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Regulatory conflict in the Chicago VOC control program

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The study analyzes the performance of an innovative cap-and-trade program designed to make cost-effective reductions of an ozone precursor in Chicago and finds that decentralized market incentives were undermined by the continuance of centralized traditional emission point or command-and-control regulation. The study makes two contributions for urban areas considering this regulatory measure: it shows that using two regulatory measures to achieve one emissions reduction goal can undercut cost-effective emissions trading, and it provides a redesign of the market system that coordinates both regulatory measures for cost-effective control and avoidance of trading problems, such as hot spots and inter-temporal spikes.

Keywords: ozone; cap-and-trade; command-and-control; regulatory coordination; cost-effectiveness; VOC redesign

1. Introduction

Finding a least-cost regulatory system to reduce urban air pollution clearly deserves high priority in areas where the regulators cite the high cost of environmental protection as a reason for the limited efforts to deal with air quality issues. This study finds that the pioneering effort of the Illinois Environmental Protection Agency (Illinois EPA) to implement a cap-and-trade program to reduce stationary-source volatile organic compound (VOC) emissions in the Chicago ozone non-attainment area led to surprising results, far short of expectations in most respects. The authors will show that traditional command-and-control regulation resulted in emission reductions well below the cap. These large emission reductions in turn led to excessive tradable permit banks, reduced emissions trading, extremely low permit prices, and the stunning expiration of about half of allocated permits. Perhaps the most disappointing aspect of this performance is that it did not measurably reduce control costs relative to command-and-control. The experience of the VOC market is also disappointing in view of the severe air quality problems in many mega-cities of other countries and the intensified search for cost-effective measures there (UN Environmental Program 2004, p. 1).

The study first describes the original motivations on the local scene for an innovative, although untested, program and the compromises necessary to get it underway. Next, the authors tabulate and demonstrate in what ways the present market design is not working as expected. The study then evaluates a number of potential reasons put forth for this poor

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performance, including hypotheses such as an over-allocation of permits, shutdowns that reduce emissions and generate permits, and the conflict of decentralized incentives with pre-existing and continuing centralized regulations. The latter, creating a conflict between two regulatory systems, is found to be the most significant cause of the program's failure to achieve desired results. This leads to a consideration of an alternative course of action that could make the program more effective, including a scrapping of the market and a return to a complete command-and-control approach or a redesign of the market system. The study concludes that redesigning the market system to minimize the problems encountered and coordinating the two regulatory systems could be the best alternative in terms of future cost-effective performance, improved coordination of different regulatory systems, and acceptance locally and elsewhere.

2. Motivations for an innovative cap-and-trade program

The Illinois EPA had several strong motivations for seeking new regulatory measures other than command-and-control. Careful studies such as Tolley *et al.* (1993) and Schreder (2003) documented that the health and welfare benefits of further reductions in ozone and its precursors were substantial. The young and the old are particularly affected and are subject to a variety of respiratory ailments. Another strong motivation for seeking a cost-effective alternative was the perception that, while emissions were being reduced, marginal control costs were increasing after more than 20 years of continuing and ever-strengthening emission-point or command-and-control regulatory controls. This has been true of most urban areas using these regulations in an effort to reduce pollution (UN Environmental Program 2004, chapter 3).

A number of theoretical explanations were being circulated prior to the start of the market demonstrating the cost savings, both public and private, that could be expected by a decentralized, competitive market approach (Case and Dunham 1997, Evans *et al.* 1997). A thorough analysis of the potential cost-effectiveness of VOC emissions trading based on case studies and engineering estimates of the leading control technologies revealed that annual savings of up to $4 million dollars at 1997 prices could be obtained in the Chicago area by trading in a well designed market (Case and Dunham 1997, p. 30). The cost-savings widely reported in the sulfur-dioxide market added to the incentive.

So pervasive was this information that the authors present, as an example, the following illustrative model that indicates some of the arguments that paved the way for initiation of the market. However, many of these models abstract from the constraints that influenced this market's performance. Therefore, the model has been expanded to include the role of traditional regulation as an aid in understanding the problems encountered. First the basic model is presented, and then the extensions.

2.1. *Pure cap-and-trade: no command-and-control*

The regulator first determines the market design features such as emission baselines, the definition of tradable permits, the cap (i.e. expected reduction in emissions), permit allotments, banking horizon, and market rules. The regulator then steps back and decentralizes specific control decisions to emitter firms. An emitter firm, with its allotted portfolio of dated permits, is assumed to know its marginal control costs. Knowing these costs, its endowments of permits and the market-determined permit price, the firm's objective is to make cost-minimizing decisions about the degree of trading and the extent of emissions reduction by control measures.

Because of the fundamental rule that each participant must return a permit to the regulator for every 90.719 kilograms of emissions during the season, the following identity holds for n emitters:

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

where h_i refers to baseline emissions of the ith firm, q_i is the allocation of currently dated permits for the ith firm, r_i is the reduction in emissions during the season for the ith firm, and t_i is the number of permits bought (if positive) or sold (if negative) during the season for the ith firm. For purposes of simplicity in developing the model, the authors assume no banking. This assumption does not affect the main conclusions derived from the model. Banking is discussed in the section dealing with the market's performance. Permits issued for future dates may not be bought or borrowed from the future for current use. All variables are measured in 90.719 kilogram units of VOC emissions.

Under traditional regulations, $t_i \equiv 0$ 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 must hold with equality and r_i and t_i become decision variables of the firm. The optimal value of one determines the optimal value of the other.

The emitter's objective under trading is to minimize the sum of control costs and trading costs. The control cost function is assumed to be ever increasing and denoted as $c_i(r_i)$. Assuming that the firm takes the permit price as market determined, and there are no transaction costs, trading costs are then pt_i. The optimization problem is:

$$\min_{r_i} \; c_i(r_i) + pt_i, \tag{2}$$

$$\text{s.t.} : \; r_i \geq 0,$$

$$t_i = h_i - q_i - r_i.$$

The first constraint requires that the emission reduction not be negative. The permit program imposes a second constraint, because the firm must hold enough permits to cover emissions, after reducing emissions by r_i. Since this constraint must hold with equality, it can be used to eliminate t_i in the objective function, yielding the following equilibrium conditions in an efficient market:

$$\partial c_i(r_i)/\partial r_i - p \geq 0, \tag{3}$$

$$r_i[\partial c_i(r_i)/\partial r_i - p] = 0, \tag{4}$$

$$r_i \geq 0. \tag{5}$$

The solution to equations (3), (4) and (5) 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. For every cost-minimizing firm, marginal control costs are equated to p. Aggregate control costs are also minimized when this condition holds (Montgomery 1972). The condition would not ordinarily hold for traditional regulations that require each emitter to adopt specific regulatory controls.

Equation (4) implicitly defines the firm's optimal reduction, $r_i^*(p)$, as a function of the permit price. The firm's net permit demand is: $h_i - q_i - r_i^*(p)$. In equilibrium, the total net demand of permits must be zero, giving the following equilibrium equation:

$$\sum_i h_i - q_i - r_i^*(p) = 0. \tag{6}$$

Prior to the start of the market, models similar in spirit to the illustration were used to prepare estimates of transactions and equilibrium permit prices based on available marginal control cost data. The estimates converged around \$250 per tradable permit, worth 90.719 kilograms of emissions, with sufficient transactions to assure savings (Case and Dunham 1997), although some ranged upwards to \$1000 (Evans *et al.* 1997). However, the successful performance of any model depends upon its applicability to a complex industry, the specific market design features worked out by the regulator in the context of strong interest group pressures, and the very important coordination with other regulations.

2.2. *Compliance costs with command-and-control*

Before analyzing the situation where firms are subject to command-and-control regulations as well as a tradable permit program, it is useful to consider the situation where only the former prevails. Specifically, each firm must reduce its emissions by at least R_i, where R_i depends on production processes and output. Assuming the abatement cost function is increasing, the firm's optimization problem is trivial, and each firm reduces emissions by only R_i. Total compliance costs equal:

$$\sum_i c_i(R_i). \tag{7}$$

2.3. *Compliance costs with a permit program and command-and-control*

The final case combines command-and-control with the permit market. The optimization problem is the same as equation (2), except that the first constraint is slightly different:

$$\min_{r_i} \; c_i(r_i) + pt_i, \tag{8}$$

$$\text{s.t.} : r_i \geq R_i,$$

$$t_i = h_i - q_i - r_i.$$

Command-and-control regulation requires the firm to reduce emissions by at least R_i. As in section 2.1, firms must purchase permits to cover excess emissions, as the second constraint shows.

The analysis focuses on the case in which command-and-control or centralized regulations reduce aggregate emissions below the cap, i.e.:

$$\sum_i h_i - R_i < \sum_i q_i. \tag{9}$$

The Appendix demonstrates that the sum of compliance costs across firms is exactly the same as under centralized regulation. That is, total costs are equal to expression (7), and the permit program does not reduce costs relative to command-and-control. The intuition behind this result derives from the fact that centralized regulation reduces aggregate emissions below the cap. Given permit allocations, some firms may not have enough permits to cover emissions after complying with command-and-control, but because aggregate emissions are below the cap there are many more firms that have excess permits. Given a competitive permit market, the permit price is bid down close to zero, allowing for transactions costs. The command-and-control regulations render the permit market redundant, essentially requiring some firms to go through the formality of obtaining permits from other firms at a cost solely reflecting transactions expenses. However, the permit market, does not affect firms' abatement decisions. Section 4 provides empirical evidence that this is exactly what has happened in the Chicago market.

3. Market design negotiations and consequent compromises

The regulator appeared to recognize that the initiation of a new, untested decentralized approach to emissions control would be more difficult in practice than in theory. The first models abstracted from traditional regulations and many important economic and political considerations. The business community was only partly supportive. Environmental groups and even some regulators were concerned about hot spots and monitoring and enforcement. The well-known experience of the RECLAIM (Regional Clean Air Incentive Market) in the Los Angeles extreme ozone non-attainment area is instructive in this connection. The attempt to introduce VOC emissions trading in that area floundered on the resistance of the business community to allotment rules, to concern about costs of the requirement that bar-coded labels be introduced on every container that included VOCs, and to the argument that the cap would impede economic growth (Lents 2000). Many environmental groups were concerned with the issue of hot spots, small areas within the larger region of trading that might experience increases in emissions after trading. In the face of this resistance, the governing body decided to drop the VOC market and continue with the markets for nitrogen oxides (NO_x) and sulfur dioxides (SO_2), which, it should be noted, called for deeper cuts in emissions than the Chicago VOC program.

VOC emissions arise from a wide variety of processes including combustion, painting, coating and the like, engaged in by a diversity of emitting firms of which about 250 in the Chicago area were mandated to participate in the markets. Within these firms, which varied markedly by size, there were close to 4000 distinct emitting processes subject to point source controls. Some VOCs are hazardous air pollutants (HAP) with different toxicity impacts, and VOCs vary in terms of their ozone reactivity. In addition, ozone formation depends upon important considerations such as meteorological conditions and the proportion of NO_x concentrations in the air, the latter being a non-linear relationship. The agency had the results of sensitivity runs from a series of air-shed models calibrated to the Chicago area that revealed that the area was VOC-limited, meaning that if only NO_x concentrations were reduced, then ozone concentrations could increase (Illinois EPA 1995, p. 18). Rural areas and distant downwind regions were found to be NO_x-limited, which led the agency to focus on reducing VOC emissions in the Chicago program and, because of some regional movement of pollutants, to call for regional and national efforts to reduce NO_x emissions.

Because of these complexities, many unique to VOC control, the Illinois EPA spent several years in dialogue with all interested groups preparing a final program that sought to address these complexities and balance the competing interests. Members of the business community, some of which were concerned about the effect of the market on growth, received a modest VOC cap reduction of 12% relative to baseline emission values.

These baseline emissions were defined as the average of two years of seasonal emissions prior to the emitter's entrance into the market.

In principle, the cap should be determined by considerations of the benefits of health and welfare as part of equating control costs, but that determination is difficult to make since it requires extensive data, could be contentious and takes time. Bargaining and negotiation has resulted in all cap-and-trade markets on this issue. In Chicago, emitters were given the full number of tradable permits for HAP emissions because of the stringent controls on these toxic substances. If emitters had introduced advanced controls prior to the market design, the resulting emissions were also not subject to further reductions. The VOC cap, which turned out to be closer to 10%, was a compromise. This small cap turned out not to be binding on a critical majority of the emitters who were reducing emissions under pressure from centralized regulations, as the authors will show.

Environmentalists negotiated a short banking horizon of one year after tradable permit issuance to help prevent neighborhood hot spots and inter-temporal emission spikes. Most important, they received assurance that traditional command-and-control regulations would be continued and extended, including tight HAP emission controls. Other important agency decisions were to have a unified market and a common tradable permit for all types of VOC emissions despite proposals for a segmented market to prevent neighborhood hot spots, and for separate permits for HAP emissions (Illinois EPA 1995). The effects of these complex and unusual design decisions are made apparent in the market's performance for the first seven years as presented in Table 1.

4. Market performance 2000 to 2006

The authors have assembled, reorganized and in a few instances corrected data from the agency's annual performance reports in order to reveal in Table 1 the structure of the market and to bring out clearly the unexpected performance of the market over the first seven years. The outcomes were neither in accord with the predictions of unrestricted cost-minimizing models, which did not include the effects of command-and-control regulation, nor with many of the expectations of interest groups.

The first row reports aggregate baseline emissions during the ozone season from May to September. They vary from period to period as a few emitters drop out or enter the market. In aggregate these totals comprise about 20% of all such emission arising from stationary, mobile and small area sources in the area.

Allotted tradable permits in row 2, locally termed allotment trading units, or ATUs, are less than the 12% reduction of row 1 for reasons mentioned. Aggregate allotments averaged about a 10% reduction from baseline.

Row 3 reveals aggregate VOC emissions during the ozone season as measured by the number of permits returned to the agency. Emitters report seasonal emissions from plant records based on VOC coefficients and on inputs and process emission rates, which are sampled and checked by the agency. The most accurate record could be provided by continuous emissions monitoring, but that was not possible considering the diverse sources and complexity of VOC emissions. This measure of actual emissions shows a significant reduction far below the cap, baseline, and far below expectations of concerned groups. While these reductions are sometimes cited by the agency as a success of the market system (Illinois EPA 2005, p. 6), the authors find abundant evidence, to be presented in the next section, that they were due to the pressures of command-and-control and not primarily due to the cap-and-trade program. That is, they would have occurred, in large part, without the market program.

Table 1. Market-wide ATU (tradable permit) transactions and prices for the years 2000–06.

Category	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006
1. Baseline in ATUs	105,479	107,777	108,718	108,424	108,549	111,186	110,875
2. Allotted ATUs	95,398	97,124	98,164	97,859	98,011	100,635	100,363
3. ATU retirements (emissions)	59,112	51,703	51,164	43,601	44,537	42,259	42,740
3.1 Vintage 2000 ATUs	58,848[a]	21,407					
3.2 Vintage 2001 ATUs		30,215	31,575				
3.3 Vintage 2002 ATUs			19,410[a]	30,380			
3.4 Vintage 2003 ATUs				13,18[a]	33,195		
3.5 Vintage 2004 ATUs					11,340[a]	31,537	
3.6 Vintage 2005 ATUs						10,722[a]	33,682
3.7 Vintage 2006 ATUs							9058[a]
4. ATU transactions							
4.1 ATUs traded	1643	3702	4483	6902	6216	9533	8479
4.2 Number of buyers	35	27	33	35	38	42	36
4.3 Number of sellers	23	21	25	31	36	34	36
5. Banked ATUs							
5.1 Vintage 2000 ATUs	37,435						
5.2 Vintage 2001 ATUs		73,401					
5.3 Vintage 2002 ATUs			82,358				
5.4 Vintage 2003 ATUs				84,678[b]			
5.5 Vintage 2004 ATUs					89,480		
5.6 Vintage 2005 ATUs						92,173	
5.7 Vintage 2006 ATUs							93,875
6. Expired ATUs							
6.1 Vintage 2000 ATUs		13,924					
6.2 Vintage 2001 ATUs			33,760				
6.3 Vintage 2002 ATUs				48,374[b]			
6.4 Vintage 2003 ATUs					49,740		
6.5 Vintage 2004 ATUs						53,065	
6.6 Vintage 2005 ATUs							42,414

(continued)

Table 1. (*Continued*).

Category	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006
7. ATU prices							
7.1 Average price	$75.87	$51.93	$32.85	$18.75	$19.65	$13.99	$17.07
7.2 Price range	$50– $150	$38– $100	$20– $50	$8– $30	$5– $23	$5– $27	$5– $22
7.3 Vintage 2000 price	$75.87	$50.54					
7.4 Vintage 2001 price		$63.93	$32.06				
7.5 Vintage 2002 price			$31.04	$18.34			
7.6 Vintage 2003 price				$20.65	$19.82		
7.7 Vintage 2004 price					$21.61	$16.10	
7.8 Vintage 2005 price						$12.93	$17.03
7.9 Vintage 2006 price							$17.19
8. Number of participants	179	172	172	175	174	167	166

Sources: Illinois EPA Annual Performance Review Reports, (2000 to 2006).

Notes: Units are in ATUs: an ATU = 90.719 kilograms of VOC emissions. ATUs have a two-year life. The internal consistency of the table is affected by several types of transactions not enumerated, such as minor gifts and purchases from a standby account. [a]Denotes calculated data. [b]Denotes corrected data.

The agency apparently did not allow sufficiently for this trend in the reduction of emissions in establishing the cap and designing the market. The problem may have arisen due to the many complex decisions involved in determining individual firm emissions, which included the baseline determinations, the delayed participation of some emitters, the difficulty of checking seasonal rather than annual emissions, and the fact that over half of the individual firm end-of-season emission reports had to be returned for correction (Illinois EPA 2003). Meanwhile another unit of the agency was implementing a steady stream of new command-and-control regulations based on either new state and federal regulations, or on the lagged implementation of prior regulations (Tietenberg 2003).

Row 4 reveals that trades were far below agency or observer expectations. Rows 5 and 6 raise some of the most serious questions about the deviation of performance of the market from expectations. In row 5, the Table makes clear that an increasing and very large proportion of each year's aggregate allotment of short-lived permits was being banked. For example, over 90% of the 2006 allotment was banked. Such huge banks, not being used to cover emissions, mean that firms were forced to allow permits to expire without use after the initial year 2000.

Row 6 confirms the consequences of these banks and contains the startling information that the proportion of expirations became very large so that by 2006 over 40% of the 2005 allotment was allowed to perish without use. The enormous volumes of permit banks and the existence of a significant number of permit expirations have not been reported in any other cap-and-trade market.

Not surprising, in view of these outcomes, was the trend of declining prices reported in row 7. The decline over the six years to an average of about $17 per permit in 2006 was far below estimates of the marginal control costs of reducing emissions in the studies cited. Given the large number of permit expirations, these prices probably reflect transactions costs. Prices also reveal evidence of backwardation in several years when prices of permits with another year of life sell for less than expiring permits. These price outcomes are inconsistent with any claim that the permit price corresponds to marginal control costs. In fact, the reduction in emissions in excess of expectations indicates that marginal control costs were considerably above permit prices as brought to light in the cost curves estimated by Case and Dunham (1997).

5. Causes of the unexpected market performance

The authors considered three major hypotheses being offered: that the agency over-allotted permits, which would explain why the market was awash in them; that shut-downs of firms led to emission decreases and additions to the supply of available permits; and that continuing and extended command-and-control regulation conflicted with market incentives and undermined cost-effective firm decisions.

To analyze the over-allotment idea, that permits issued by the agency were more than required by the cap and therefore greatly limited emission reductions and influenced permit purchases and sales, the authors tested the statistical significance of two constructed variables that could be proxy variables for over-allotment. The first was a dummy variable set to unity for all firms which received permits in full for HAP emissions or which received extra permits because they had installed advanced controls. This variable proved to have limited significance as an explanatory variable for permit purchase or sales during the six years of market activity (Kosobud *et al.* 2006). For the second variable, the authors estimated the *number* of extra permits allocated to firms because of HAPs or other reasons, estimates that were based on our own firm-by-firm check. These extra permits amounted to a little over 2% of the total. This variable also proved to have limited significance in explaining transactions. Moreover, over-allotment does not seem consistent with the fact that emissions were much lower than baselines because of continuing traditional regulation on HAP and other VOC emissions.

A recent paper has put forward the claim that over-allotment was a main source of excessive permits and a cause of the market's unexpected performance (Evans and Kruger 2006). Shutdowns also played a role in their discussion. They provide little direct evidence for these claims. Their main source of support for this position is the fact the actual emissions were down by 33% below the cap in 2000 because baseline emissions authorized by the agency were too high. However, in their model nothing prevented emitters with excess permits from increasing emissions up to the cap.

With respect to the second hypothesis, it is true that the shutdown of facilities or specific processes result in permits that continue to be allotted. The agency reports that 2.7% of allotted permits were allocated to shutdown facilities in 2006, a typical year (Illinois EPA 2006). However, these permits can also be sold or transferred increasing emissions elsewhere. Illinois EPA allotment reports reveal that close to 20% of these permits were sold or transferred resulting in increases in emissions elsewhere. These facts limit the weight to be placed upon the contribution of shutdowns to emission decreases.

With regard to the third hypothesis, the authors considered several types of evidence that could reveal how command-and-control regulation conflicted with the cap-and-trade program. The authors' hypothesis is that the former played a major role in reducing VOC emissions prior to and during the period of the market effort. Indicative of the pressure of these requirements on reducing emissions prior to the market are the data available on aggregate Illinois emissions over time and on more specific facility emissions. The former revealed a decline of over 60% from 1981 to the start of the market and the latter, more closely related to market participants, revealed a more precipitant decline from 1992 to 2001 (see Figure 1 and sources cited). Such command-and-control regulations also applied to other ozone non-attainment areas, most of which required less stringent controls than the severe classification of the Chicago area. For these areas the figure reveals about a 25% national decline from 1983 to 1999. This trend provides one strong piece of evidence about the pervasive reductions brought about by traditional emission point controls.

A variable constructed to measure this dominant command-and-control effect proved highly significant in explaining emission reductions and the impact of traditional regulations, before and during the market period, on individual firm purchases and sales of permits (Kosobud *et al.* 2006, chapter 6). The details of the statistical tests carried out by probit analysis are fully available in that publication, and need not be repeated here, as the main result can be conveyed succinctly in Figure 2. The variable was prepared for each firm by calculating the ratio of 1998 emissions to historical emissions (an average of 1994–1996 volumes) on the grounds that command-and-control regulation had continued to reduce VOC emissions before the start of the market, but after determination of the historical events. Individual firm data were obtained from the Illinois EPA for this computation.

It is plausible to conclude that these trends continued after 1998. Evidence for this view is available in the decline in reported emissions from 2000 to 2006 of over 27% as shown in Table 1, row 3. These were continuing declines in counterfactual emissions brought about by traditional regulations as if the cap-and-trade market did not exist. This decline in emissions in the VOC program, far below the cap, cannot be explained by the changes in the number of participants as indicated by the small change in aggregate baseline values in Table 1.

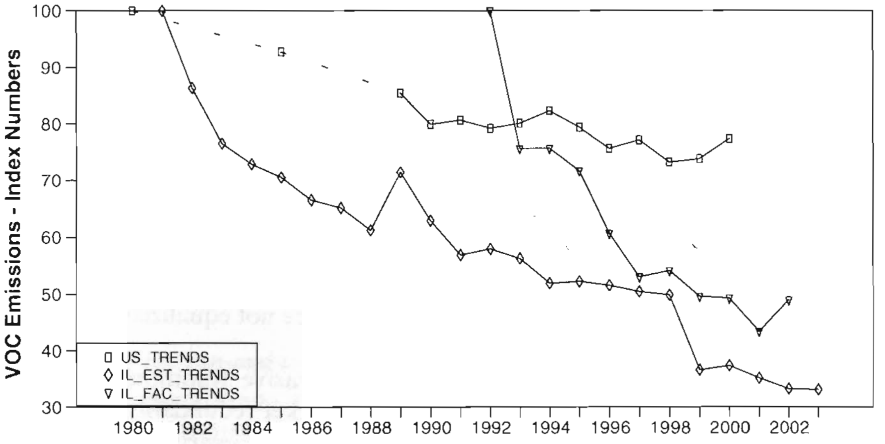

Figure 1. US and Illinois annual VOC emission trends.
Sources: US trends from US EPA 2003. Illinois state estimated total and facility trends from Illinois EPA 2003.

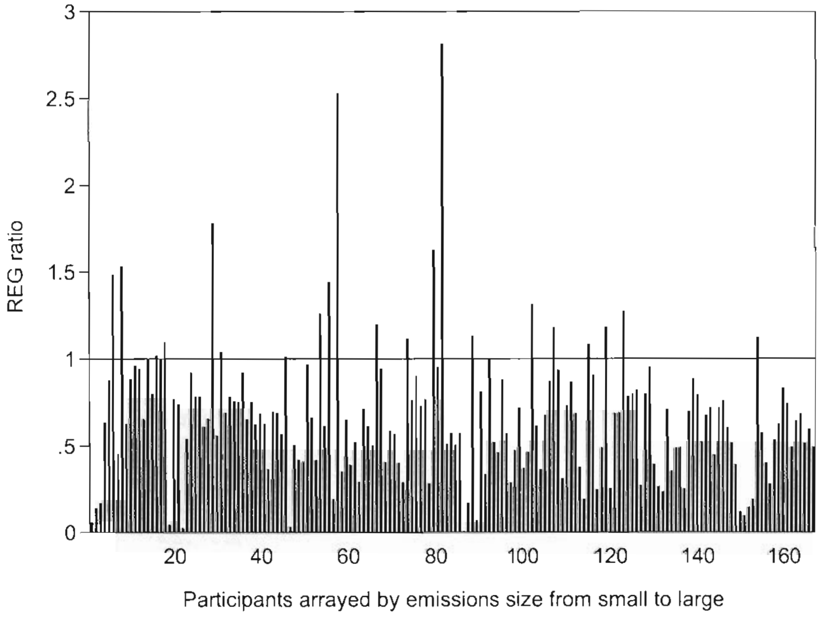

Figure 2. Variation in REG ratios by emission size of participants ($N = 168$).

As can be seen in Figure 2 the ratio variable, termed 'REG', by 1998 already lies well below unity for most firms, indicative of the heavy pressures for reduction on emissions by command-and-control regulation. Those firms for whom the ratio was far below unity had excess permits to sell and were attempting to do just that, whereas the smaller number of firms with ratios above unity were more often in the market to purchase permits. Statistical probit tests revealed that the REG variable had a significant, but positive, coefficient when permit purchases were regressed on it, and a significant, but negative, coefficient for sales.

A further insight is provided by Figure 2 where it is revealed that firms with larger emissions were not favored with smaller permit reductions from baselines. Moreover, the idea that command-and-control falls evenly on emitting firms is refuted by the wide variation of the ratios, which can be attributed to the wide variation in VOC emitting processes and inputs among firms. Many such sources are subject to specific, detailed controls applicable to specific emission processes that are monitored by the state agency.

It may be concluded that marginal abatement costs are not equalized across emitters, a requirement for minimum aggregate control costs.

The existence, continuation and extension of pervasive traditional command-and-control regulation reduced emissions and made the market redundant. In effect the local agency had utilized, without coordination, two regulatory instruments to achieve one target – emission reductions – with the result that command-and-control regulations by reducing emissions significantly undermined trading and led to few transactions, excessive banks and expirations of permits. The agency prior to the start of the market extolled this two instrument approach hoping they would be complementary. As the agency stated, "Illinois does not allow sources to avoid other emission limits by participating in ERMS", where ERMS stands for the Emissions Reduction Market System (Illinois EPA 2001, p. 4). However, the unforeseen consequence was that command-and-control was a dual regulatory system to the cap-and-trade market, the former driving up marginal control costs while the latter was ineffective in saving control costs.

Cap-and-trade markets for other pollutants have an underpinning of command-and-control regulations also, but most of them have deeper caps, which make the cap binding, and have longer if not infinite permit banking horizons, which facilitates more efficient inter-temporal cost minimization.

6. Alternatives to correct the present problems

A control policy change is required. Abandonment of the cap-and-trade program is reported to have been considered by the agency, but was held in abeyance in view of future policy changes that might require further reductions in VOC emissions, for which the cap-and-trade approach could be valuable. Redesigning the cap-and-trade program, if such redesign were effective, could salvage some of the initial hopes for a cost-effective regulation and serve as a model for pollution control elsewhere. A central issue for any redesign would be how to coordinate the centralized command-and-control regulation with the decentralized market incentives.

6.1. Abandonment of the market and return to the command-and-control approach

Traditional regulations had been in widespread effect long before introduction of the market, and remain in effect at present, so that the regulating and regulated communities are familiar with specific control measures, their implementation, monitoring and enforcement. There is unlikely to be a unified chorus of objections from the environmental community to scrapping the market approach, where suspicions were raised about the abdication of control to an autonomous and anonymous market system. Even some members of the business and regulating community had reservations about the market system as being just another layer of regulations, along with the traditional measures, that they knew so well from experience. But supporters of market incentives from these groups are now much more numerous than 20 years ago.

The academic community in general had high hopes and great expectations for the path-breaking cap-and-trade market at the local level, and many undoubtedly would join the authors in resisting abandonment of a potentially decentralized, cost-effective and flexible approach. The fact that many urban communities are adversely affected by ground-level ozone, and the fact that the problem, in general, is increasing in many countries, means that the negative experience of the Chicago approach could have a chilling effect. A redesign of the emissions trading program is worth careful attention.

6.2. Redesign of the cap-and-trade approach

If the present cap-and-trade design is not to disappear as a viable policy option, redesigning its significant features and improving its coordination with command-and-control measures are essential. A starting place for purposes of comparison is to set the major design features of the VOC market alongside those of other extant cap-and-trade programs. This is carried out in Table 2 for four leading programs currently in effect to reduce sulfur dioxide (SO_2), nitrogen oxide (NO_x), and carbon dioxide (CO_2) emissions. Two features stand out in striking contrast. First, the required reduction for the VOC market at 12% (10% in reality) is far below the other reductions with the possible exception of the European CO_2 market where the present cap is subject to increases in the future. It is of interest that some of the early low permit price problems experienced by the carbon market have a resemblance to the VOC market.

Second, the VOC banking horizon of one year after issuance is an outlier except for the RECLAIM markets where much deeper cuts in emissions are required. That is, tradable permits are much longer lived in three of the other four programs, thus allowing for decisions, where appropriate, to reduce emissions and increase banks for future use. Not unrelated to these different design features, in the authors' view, is the fact that transactions are much lower in the VOC market and tradable permit banks much higher. No other market has as yet revealed permit expirations, with the possible exception of some expirations in 2007 in the EU carbon market. The large expirations in the VOC market remain as the leading symptom of design failure. While such differences are not compelling reasons for revising the cap and shelf-life of the VOC permit, they do focus attention on these features, and especially their interaction with the numerous traditional regulations affecting VOC emissions, and thus market activity.

As mentioned, in principle the cap should be set in terms of health and welfare objectives or as a surrogate, in terms of helping the region achieve attainment of the 8-hour ozone standard at minimum cost. Setting the appropriate cap has rarely been based on a careful benefit cost analysis. Even in the successful sulfur dioxide market, the US Congress set a cap at about 50% for political reasons. Setting a binding cap would raise some resistance, but a meaningful cap is the centerpiece of a decentralized market system if cost-effectiveness is to be achieved. There are essentially two ways to redesign the cap: either reducing the baseline emissions, against which the same cap would apply, or changing the cap to reduce emissions from the same baseline. A combination of the two is also possible. For example, a firm with a baseline of 100 ATUs could have its baseline reduced to 75 and under the same 88% cap receive 66 tradable permits. Or, the firm's baseline could remain unchanged at 100 and the cap could be changed to 66% yielding again 66 tradable permits.

The least disruptive choice would be a new cap brought into line with new policies. The ozone standard has been tightened from 0.12 ppm (parts per million) on a one hour basis

Table 2. Comparative design features and selected performance of five current cap-and-trade markets.

Features	ERMS (VOC)	RECLAIM (SO_2 & NO_X)	SO_2	NO_X budget	EU (CO_2)
Trading start date	2000	1994	1995	2004	2005
Baseline period	Average of two years prior to firm's market entry	1989–92 negotiated	1985–1987	1990–2000 Compliance Supplemental Pool	Variable by country, but earlier than 2005
Aggregate cap on baseline	12%	Declining to 60% in 2002 for NO_X and to 84% in 2002 for SO_2	About 50% in 2 phases	Varies by state about 35% for Illinois	Varies markedly by country
Allotment rules to firms[a]	Free	Free	Free	Free	Mostly free, but limited auctioning permitted
Permit life (banking)	One year after issuance	Banking and borrowing between six month compliance cycles	No limit unless policies change	No limit; discounted if bank is large	No limit within trading periods
Transactions as a % of allotments	9.5	40	50	40	25
Banks as a % of allotments	92	30	25	25	Under 10%

Sources: For the ERMS VOC, Illinois Environmental Protection Agency Performance Reports (2000–2006). For RECLAIM, Lents (2000). For SO_2, Ellerman *et al.* 2000. For the NO_X Budget, Martin *et al.* 2007. For the EU CO_2, Ellerman and Buchner 2007. Most data on transactions and banks refer to estimates available in 2005.

Notes: ERMS is the acronym for the Chicago Emissions Reduction Market System. RECLAIM is the acronym for Regional Clean Air Incentives Market program implemented in the Los Angeles region. SO_2 stands for the acid rain sulfur dioxide market. NO_X Budget stands for the nitrogen oxide cap-and-trade market. EU CO_2 stands for the European Union carbon dioxide markets.

[a]Individual emitter allotments may not equal the cap times individual benchmarks, but a negotiated amount.

to 0.08 ppm on an 8-hour basis. Further tightening is under serious discussion. The example of a new cap at 66% may not be far from what would be required.

Concurrent with the redesign of the cap should be a substantial lengthening of the permit banking horizon, which should find support in the business community as it would enable them to secure inter-temporal cost savings. The banking shelf life of other permits noted in Table 2 ranges up to an unlimited horizon. That horizon is unlikely to be established for the VOC permit, but a major time extension should raise few objections.

These changes would have an impact on permit prices, as the cap became more binding and emitters move up the marginal control cost functions. As for equilibrium prices, the VOC emissions control industry has advanced since the 1990s and now offers new and cheaper options (DePriest 2000, p. 185). Further reductions required by the new cap should be obtainable below the early estimates of $258 per ATU made in 1996 (Case and Dunham 1997).

6.3. New roles for command-and-control regulations and regulatory coordination

Several problems emerge both from the complexity of the chemistry and meteorological conditions giving rise to ozone formation, and from the possible neighborhood effects of emissions trading. These problems are difficult to manage in a decentralized market system that is too blunt to resolve them, but they do provide opportunities for the use and coordination of command-and-control regulation.

The first problem, an inter-temporal one, arises because high concentrations of ozone occur during relatively brief periods of hot summer weather. The hot summer of 2007 revealed a number of days with spike readings over 85 ppb of ozone, and more can be expected. The other problem, a spatial one, arises because trading may result in higher than baseline emissions arising in neighborhoods, the hot spot issue, due to trading even though aggregate levels have declined.

For the first problem, the immediate question is predicting these spikes. The agency now announces Air Pollution Action Days that have turned out to be good predictors of these spikes. The authors carried out a regression of ozone concentrations on these days and found a significant positive effect, somewhat different from their expectation (Kosobud *et al.* 2006, chapter 8). This positive effect was due to the agency's method of calling around the larger region to obtain an account of the build-up of ozone and its precursors and the movement of weather and wind, thus obtaining a forecast of pollution levels in the area. This forecast can provide the basis for regulatory action.

On those days when high ozone levels, as an indicator variable, are forecasted, the Illinois EPA could implement more stringent traditional regulations to apply to stationary sources in the entire region to last until the emergency is over, typically a few days. Changing the ratio of permits that could be used during these days, a potential feature of the NO_x trading program, is not feasible because of numerous real-time VOC emission monitoring difficulties, which also limits discounting of banked permits.

For the larger sources, such as refineries, drug and chemical companies, the agency could require extra storage containers, compressors or afterburners during critical periods. Less stringent regulations for smaller facilities, such as plating, cleaning and painting companies, such as a reduction in hours of operation, could prove sufficient. These measures could help achieve the benefits of banking and borrowing of permits in the VOC market without incurring overriding costs.

Electric generating facilities in the area need not be covered by such short-term requirements as the few facilities in the area generate only a small percentage of VOC emissions and over half the local electricity use is generated by nuclear energy. In addition, the welfare costs of reducing electricity output during hot summer periods could be very high.

A recent study of the Houston, Texas region indicates what could be done in coordinating regulatory systems. Refinery hydrocarbon emissions were found to be variable day-by-day and week-by-week and when high led to ground-level ozone increases. The study proposed instituting temporary storage and compressor equipment to be used during critical periods (Nam *et al.* 2007). Further research into regulatory coordination deserves a high priority.

With regard to the second problem, neighborhood effects, the authors carried out a systematic study of hot spots (emission increases over baseline values) on a zip code small area basis and found only an insignificant number of such spots, and these were in outlying areas with few residents. Using data provided by the Illinois EPA on individual firm emissions, the authors found fewer than 4% of codes with such increases over baseline out of 298 zip codes in the non-attainment region.

The persistence of such hot spots could be the more serious problem. During the period 2000 to 2004 persistent readings were recorded in three codes in four out of five years, and one code that recorded increased emissions in all five years (Kosobud *et al.* 2006, chapter 7). If significant persistent neighborhood increases are detected in the future, typically during the reporting period at the end of the ozone season after September, during the following season the agency could then suspend the purchase of tradable permits in the particular code, and, if necessary, increase traditional regulations in the neighborhood until the hot spot was extinguished. As the agency requires detailed emission reports and prescribes detailed operating permits on emissions from processes and inputs, the data are available for implementation of this policy.

These proposals would establish distinct objectives for the two major regulatory systems. The decentralized market system would be utilized to obtain cost-effective reductions of emissions and the centralized command-and-control system would be utilized to control neighborhood hot spots and inter-temporal spikes in emissions.

7. Conclusion

The authors have found that the pioneering Chicago cap-and-trade market to reduce stationary-source VOC emissions requires a major redesign if it is to contribute to the cost-effective attainment of regional air quality goals and serve as a model for use elsewhere. The study makes two contributions in analyzing the problem and recommending what to do about it: one is the specific redesign of the market program and the other is a proposal on how to coordinate two apparently inconsistent regulatory systems.

The fact that emissions are below the cap is primarily due to continuing and ever more comprehensive command-and-control regulation. That is, there are two uncoordinated regulatory instruments in use to achieve one target, emission reductions. This is a classic problem in the design of economic policy (Mundell 1968), now emerging in the area of environmental regulation.

To illustrate this design flaw, the authors compared the design of the VOC program with four other cap-and-trade markets in existence and found the VOC program far out of line with the others with respect to the level of the cap, permit expirations and limited banking horizon. The coordination problem requires a redesign of the existing cap-and-trade design in view of the findings that the shallow emission reduction required and short shelf life of the tradable permit, combined with command-and-control regulation, have resulted in the market incentive program not being binding on most emitters.

The recommendation is that the cap be tightened, which would find support among environmental groups but resistance in the business community. The recommendation is that the shelf life of the permit be lengthened, which would find support in the business community but resistance in the environmental communities. Such changes could make the market more binding on emitter decisions, and contribute to the desired cost-effectiveness.

Traditional regulation could be reoriented to be applied at critical times to problems that the blunt market system cannot resolve. The important problem of neighborhood increases in emissions despite aggregate reductions – the hot spot problem – could be addressed by restricting purchases of permits and instigating tighter command-and-control measures in these neighborhoods. The more troublesome short-term spikes due to precursor concentrations interacting with hot summer days require a different approach. The agency's forecasts of Air Pollution Control Days, based on reports from a larger region, have been a good predictor of high ozone concentrations. Based on these forecasts, more stringent command-and-control regulations could be imposed on all emitting firms for the few days of such occurrences.

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Appendix

The Appendix shows that if command-and-control regulations reduce emissions below the cap, the permit price is zero and compliance costs are the same as under command- and-control regulation alone, as shown in expression (7). For a given permit price, $p \geq 0$, firms can be partitioned into two groups. For a subset of firms, C, the marginal abatement cost at $r_i = R_i$ is greater than the permit price, so these firms do not reduce emissions more than required by command-and-control. More precisely, the first constraint in (8) binds, and firms reduce emissions by R_i. Indexing over j firms, the total net demand for permits is:

$$\sum_{j \in C} [h_j - q_j - R_j]. \tag{A1}$$

For the second set of firms, UC, the constraint does not bind. These firms reduce emissions until the marginal abatement cost equals the permit price, as in expression (3). Indexing over k permits, the net permit demand for these firms is:

$$\sum_{k \in UC} [h_k - q_k - r_k^*(p)]. \tag{A2}$$

Because firms face the same permit price, the firms in UC either have lower abatement costs or lower emission reductions required by command-and-control. Combining expressions (A1) and (A2) yields the total net permit demand:

$$\sum_i t_i = \sum_{j \in C} [h_j - q_j - R_j] + \sum_{k \in UC} [h_k - q_k - r_k^*(p^*)] = 0. \tag{A3}$$

For an equilibrium with a positive permit price, p^*, net permit demand must equal zero.

Two final pieces of notation simplify the following discussion. Let the total number of permits allocated be: $Q = \sum_i q_i$. Command-and-control requires each firm to reduce emissions by at least R_i. This regulation therefore places an upper bound on emissions, labeled C:

$$\sum_i h_i - R_i = C. \tag{A4}$$

The relative magnitudes of C and Q determine how the permit program interacts with the command-and-control regulation. If Q < C, emissions under the cap are below the level required by command-and-control. Some firms reduce emissions more than R_i because marginal abatement costs are less than the permit price at R_i.

The second possibility is that Q > C, in which case command-and-control regulations reduce aggregate emissions below the cap. Section 2.3 discusses this situation, corresponding to expression (9).

Inserting the definitions of C and Q into the middle term in (A3) gives:

$$[-Q + C] + \sum_{k \in UC} [R_k - r_k^*(p^*)]. \tag{A5}$$

The first term in brackets is negative by assumption. The second term must be less than or equal to zero because by construction $r_k^*(p^*) \geq R_k$ for $k \in UC$. Thus, net permit demand is negative for any positive price, or in other words, the permit price must be zero in equilibrium.

This result has an important implication for compliance costs. Assuming that marginal abatement costs are strictly positive for all firms, firms will not reduce emissions more than R_k; UC is an empty set. Since all firms reduce emissions by exactly R_k, total compliance costs must equal total costs in the case with command-and-control and no permit market, given by expression (7).