 36%, the tradable credit price increases from $76 to $238 as shown in Table 1. Decentralizing control decisions in the cap-and-trade market at the 12% reduction rate can bring about a third of a million dollars in savings per year compared with traditional regulation. These savings increase to just under 3 million dollars as the emissions target rate of reduction increases to 36%, implying that as the number of credits allocated decrease and prices increase, the incentives to trade strengthen with the consequence of a more than proportionate increase in savings.

Our approach enables us to report the number of credits traded at each reduction rate, as in the last column of Table 1. Recall that the reductions in emissions are obtained by issuing tradable credits to pollute in amounts below the benchmark or historical emission level. The benchmark emissions utilized in the cap-and-trade program were equivalent to 107,617 credits; thus, to achieve the 12% reduction required that 94,703 credits be allocated for the year 2000 season. A slight difference between these numbers and those reported in the Illinois EPA Performance Report occur due to the special circumstances of certain emitters. The amounts allocated decrease as the desired reduction rate increases, so that 68,875 credits would have to be allocated to achieve a 36% decrease in emissions. The number of credits traded in the 12% scenario is 3,371, about 4% of those allocated in that case. The number of credits to be traded if the reduction rate were set to 36% increases to 11,312, a little over 16% of the total allocated in that scenario. These results confirm our expectations, based on rising marginal control cost schedules, that as reduction rates increase and credit allocations decrease, cost-saving opportunities through trade increase even more rapidly.

Table 1
Estimates of Credit Equilibrium Price, Number of Credits Traded, and Emissions Trading Cost Savings for Different Emission Reduction Rates (Year 2000 Trading Season)

[1] Emissions Reduction Rate	[2] Number of Credits Allocated	[3] Credit Equilibrium Price ($)	[4] Control Cost Under Traditional Regulation (x $1000)	[5] Control Cost Under Trading (x $1000)	[6] Control Cost Savings (4-5) (x $1000)	[7] Number of Credits Traded
0.12	94,703	76	801	491	310	3,771
0.18	88,246	114	1,802	1,104	698	5,656
0.24	81,789	152	3,205	1,963	1,242	7,542
0.30	75,332	190	5,007	3,067	1,940	9,427
0.36	68,875	228	7,210	4,417	2,793	11,312

Notes: There were 174 emitters included in the model runs. The number of credits allocated depends upon the emission reduction policy goals. For the current 12% reduction, 94,703 credits were issued to these emitters for the ozone-trading season, May through September 2000. This number differs slightly from official records because of the special circumstances of certain emitters. Prices and cost estimates are in current (2000) dollars.

Introducing transactions costs into the emissions trading section of the model is expected to decrease cost savings, increase credit prices, and decrease the number of trades (Stavins 1995; Montero 1997). In essence, transactions costs drive a wedge between the sale and purchase price. These costs were introduced into the model in the case of the 12% reduction rate with both seller and buyer sharing the transactions costs equally. The results are as expected and are reported in Table 2. Savings from trading and the number of trades decline appreciably as transactions costs increase. This simulation confirms that extremely high transactions costs can eliminate a market, as in our case where transactions costs are equal to $250.

Table 2
Effects of Transactions Cost Changes on Credit Equilibrium Price, Number of Credits Traded, and Emissions Trading Cost Savings
(12% Reduction: Year 2000 Trading Season)

[1] Transactions Costs ($)	[2] Equilibrium Price ($)	[3] Control Costs Under Traditional Regulation (x $1000)	[4] Control Costs Under Trading (x $1000)	[5] Control Cost Savings (3-4) (x $1000)	[6] Number of Credits Traded
No transactions costs	76	801	491	310	3,771
10	82	801	496	305	3,233
50	105	801	621	180	1,127
100	146	801	738	63	274
250	196	801	801	0	0

Notes: Transaction costs are considered to include a component for search, negotiation and bargaining expenditures required for trades. Broker fees may approximate part of these expenditures. Any extra expenditures by emitters for special reporting and management required by the trading program could also be included as well as anticipated expenditures for public relations or legal services.

The Illinois EPA has attempted to reduce transactions costs by maintaining a free electronic bulletin board of offers and bids. Transactions costs typically include search and negotiation expenditures, but they may also include anticipated emitter expenditures for legal and public relations assistance in the case of regulator challenges to trades, or public disapproval of trades.

A powerful implication of emissions trading theory is that changes in the allocation of credits among emitters ought not to affect prices, quantities, or savings in the static case, presuming that the market remains competitive and free of uncertainties and transactions costs (Montgomery 1975). As discussed in the theory section, we simulated an auction in which the final equilibrium price balances the given supply with the demand schedules derivable from the marginal cost schedules. We found that the auction results should the cap or reduction rate be changed are the same as those under free allocation. The difference between these two methods of allocation is the transfer of wealth. Under the free allocation, the value of the credit is transferred to the emitter, under the auction, the revenues go to the government. We may estimate these transfers of wealth by multiplying the number of credits allocated by the price. At a 12% level of reduction about $25 million will be transferred to the government or emitters depending on the method of allocation. This transfer of wealth would increase to about $54 million if the reduction rate were 36%.

Individual firm purchases and sales of credits also differ under the auction and free allocation. Assuming a free allocation, we have arrayed emitter firms from low to high marginal costs in Figure 2 and plotted their purchases and sales at a 12% level of reduction. Note Figure 2 confirms our previous point that marginal control costs differ significantly among emitters, a precondition for an efficient market.

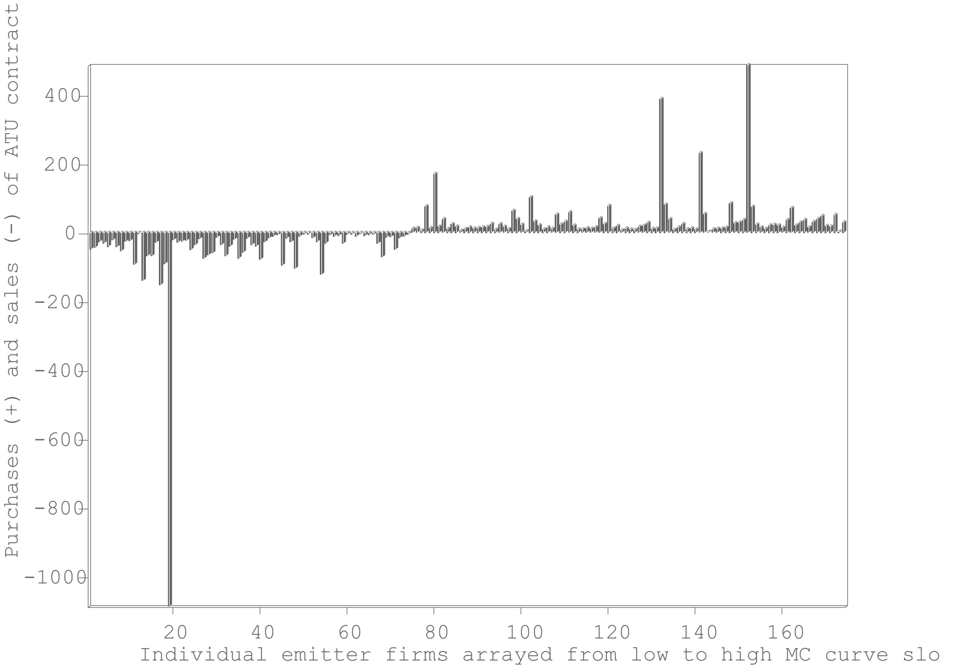

Figure 2. Individual emitter purchases and sales of credits (ATUs) under a reduction rate of .12, equilibrium credit price of $76, and free allocation of credits. The ordinate values are credit sales if negative and purchases if positive. The abscissa values are 174 individual emitters arrayed from lowest marginal control cost slope value on the left to the highest on the right.

In both the auction market and under free allocation emitters are equating their marginal costs to the tradable credit price. Total purchases for each emitter in the auction market, where all credits must be purchased from the government, are the algebraic sum of what they would have gotten under free allocation, q_i, plus their trades, t_i, which is positive for buys and negative for sells. Emitter control costs are the same in both markets but not their balance sheets. It should be noted that there are also reasons to believe that auctioning tradable credits can induce greater innovations and diffusion of pollution control technology than free allocation.

7. Emission Trading Results if the Market Was Spatially Segmented.

Spatial restrictions on cap-and-trade markets by the government have been proposed to allay concerns that neighborhoods could experience increases in emissions despite a regional reduction. We examine one feature of this matter and that is the possible loss in efficiency in the market if spatial segmentation is imposed. This loss would have to be balanced against any gains in the reduction of neighborhood harms due to redistribution of emissions. Actual data of the first year revealed that no significant increase in neighborhood emissions were detectable (Illinois EPA 2001).

There is a second, more subtle, consequence of spatial constraints. Restrictions on purchases of emissions in one neighborhood mean increased emissions in others. Total emissions remain capped, of course, but the decline in credit price caused by spatial constraints leads other emitters to reduce emissions less by control measures and buy more credits, allowing them to emit more. Only a careful spatial analysis can reveal the changing emission patterns that result from imposing constraints on the market.

The loss in efficiency caused by special constraints in the market can be explored in the model by starting with the 96 zip codes in which emitters are located and restricting credit purchases by those emitters located in specific zip codes. First we restricted purchases by emitters in those zip codes in the southern part of the region on the grounds that prevailing winds blow emissions from south to north. Once these emitters are restricted from buying, the price falls as expected from $76 to $70. Next, we eliminated the zip codes located in Chicago on the grounds that population densities are greatest in the city, which caused the price to fall to $68. If we restrict purchases in both the Chicago and the southern zip codes, the simulated equilibrium price falls to $65. The results in Table 3 reveal that credit prices, trades, and cost savings decrease as expected. Control cost savings fall from $310,400 in the case of no spatial restrictions to $182,000 in the most restrictive case. Spatial restrictions on the market can have significant adverse effects that must be kept in mind when evaluating the environmental equity benefits of such restrictions (Mendelsohn 1986).

8. Disclosure, Measurement and Valuation issues.

Firm holdings of tradable credits represent intangible assets that must be disclosed, measured, valued, and placed on the firm’s profit and loss statement and balance sheet in the appropriate places. Full and fair reporting of these assets will allow careful readers to form their own judgment and correctly assess their economic potential. While tradable credits are dated and have a one year life after the year of issuance, the government is committed, unless the policy cap changes (always a contingency), to issue a future stream of future dated tradable credits. Firms can buy, sell, or bank their current issue, and they can buy or sell future dated credits for use at the proper time.

Viewed from the firm’s perspective, the allotment credit is denominated in 200 pounds of volatile organic compound emissions or pollution. One credit must be returned to the government for every 200 pounds of pollutant emitted during the ozone period from May to September of the year. The firm’s basic decision is to decide whether to use pollution control processes to reduce emissions or to turn over credits to the government for the remaining emissions. For the cost minimizing firm, this means equating the marginal control cost of that reduction to the market price of the

Table 3
Effects of Sub-area Restrictions on Emissions Trading Cost Savings, Credit Equilibrium Prices, and on Number of Credits Traded
(12% Reduction: Year 2000 trading season)

[1] Restrictions on ATU Purchases in Selected ZIP Codes	[2] Credit Equilibrium Price ($)	[3] Control Costs Under Traditional Regulation (x $1000)	[4] Control Costs Under Trading (x $1000)	[5] Control Cost Savings (3-4) (x $1000)	[6] Number of Credits Traded
No restrictions (12 % reduction)	76	801.1	490.7	310.4	3,771
Restrictions on purchases in 25 South zip codes	70	"	545.7	255.5	2,987
Restrictions on purchases in 19 zip codes in Chicago	68	"	580.6	220.5	2,701
Restrictions on Purchases in both above cases	65	"	619	182	2,228

Notes: There are 96 Zip codes in the non-attainment area in which emitters are located. Zip codes were chosen for restrictions on buying credits to investigate the effect of spatial restrictions on the gains from trading. All dollar values are in current (2000) prices.

credit to determine the optimal level of reductions. If the control cost is less, the firm will continue to reduce emissions until the rising control cost equals price. After that is it advantageous for firms to use credits to cover emissions rather than reduce.

In a competitive market with well-informed traders, the equilibrium price of the credit will reveal the marginal pollution control costs. Every trading firm will have equated their own costs to that equilibrium price. As we have shown, our model, simulating that efficient market, estimates that equilibrium price based on the policy cap and the estimated firm cost functions. The market responds to demand and supply curves of the firms so that at equilibrium, some buyers enjoy a buyer's surplus for those acquired credits they valued above the equilibrium price, and some sellers enjoy a seller's surplus for those credits they would have sold below the equilibrium price. The efficient market maximizes the sum of these surpluses, as is true of any efficient market. The market for tradable pollution credits is no different than other markets, and many of the finance and accounting principles carry over.

The firm has a problem, as do finance and accounting experts, in discovering price. The Illinois EPA maintains an electronic bulletin board for recording bids and offers, but does not publish particular transaction prices. Brokers in the market can provide some information. The Illinois EPA does publish average prices from time to time that give indications of where the price is heading. For many purposes the estimate of price at any moment is probably not far off the mark. It should be noted that tradable credits are given free to firms so that interesting questions about their valuation arise. They have value in the market so their use in covering emissions is not free, but should be valued at the market price as a cost of production. If they are banked, they also have a value that is the estimated price during the next period. Here they appear on the firm's balance sheet. There is an additional interesting question about accounting for the future stream of tradable credits that the government will issue to the firm. These clearly have value and should be noted for the record. Note the interesting tax implications that arise if they are sold since they were obtained free of charge.

There are similarities in the pricing of credits with other production inputs. The tradable credit is valued by the firm because it can be used in place of expensive control equipment. That value is based on the marginal control cost function of the firm. The forward-looking firm is aware the marginal control costs can change due to technological progress, or technological difficulties. Therefore, the present price depends upon expectations of future control cost developments and public policy changes. If costs are expected to decline in the future, that expectation will increase the present price of the credit since it is advantageous to use credits now rather than later.

Since the anticipated future stream of dated tradable credits may be banked, they enter the balance sheet at market prices subject to fluctuation as future marginal control costs change and public policy changes. This makes tradable credits comparable to the companies stock, which can be priced as the present discounted value of future earnings.

9. Conclusions and Research Directions.

Emissions trading compared with traditional regulation compels us to take a fresh look at and ask different questions about the workings and impacts of environmental regulation. Under a trading system, the government makes key policy decisions about the cap and devises general market rules and appraisal procedures, subject to the scrutiny and comment of the regulated community and public interest groups. The regulated or business community, in turn, makes decisions about the choice of control options, the search for new options, and the management of the tradable credit portfolio. The financial community, in turn, is presented with a new set of financial assets to analyze.

Our model can help reveal the potential of emissions trading under a variety of assumptions about the parameters of relationships and changes in emission targets or goals. The model can become a guide to the workings of the trading program with its goal of reducing stationary source emissions by 12%. As recorded data become available, the model can be used to appraise the program and to investigate any slippages between the simulated and actual market performance. The model can also be extended to include banking behavior and provide forecasts of future credit prices and excess demand functions.

Our first results indicate that the present program can bring about significant cost savings, up to one third of a million dollars per period, compared with traditional regulation. This result can be achieved when firms trade about 4% of all credits allocated and micro control decisions are decentralized among emitters. Equilibrium prices of the tradable credit are then generated under varying assumptions such as changes in costs, altered caps, and spatial restrictions on the market.

If emitters confront transactions costs in the market, the model enables us to demonstrate that the higher these costs, the lower the credit price, the fewer the trades, and the lower the cost savings. The model also enables us to simulate government changes in policy objectives, such as tightening the cap. Allocating fewer aggregate credits causes higher prices, more trades, and greater cost savings compared with traditional regulation. The model enables us to show that if the government chose to allocate credits through an auction rather than through free allocation, in a competitive market, there would be no change in current credit equilibrium price or cost savings. However, there would be a change in the transfer of wealth and the incentives to innovate. Auctioning of tradable credits typically encounters serious resistance from emitters due to the change in the transfer of wealth that would occur. We have also been able to show that if spatial constraints are placed on the market the credit price falls, cost savings are reduced, and the distribution of emissions over the area is altered.

Our results have revealed that tradable credit prices will depend upon a number of variables that require close examination including marginal control costs, transactions costs, changes in government policy with respect to the cap, the method of allocation, and constraints on the market. This study provides a framework for explaining the changes in the valuation of tradable pollution credits, and for understanding future developments.

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Appendix

The model in our paper requires that we develop an implementation methodology to specify the excess demand function in the case of a 12% emission reduction goal. The key variables in our dataset of 174 firms are:

$c_{ri}(r_i)$ = the marginal cost of reduction of emission reduction for firm *i*.

λ_0 = the reduction goal of 12%. The cap then becomes 88% of historic emissions.

h_i and q_i as given by prior recorded emissions and government policy where $q_i = (1-\lambda_0)h_i$. In other words, if the firm reported historic emissions of 100 units of emissions as an average during 1994-1996, the firm was then allocated 88 credits for the ozone season. The next task is to estimate the marginal control cost based upon reported values, Illinois EPA, Technical Support Document (1996) at a 12% reduction. One assumption would have been to assume constant marginal costs. We rejected this approach as not realistic in favor of the increasing marginal cost case. The question then becomes are the costs increasing at an increasing rate, at a constant rate, or a decreasing rate? In our preliminary model, we assumed the constant rate case where the cost curve was fitted to the 12% reduction value and the origin. As more detailed data on costs become available, other cost functions can be employed in the model.

These estimated marginal cost curves underlie our excess demand functions and enable us to generate equilibrium prices, quantities of credits traded, and control costs under both traditional and trading regulation. We show how we derive these values in the next section where we illustrate the flexibility of the model by explaining the implications of varying emission caps or emission reductions.

Assume λ_0 = base reduction rate (.12) and λ_j = the reduction rate mandated in period *j*.

then

$$c_{ri}(r_i, \lambda_j) = c_{ri}(r_i, \lambda_0)[\lambda_j / \lambda_0]. \tag{A1}$$

where we introduce λ_j to indicate that we are comparing the cost value of a different cap point along the curve, although the slope remains the same. In other words, if the marginal costs of reducing emissions was \$200, assuming the base reduction was 12% ($c_{ri}(r_i,.12)$ = \$200) and the reduction rate was mandated to increase to 16%, then marginal costs will rise to \$266.67 [$c_{ri}(ri,.16)$ = \$200*(.16/.12) = \$266.67].

Define $\widehat{r}_i(\lambda)$ as the amount of emissions that firm *i* needs to reduce, given any λ. As explained in section 5, the relation $r_i - h_i - q_i$ holds if there is no trading under traditional regulation. When trading is permitted $r_i - h_i - q_i - t_i$. Define $t_i(\lambda,p)$ the amount firm *i* sells (if negative) or buys (if positive), given the required reduction λ and the market price of a credit *p*. We will show later that the price of a credit, *p,* is an increasing function of λ or the required reduction percentage. Equations (A2) and (A3) explain how we calculated the optimal trading for the firm; that is, how we determined $t_i(\lambda,\mathrm{P})$ given the allocation of credits and the marginal control cost.

$$For\ p \geq c_{ri}(r_i, \lambda) \quad t_i(\lambda, p) = \min((p - c_{ri}(r_i, \lambda)(\widehat{r}_i(\lambda) / c_{ri}(r_i, \lambda)), \quad q_i(\lambda)). \qquad \text{(A2}$$

$$For\ p < c_{ri}(r_i, \lambda) \quad t_i(\lambda, p) = \max((p - c_{ri}(r_i, \lambda)(\widehat{r}_i(\lambda) / c_{ri}(r_i, \lambda)), -h_i + q_i(\lambda)). \tag{A3}$$

Note that (A2) limits the maximum sales to the amount the firm has been allocated q_i (λ) while (A3) limits the amount bought to what they need or their historic emissions minus the credits they have been given. The optimization problem is to find p such that $\sum_{i=1}^{174} t_i(\lambda_j, p) \equiv 0$ or a λ_j value for a value. Given p_1 is the equilibrium price, our empirical work shows that, everything else equal, $\partial p_1 / \partial\lambda > 0$ or the greater the required rate of reduction, the higher the price of the credit. The higher price results in more credits traded due to the increased incentive to acquire credits as marginal control costs mount. It also revealed that cost savings of trading increase compared to traditional regulation. More specialized cases can easily be solved if for an individual firm i we place a cap γ on the amount it can buy) $(t_i(\lambda,\text{p}) \geq \gamma$ or in fact restrict the firm to only selling credits $(t_i(\lambda,\text{p}) \geq 0.0$). In summary, our model allows more specialized excess demand functions whose implications are a task for future research.

The above analysis assumes that each firm was given an allocation of credits, $q_i(\lambda)$ and that some firms would buy credits and some firms would sell credits, depending on their individual cost functions. If there is a government auction of credits, we do not allocate any credits to firms. In this mode of operation, each firm must either reduce all emissions or buy from the government to cover emissions at an auction where a single price clears the market. As in the free allocation case, the market clears when all credits offered by the government are sold and the sum of excess demands equals zero. Our approach to estimating prices, quantities traded, and costs is the same in both the auction and free allocation scenarios. It will be noted that both scenarios yield, in the static case, the same prices, same number of credits traded, and same cost savings, although the transfer of wealth is different. This turns out to be an application of the Coase theorem (Coase 1960).

In all cases command and control costs have been calculated as $r_i(\lambda)c_{ri}(r_i,\lambda)/2$ and trading costs as $r_i^*(\lambda) = t_i(\lambda, p))^2 (c_{ri}(r_i . \lambda) / 2r_I^*(\lambda))$. The gain from trading for firm i becomes $(c_{ri}(r_i, \lambda) r_i(\lambda)) / 2 - ((r_i^*(\lambda) + t_i(\lambda, p))^2 (c_{ri}(r_i, \lambda) / 2r_i^*(\lambda)))$.

The percent reduction of the firm becomes $r_i^*(\lambda) + t_i(\lambda, p)) / h_i$. which suggests that the more a firm sells credits the more it reduces its emissions, while the more a firm buys credits the less it reduces its emissions.

Because we have been using a general nonlinear optimizer to solve our model, it is possible to add other parameters to the model and place complex nonlinear constraints on the solution. The B34S program (Stokes 1997), contains a function that supports nonlinear programming with nonlinear constraints. This function was not needed in this preliminary analysis, since the only constraint placed on the solution was that p must be greater than or equal to zero. The nature of these constraints is left to further research. Our model has been designed to highlight both the price and spatial effects of such changes.

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