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Pollution Permit Allocations and Firm-Level Emissions in Cap and Trade Programs

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Abstract

According to the Coase theorem, if property rights to pollute are clearly established and emissions markets nearly eliminate transaction costs, the market equilibrium will be independent of how the permits are initially allocated across firms. Using panel data from Southern California's RECLAIM program, we find that initial allocations are a statistically significant determinant of firm-level emissions, particularly for firms facing relatively high transaction costs. These results suggest that care must be exercised in the initial allocation of permits to ensure efficiency.

Outline

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> *"By employing a system that generates the most environmental protection for every dollar spent, the trading system lays the groundwork for a new era of smarter government regulation;… [one that] relies on the market to reconcile the environment and the economy."*
>
> *Statement by President George Bush upon signing the 1990 Clean Air Act Ammendment.*

1. Introduction

Using data from Southern California's Regional Clean Air Incentives Market (RECLAIM), we test the hypothesis that the initial allocation of pollution permits does not affect firm-level emissions in equilibrium. One of the most appealing qualities of the "cap and trade" (CAT) approach to regulating industrial emissions is that, provided transaction costs are negligible, the market should direct those firms with the lowest abatement costs to reduce emissions first, regardless of how permits are initially allocated. We find that permit allocations are a significant determinant of firm-level emissions in the RECLAIM program. Consequently, an important administrative advantage of the cap and trade approach does not hold. We also find that the relationship between permit allocations and emissions is stronger among some firms who likely face higher transaction costs.

Over the past three decades, governments have substantially increased the environmental regulation of industry (Rinquist and Feiock, 1998, Haq et al., 2001). With this increase have come some major successes. The quantity and toxicity of emissions from U.S. industrial air pollution sources has decreased significantly, largely as a result of the federal Clean Air Act

(U.S. EPA, 1997). This successful reduction of industrial emissions comes at a cost. According to the 1999 U.S. Survey of Manufactures, 3% of the new capital expenditures were related to pollution abatement (U.S. Census, 2002). Industry groups have expressed concern about the extent to which increasingly stringent environmental regulation increases their operating costs and reduces their ability to remain competitive in international markets. Consequently, there is tremendous pressure on regulators to find ways to keep the economic costs of achieving environmental standards to a minimum.

Historically, U.S. regulators have favored what has been dubbed the "command and control" (CAC) approach; regulators set performance or design standards that specify the type of equipment individual firms should operate or limit the amount of a given pollutant a firm can discharge. Dales (1968), Montgomery (1972), and many other economists have argued that a "cap and trade" (CAT) approach offers a more efficient means of reducing industrial emissions. A growing number of politicians and regulators have embraced CAT programs as a means of addressing problems of local smog, acid rain and climate change.

The CAT approach to regulating industrial emissions was first applied in the United States in a 1974 EPA program that regulated new emissions from existing plants (Hall, 1996). Subsequent applications of the CAT approach have included a program designed to control water pollution in Wisconsin's Fox River beginning in 1981, EPA's lead phase-out program beginning in 1982, the Regional Clean Air Incentives Market (RECLAIM) that controls NO_x and SO_x emissions in the Los Angeles basin implemented in 1994, and a nationwide program to control SO_2 emissions from power plants in 1995. U.S. markets have already emerged for CO_2 in anticipation of future regulation; emissions trading will undoubtedly play a central role in any international efforts to curb greenhouse gas emissions (Lecocq, 2001).

Economists have argued that a CAT approach has two substantial advantages over the traditional CAC approach. First, Hahn (1984), Milliman and Prince (1989), Tietenberg (1980), and others have contended that a CAT program is more cost effective because a market more efficiently co-ordinates abatement activity across firms with heterogeneous abatement costs and creates incentives for firms to develop and adopt of more efficient abatement technologies. Second, Montgomery (1972) and Rose and Stevens (1993) highlight another major advantage of market-based permit programs over a CAC approach: a CAT program reduces a regulating agency's information requirements substantially because a market will allocate pollution reduction so as to minimize total cost *regardless of how permits are initially distributed* if transaction costs are negligible.

Because CAT programs are increasingly being relied upon to control point source pollution, it is important to understand how the theory behind emissions trading is playing out in practice. This paper investigates the independence of permit market outcomes and the initial allocation of permits by testing two hypotheses. First, we examine whether firm-level emissions depend on the initial allocation of permits. Second, given that the first hypothesis is rejected, we examine whether the relationship between permit allocations and emissions is stronger among those firms that face higher transaction costs.

We test these hypotheses using data for Southern California's RECLAIM market for nitrogen oxide (NOx). The RECLAIM market has the longest history of any locally designed and implemented CAT program and is one of the few emissions control programs in the United States that incorporates a broad range of industries and sectors.

In Section 2, we describe the RECLAIM program in detail. We then summarize the necessary conditions for emissions to be independent of the initial allocation of permits. In

Section 4 we discuss whether these conditions are likely to be met in the RECLAIM market. In the fifth section, we describe our estimation model and the formal hypothesis tests. The data and variables are discussed in section 6. We then test the first and second hypotheses and summarize our results.

2. The Regional Clean Air Incentives Market

The RECLAIM program was designed to address serious air quality problems in the Los Angeles basin. In 1991, ozone levels there exceeded state standards on 184 days (Hall, 1996).[1] Hall et al. (1992) estimated that health-related losses in that region due to poor environmental quality approached $10 billion per year. NO_x emissions, which are a precursor to ground level ozone formation, contribute to heart /respiratory disease, ecological damage via acid rain, eutrophication of waterways, increased rates of biological mutation, global warming and reduced visibility.

The South Coast Air Quality Management District (SCAQMD)[2] introduced the RECLAIM program in 1994 to bring the region into compliance with state and federal NOx and SOx emissions standards at minimum cost. The majority of facilities in the SCAQMD emitting four tons/year or more of either NOx or SOx were included in the program.[3] The RECLAIM program replaced 21 rules and 13 control measures contained in the 1991 Air Quality Management Plan (AQMP) that was designed to meet air quality standards using more

[1] Ozone is formed in a photochemical reaction from nitrogen oxides and volatile organic compounds. Adverse effects include damage to lung tissue that reduces lung capacity.

[2] SCAQMD is a 10,740 square mile area of southern California including all of Orange county and parts of Los Angeles, Riverside and San Bernadino counties (White, 2002).

[3] Although over 50% of the region's NOx emissions come from mobile sources (cars, trucks, buses), these sources are not in the jurisdiction of the SCAQMD and thus are not regulated under RECLAIM.

conventional CAC approaches. Johnson et al. (1996) predicted that RECLAIM would save an average of $57.2 million per year ($1987) in abatement costs compared to the CAC measures it replaced.

Initially, the RECLAIM program included 390 firms whose combined NOx emissions accounted for over 65% of the region's stationary NOx emissions (Burnside et al., 1996). Of these firms, 73% were in manufacturing; 13% in communication, transportation or utilities; 2% in construction, 3% in the service sector; 6% in wholesale; 2% in retail; and the remaining 3% were government facilities.

At the start of the program in 1994, each firm received a schedule that specified how many pollution permits they would receive each year between 1994 and 2010. Each RECLAIM trading credit (RTC) represents one pound of NOx emissions and is valid for one year. Permit allocation schedules were based on the historical (1989-1992) baseline emission rates for each facility, industry and equipment type(SCAQMD, 2001).

The total number of permits allocated each year has fallen over time so as to reduce pollution levels overall. Allocations depreciated between 1994 and 2000 at a facility-specific rate (based on baseline emissions and equipment type). From 2000 to 2003, allocations depreciated at a common rate across facilities. Allocations cease to depreciate after 2003. The annual weighted average reduction in RTC allocations for the population of 390 facilities from 1994-2003 was 8.3% (Johnson et al., 1996).

To remain in compliance, a firm has several options including reducing production, increasing operational efficiency, installing abatement technology, or purchasing permits.[4] If the

[4] A RECLAIM facility also has the option to offset emissions by purchasing and scrapping pre-1982 vehicles. Offsets are determined based on vehicle type, vintage, resale value and the rate of

firm reduces its emissions beyond the required amount, it can sell its excess permits in the market to other firms for use in the current year—RTCs cannot be banked for use in a later year. As of 2003, 12% of RECLAIM facilities had not participated in the market, 13% had participated as buyers only, 19% as sellers only, and 55% had acted as both buyers and sellers.

Because it was expected that firms would wait to purchase or sell permits until the end of the year, regulators designing the program feared that this behavior would lead to price spikes in the permit market in the last weeks of the year. To reduce price volatility, firms in the program were randomly assigned to one of two staggered 12 month cycles; Cycle 1 lasts from January 1 to December 31, while Cycle 2 lasts from July 1 to June 30. A facility can use either Cycle 1 or Cycle 2 credits. In the three months following any trading cycle, a firm must account for any emissions in excess of their allocation by reporting details of any permit transactions.

SCAQMD has not set up a formal auction to facilitate the trading of RTCs. Firms wishing to trade RTCs must find trading partners themselves or use one of several private brokers.[5] The fraction of RTC transactions involving private-sector brokers increased from 38% in 1994 to 75% by 2001.

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fleet turnover. Firms are limited to a maximum of 30,000 vehicles per year (Johnson, 1996). As of 2002, 10 firms had used these "mobile source credits" to offset emissions.

[5] Cantor Fitzgerald's continuous RTC auction service on the Internet provides market participants access to price and quantity information about past transactions and current offers to buy and sell. Another brokerage service, the Automated Credit Exchange, operated RTC auctions on five days of every quarter; but is temporarily suspended. Other brokers active in the RECLAIM market include Natsource LLC, Boldwater Brokers and Multifuels, L.P.

3. Theory of Permit Allocation and Emissions Trading

One possible solution to industrial pollution is to turn the right to pollute into a traded commodity. Kenneth Arrow (1969) used a general equilibrium model to prove that one can expand the commodity space so as to "internalize" an externality.

Montgomery (1972) established a result similar to that in Coase (1960) to show that the initial allocation of permits is irrelevant to the final equilibrium in a CAT emission market if certain conditions are met. In particular, he demonstrated that the emissions vector and shadow prices that minimize the social cost of achieving a given emissions target also satisfy the conditions of a competitive equilibrium. He showed that a firm's choice of an optimal level of emissions is based on the price of permits, the firm's costs of production, pollution abatement costs, and the price the firm receives for its product, but *not* on the initial allocation. He concluded that (p. 202):

> …the management agency can distribute licenses as it pleases. Considerations of equity, of administrative convenience, or of political expediency can determine the allocation. The same efficient equilibrium will be achieved.

Montgomery's results hold if several assumptions are met: Zero transaction costs, perfectly competitive permit and product markets, profit maximizing behavior, full compliance and enforcement, and full information on the part of firms with respect to abatement costs and permit prices. His Coase-like conclusion that the least-cost equilibrium outcome is independent of how property rights are assigned depends particularly crucially on the zero transaction costs and full information assumptions.

Stavins (1995) incorporated a transaction-cost function in his model of firm decision making in a CAT market. Assuming that all firms face the same transaction cost function and that marginal abatement cost curves are continuous, he demonstrated that, in the presence of transaction costs, the aggregate abatement costs associated with the post-trading equilibrium are sensitive to how permits are initially allocated.

Montero (1997) incorporated discontinuous marginal abatement cost curves into a theoretical model and uses numerical simulations to examine how the presence of transaction costs and uncertainty affect the performance of emissions markets. He illustrated that both aggregate control costs and the emissions market equilibrium are sensitive to the initial allocation of pollution permits when transaction costs are positive.

4. Perfect Competition Assumptions Are Not Met in Pollution Permit Markets

Unfortunately, participants in actual CAT programs, such as the RECLAIM market, face transaction costs and have incomplete information. Moreover, some of the other necessary conditions for a perfectly competitive market also are not met.

4.1 *Transaction Costs*

Empirical studies of CAT programs indicate that transaction costs in pollution permit markets can be significant (Atkinson and Teitenberg, 1991; Gangadharan, 2000; Hahn and Hester, 1989; UNCTAD, 1998). Firms incur many transaction costs. Prior to entering a permit market, a firm must learn how the CAT program works and determine what it would cost to reduce emissions internally. If a firm decides that it wants to enter the permit market as a buyer or seller, it consumes resources searching for a trading partner, negotiating a transaction and hiring any legal, insurance and/or brokerage services it deems necessary. It is also possible that a firm will bear some of the costs of monitoring and reporting its emissions to the regulating agency .

According to the Chicago Federal Reserve Board, Cantor Fitzgerald required a fixed fee of $150 per trade and a variable fee of 3.5% of the transaction value in 1996 (Burnside et al.

1996). A more recent EPA study asked firms participating in the RECLAIM market about their transaction costs. Participants who chose to employ a broker rather than enter into private negotiations with other RECLAIM facilities estimated that total broker fees amounted to 1%-3% of the total value of the trades (EPA, 2002). Unfortunately, in the EPA study, no questions were asked about the costs of searching for and negotiating with trading partners when no broker was used. Thus, we know that transaction costs exceed zero in the RECLAIM market but do not know exactly how large they are.

4.2 *Full Information*

Evaluating the extent to which firms have access to "full information" is difficult. In a recent EPA study, RECLAIM participants were asked whether they felt they had sufficient information to make long-term emissions control decisions. Because RECLAIM participants do not know what control technologies other facilities have installed, respondents stated that they did not have a good sense of what future RECLAIM market conditions might look like and thus felt ill-equipped to make decisions about installing abatement equipment or pursuing other emissions-reducing innovations (EPA, 2002).

4.3 *Perfect Competition*

The efficiency of CAT programs depends in part on the assumption that all firms act as price takers in their respective industries. Electricity generators in the SCAQMD region exercised market power in California electricity markets in 2000-2002 (Borenstein et al., 2002). In other industries such as ready-mix cement, where regional imports and exports are limited, it is also possible that regulated firms as a group could increase regional prices to reflect RECLAIM-related increases in production costs.

RECLAIM permits were allocated so that there was little potential for a single firm to exercise market power as either a buyer or seller.[6] However, Kolstad and Wolak (2003) provide evidence that some of the electricity generators in SCAQMD purchased NOx RTCs at higher than "competitive" prices so as to be able to raise the wholesale price paid for electricity in California during the 2000-2001 energy crisis. Because there are no other firms in the RECLAIM program that have incentives to purchase permits at higher than competitive prices or sell permits at lower than competitive prices, it seems likely that this (permit) price taking assumption has been violated only in the case of some electricity generators.

4.4 *Compliance*

A RECLAIM firm is in compliance if, in the three months following a trading cycle, it has rationalized its emissions during the cycle with sufficient permits of the correct vintage. On average, SCAQMD reports that 91% of firms were in compliance between 1995 and 2000 (EPA 2002). A 1998 SCAQMD document indicated that non-compliance could be attributed to misunderstanding of the regulation or mistakes in calculation prior to 1998 (Lieu et al., 1998). The data suggest that aggregate emissions in the SCAQMD region significantly exceed the total quantity of allowances issued, particularly during the electricity crisis in 2000 (Wallerstein, 2001). This non-compliance may have occurred because selling electricity in California's wholesale markets was unusually profitable during this period, even accounting for the fines associated with exceeding emission allowances.

[6] A Herfindahl-like measure can be calculated using the sum of squares of each firm's permit allocation as a percentage of the total number of permits allocated. The average annual value is 267.5 for allocations from 1994 through 2008.

5. Estimation Model

To determine whether a firm's emission level is independent of its permit allocation, we estimate a reduced-form equation. This equation includes the firm's RTC allocation, RTC prices, input and output prices. Assuming log-linearity, the firm's reduced-form emission function is

$$\ln\ E_{\mathrm{it}} = \alpha_i + \beta \ln A_{it} + \phi \ln Z_{it} + u_{it}. \qquad (1)$$

where E_{it} is firm *i*'s firm-level NO_x emissions in pounds in period *t*; α_i is a firm-specific fixed effect; A_{it} is the firm's quarterly permit allocation in pounds; Z_{it} is a vector of exogenously determined variables including the current and lagged average RTC price, a proxy for the firm's average product price, and the average gas and electricity prices (input prices facing the firm). The disturbance term u_{it} is assumed to have zero mean and constant variance σ_u^2. We assume that all firms in the sample treat prices of output, permit prices, and energy prices as exogenous.[7]

The parameterization in Equation (1) forces the coefficients to be equal across firms except for the individual intercepts α_i. These fixed-effect coefficients control for a firm's unobserved, time-invariant size, baseline emissions, production technologies, and management characteristics.[8]

If the firm's unobserved abatement costs change from year to year, abatement costs constitute an important omitted variable that is not entirely captured by α_i. Because it seems plausible that pollution control costs will also be affected by unobserved time-variant factors,

[7] Kolstad and Wolak (2003) provide strong evidence that some generators used their NOx RTC purchases to increase California energy prices in 2000-2001, thereby affecting both RTC and electricity prices. To avoid this potential endogeneity, we dropped the 27 electricity-generating facilities from the sample.

[8] Past research has underlined the importance of management ability/attitudes towards energy efficiency as important determinants of environmental performance (Hettige et al., 1997).

time dummies were included in the Z vector to capture the effects of changes in unobserved variables (such as exogenous technical change) that influence companies equally across time.

Provided the assumptions underlying the efficiency of permit markets are met, firm level emissions will be determined by permit prices, the firm's production costs, pollution abatement costs and the price the firm receives for its product (Montgomery, 1972). The initial allocation of permits should not, in theory, affect firm level emissions. Consequently, when we control for permit prices, product prices, energy prices, time and firm fixed effects, the coefficient on initial permit allocation (β) should not be statistically significantly different from 0. Given that we reject this hypothesis, we are interested in testing our second, stronger hypothesis that the link between emissions and initial allocations is tighter, the larger is a firm's transaction costs, *T*.

To be able to examine the role of transaction costs in the relationship between initial allocation and emissions, we modify Equation (1). We assume that the coefficient on the initial allocations is a function of the firm's transaction costs, *T*: $\beta = \gamma_0 + \gamma_1 T$. That is, Equation (1) becomes:

$$\ln E_{it} = \alpha_i + \gamma_0 \ln A_{it} + \gamma_1 T_{it} \ln A_{it} + \phi \ln Z_{it} + u_{it}. \qquad (2)$$

Our second hypothesis test is a test of whether $\gamma_1 > 0$.

6. Data and Variables

Our data set contains information by firm from the first quarter of 1994, the beginning of the RECLAIM program, through the second quarter of 2002 (34 quarters). Because we are interested in the relationship between allocation and emissions, only those firms that received RTC allocations are included in this study.[9] SCAQMD makes available a modem accessible

[9] Only the original firms present when the program began in 1994 received quarterly allocations. Any new firms entering SCAQMD who are NOx emitters must either purchase credits to cover

bulletin board on which it posts for the name, address, facility identification number, zone, and cycle assignments of all firms in the RECLAIM program. We use this information to link data from other sources to those we obtained from SCAQMD.

6.1 *Quarterly Emissions*

The dependent variable is quarterly emissions. These data are taken from the emissions reports that all RECLAIM facilities are required to submit to SCAQMD. SCAQMD provided data from the inception of the program in 1994. On average, there are 22.3 quarterly emissions reports per firm (of a possible 34 quarters), and 11 quarterly emissions reports per firm over the 14 quarters considered in this study(January 1999- June 2002). There are several reasons why emissions reports are not available for some firms for all possible quarters. In the early years of the program, more than 60 of the original facilities dropped out of the RECLAIM program. Some firms closed down for reasons unrelated to the RECLAIM program or were found to be exempt from RECLAIM after adjustments of initial emissions calculations revealed that the facilities produced fewer than the limit of four ton/year (Lieu et al., 1998). In addition, emission data is missing in some quarters because of malfunctioning emissions monitoring equipment or late reporting. If emissions are transmitted after the deadline, the report is rejected and recorded as missing.[10]

6.2 *Quarterly Allocations*

SCAQMD also maintains a database tracking all NOx permits. This database contains initial RTC allocations, allocation adjustments, retirements, and trades (measured in pounds).

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their emissions or, in some cases, take advantage of a special reserve of RTCs earmarked for job-creating, clean companies (Schwarze and Zapfel, 2000).

[10] Personal correspondence with George Haddad, a SCAQMD engineer, in 2002.

From these data, we could recover the NOx permit allocation schedule for the 383 RECLAIM firms that are not electricity generators.[11]

Allocations and NOx emissions reported by firms in the sample were summed within years and across firms to generate Figure 1. In the early years of the RECLAIM program, most firms allocations that exceeded their desired emissions. SCAQMD estimates that initial allocations were 40-60% above actual emissions in 1994-1996 (EPA, 2002). Figure 1 illustrates that the sum of allocations across all firms in the sample in early years exceeded reported NOx emissions. The first year in which aggregate allocations bind was 1999 (Wallerstein et al., 2001).

6.3 *RTC Prices*

The price of permits reflects the marginal opportunity cost of producing one more pound of NOx. Firms use the current price of permits—the opportunity cost—in making short-term production decisions that affect emissions. The prices they pay for future vintages reflect firms' expectations, which presumably influence their long-term decisions affecting emissions levels, such as whether to invest in abatement technologies.

From SCAQMD and two private-sector brokers, we obtained RTC transaction information, including the identification of buyers and sellers, the date, price, quantity, zone, and vintage of permits traded. Calculating quarterly mean RTC prices is complicated by the manner in which RTC trades are executed and reported. Because 61% of the registered trades are recorded as $0 price transactions, the mean prices calculated using the complete transaction data set underestimate what it cost a firm to purchase permits from another firm.[12] Consequently,

[11] A firm's allocation for a given year is calculated by summing the RTC's, emission reduction credits (ERC's) and non-tradable credits (NTC's) that it was allocated for that year. For cycle 2 firms, a "year" is defined as July through June.
[12] There are three reasons why RTCs are traded at a price of zero:

quarterly means of non-zero transactions are more meaningful indicators of expected prices for firms planning to participate in the RECLAIM market. RTC prices are adjusted for inflation, using 2002 as the base year.

The common practice of bundling trades causes a second complication for us. Many of the broker-facilitated trades are bundles of multiple vintages that sell for a single price. Hence, each permit in a bundle is recorded at the same per unit price. As a consequence, the variability of reported average quarterly prices for permits of different vintages is an underestimate of what would be the unbundled price variability.

Before RECLAIM began, SCAQMD economists predicted that trading in the market would be slow at first because initial allocations exceeded actual emissions. In 1994, these economists predicted that prices for NO_x RTCs would average around $0.29/lb in 1995 and rise to approximately $5.50/lb in 1999 (Miller, 1994). Figure 2 plots the trend in average "current" and "lagged" mean annual prices. The solid line connects the points corresponding to the mean price of permits of vintage *v* sold in year *v*, while the broken line connects points corresponding to the mean price of permits of vintage *v* sold in year *v*-1. The figure illustrates that, in the first 5 years of the program, prices for NO_X RTCs remained low and relatively stable, as expected. The 1999 increase in prices was much larger than SCAQMD regulators had predicted. The unanticipated magnitude of this jump can almost certainly be explained the energy-crisis, which

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(i) RTCs are allocated to facilities rather than parent companies. If a company transfers RTCs between two of its RECLAIM facilities, it records this transaction with SCAQMD as a $0 trade.

(ii) Because SCAQMD wants to keep track of all RTCs at all times, when firms are trying to sell RTCs through a broker, the transfer of the permits from the seller to the broker is recorded as a $0 transaction. Consequently, brokered transactions are counted as two separate transactions, at least one of which is a $0 transaction.

(iii) If RTCs are retired or donated to environmental groups, or if the facility is bought by another company and the RTCs are transferred to a new owner, these transactions are recorded at $0.

caused statewide demand for electricity from generators in this region to increase. Beginning in early 1999, electrical generators found it profitable to increase the operation of older, less-efficient equipment. Consequently, many generators exceeded their RTC allocations significantly, and some allegedly purchased RTCs at inflated prices so as to artificially inflate regulated electricity prices (Kolstad et al., 2003). Consequently, the number of RTCs available to other firms fell and the price of RTCs rose substantially. RTC prices increased from approximately $2.15 per pound traded in 1999 to approximately $19.50 per pound traded during the first ten months of 2000.

6.4 *Industry-Level Variables*

Using the information SCAQMD provides about the identity of RECLAIM facilities, we determined the four 4-digit Standard Industrial Classification (SIC) code for each facility. The firms represented in the sample fall into 144 different industrial classifications.[13]

We also obtained a measure of industry-level product price for each facility. When a firm is deciding whether to buy or sell RTC's, reduce production (and thus emissions), and/or install abatement equipment to remain in RECLAIM compliance, it must compare its gross profit per unit of output with the costs of producing additional pollution. While we could not obtain systematic profit data, we used the Producer Product Index (PPI) as a proxy for shifts in demand facing firms. Deflated monthly price index data are provided at the 4-digit SIC level by the Bureau of Labor Statistics.[14]

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[13] Three facilities could not be matched with SIC codes because they had multiple facility identification numbers and SIC codes associated with a single address, making it impossible to match the source of the emissions with an industry. These cases were dropped from the sample.

[14] There are 20 categories for which price series could not be found. Consequently, 26 facilities falling into the broader categories of finance/insurance/real estate, some entertainment, and public administration were dropped from the sample.

Admittedly, the PPI is an imperfect and biased measure of the prices received by the firms in our sample for their products. Because the PPI price indices tend to be based on surveys of larger firms, the error in measurement of this product price variable is likely larger for smaller firms. This could cause other variables highly correlated to firm size (such as allocation) to be correlated with the error term.

Quarterly emissions are likely to be highly correlated with quarterly energy use. Woodland (1993) and Bjorner et al. (2001) demonstrated that energy prices significantly affect firms' demand for energy, particularly in energy-intensive industries. RECLAIM firms use a variety of fuel types including natural gas, diesel, coal, propane, butane and electricity (SCAQMD, 2001). Unfortunately, firm-specific information regarding fuel use or energy contracts was unavailable. Instead, we use natural gas and electricity prices to proxy for energy prices in general.

The Energy Information Administration's *Natural Gas Monthly* provides monthly commercial and industrial natural gas rates for the state of California. Based on each firm's SIC, we classified firms as industrial or commercial energy consumers and then assigned the appropriate rate schedule to each firm.

The California Independent System Operator (ISO) reports real-time electricity prices for the zone that includes all of SCAQMD. We obtained these weekly prices from the University of California Energy Institute website.

6.5 *Quarter*

We also included a dummy for the last quarter of the RECLAIM cycle in our reduced-form equation. RECLAIM facilities must demonstrate at the end of each annual cycle that their emissions over the past 12 month cycle did not exceed their allocation plus net permit purchases. It is conceivable that firms might pollute less in the fourth quarter of their RECLAIM cycle so as to ensure they remain in compliance. For facilities in Cycle 1, the fourth quarter occurs in October-December. For facilities in the second cycle, the fourth quarter is April-June. A dummy variable is included in the model that equals 1 if the firm is in the last quarter of its cycle.

Figures 1 and 2 clearly illustrate that the market for RTCs changed after 1999 due to both rising electricity prices and the “cross-over” of aggregate allocation and emissions. Table 1 presents summary statistics for these two periods respectively. It is only in the second period that allocations are binding and permit prices are significantly different than 0. This is the period we will focus on in our hypothesis testing.

Table 1 presents summary statistics. Although the mean of quarterly firm-level emissions in the period 1999-2002 exceeds the mean quarterly allocation, the total allocation of RTCs over this period slightly exceeds total reported emissions because several firms did not report emissions in all quarters.[15] The median quarterly emissions for the period 1999-2002 is 2, 760 pounds while the median quarterly allocation is 3, 006 pounds.

7. Estimation of the Base Model and Test of the First Hypothesis

We started by estimating our base-model of firm-level emissions, Equation (1). Table 2 presents the estimation results for our fixed-effects (FE) model.[16] Based on our FE estimates, we

[15] Table 1 summarizes data for only those firms that originally received allocations, whereas figure 1 includes emissions data from all firms, including those joining the program after it had already begun.

[16] This analysis was conducted using quarterly data. The analysis was also done with data aggregated to the annual level with similar results. The coefficient on allocation is estimated to be 0.22 and significant. None of the other variables in the model are statistically significant. The problem with using annual data is that many quarterly observations could not be used. Any firm that did not report emissions for all four quarters of a year was counted as “missing” for that year. This leaves only 628 annual observations (versus 3 352 quarterly observations).

strongly reject the first hypothesis that emissions are independent of initial allocations. The t-statistic is 3.3 for the FE model. Thus, we reject the null hypothesis that the coefficient equals zero at the 0.05 confidence level. Given the coefficient on the allocation variable is 0.53, a 1% change in allocation is associated with a 0.53% change in NOx emissions. Equivalently, a one pound increase in a firm's NOx allocation in a given quarter increases its emissions by 0.6 pounds on average.

Coefficients on current and lagged RTC prices are both negative and collectively are not significant at the 5% level. We cannot reject the hypotheses that the coefficients on product price and energy prices are zero at the 5% level. We cannot reject the null hypothesis that the fourth quarter dummy is zero at the 5% level; this data does not support our expectation that firms would emit less in the last quarter of each emissions reporting cycle. To assess the validity and robustness of the FE model, we conducted several tests, which are described in the following subsections.

7.1 *Model-Specification Tests*

If the unobserved fixed effect α_i does not actually belong in the model, $\sigma_\alpha^2 = 0$ and the OLS estimates are efficient. To assess whether we should include the fixed-effect terms α_i, we estimated a model that did not include fixed-effect terms but did include observable firm characteristics: baseline emissions and two -digit SIC dummies. We estimated this modified model using OLS and then tested for AR(1) serial correlation based on the OLS residuals. The allocation coefficient estimated using OLS is 0.57 and significant. A standard normally distributed test statistic was constructed and the null hypothesis, H_o: $\sigma_\alpha^2 = 0$, was rejected (Wooldridge, 2002). One interpretation of this test is that the alternative OLS model omits important and hence using a firm fixed effects model is warranted.

To test for misspecification in the functional form, we augmented the FE model with a set of higher-order terms and interaction terms involving all of the variables in the X_{it} matrix except the time dummies. None of the higher-order terms or interaction terms were statistically significantly different from zero at the 0.05 level and the estimates of the original parameters do not change dramatically. Thus we fail to reject the log-linear functional form for the emissions function.

7.2 *Sample-Selection Test*

The panel used to estimate model is unbalanced: Emissions data are available for 14 quarters from the beginning of 1999 through the second quarter of 2002. On average, firms reported emissions in 11 of the 14 quarters. Reasons for missing observations include late reporting, malfunctioning emissions recording equipment, allocation adjustments or plant closures. A common approach to dealing with the problem of unbalanced panel data has been to use only those units that are observed over the entire sample. With less than 20% of firms in the 1999-2002 sample reporting emissions for all quarters, using a balanced sample to estimate the model would dramatically reduce the sample size. However, if the missing observations in the sample are not missing at random, using the unbalanced sample will yield inconsistent estimators (Nijman et al., 1992).

The mean quarterly emissions for the 70 firms in the sample for which all 14 quarterly emissions reports are available is 11, 727, over 40% smaller than the overall sample mean. The mean allocation in the balanced sample is 10, 007 lbs, 48% smaller than the overall average quarterly allocation. These summary statistics suggest that, on average, the firms reporting emissions in all periods are smaller polluters than those firms who fail to report emissions in at least one period.

Let s_{it} be the binary selection indicator for Firm i in period t such that $s_{it} = 1$ only if (X_{it}, y_{it}) are observed. The significant differences in the mean emissions and the mean allocations for the balanced and unbalanced samples suggests that s_{it} is not independent of (X_{it}, α_i) . Given (X_{it}, α_i), if the idiosyncratic error u_{it} is not correlated with s_{it}, the FE estimator is consistent, even if there is correlation between s_{it} and X_{it} and/or α_i (Wooldridge, 2002). To test whether the selection indicator s_{it} is independent of the idiosyncratic error u_{it}, we use a test developed by Wooldridge (1995) that makes no distributional assumptions about α_i and allows for serially correlated and heteroskedastic idiosyncratic errors. The null hypothesis that s_{it} and u_{it} are independent could not be rejected. Consequently, it is assumed that the unbalanced nature of the panel will not affect the consistency of the estimates.

7.3 *Spherical Disturbances Test*

If we assume that

$$\mathrm{E}(u_i\, u_i' \,|\, X_i, \alpha_i) = \sigma_u^2 I_T, \tag{3}$$

where I_t is a t-dimension identity matrix, then the fixed effects estimator is efficient (Wooldridge 2002). Equation (3) implies that the idiosyncratic errors have constant variance across time and across individuals, and that they are serially uncorrelated.

We started by testing whether the idiosyncratic errors are uncorrelated over time. Although the serial correlation in the composite errors $v_{it} = \alpha_i + u_{it}$ is likely dominated by the fixed effect α_i, it is still possible for there to be serial correlation in the u_{it}. The F-statistic (1, 785) is 4955. We reject the null hypothesis of serially uncorrelated errors.

There are several reasons to suspect that the errors may be heteroskedastic. Not only is the sample unbalanced, but the firms represented in the sample vary by size, industrial sector, and other dimension, so that it seems likely that σ_u^2 will differ across firms. Greene (2000) discusses a test for cross-sectional heteroskedasticity that uses a modified, chi-square distributed Wald statistic to test the null hypothesis of constant variance across firms. Using the estimated disturbances obtained when we estimated Equation (1) using a balanced subset of the original panel, we calculated the modified Wald test statistic for the null hypothesis that $\sigma^2_i = \sigma^2$ for $i = 1, \ldots, N$. Based on that test, we reject the hypothesis that the disturbance variances are equal across all firms in the sample.

Because the idiosyncratic errors are both serially correlated and cross-sectionally heteroskedastic, we should be using Arrelano's "clustered" robust asymptotic variance matrix estimator, generalized to the unbalanced case, to generate robust estimates of the standard errors (Arellano, 1987; Kezdi, 2002). For now we are using White's robust standard errors to correct for heteroskedasticity. Addressing the serial correlation of the errors is a work in progress.

7.4 *Endogeneity Tests*

In Table 2, we assumed that permit allocations were exogenous. Allocation schedules were based on the firm's past emissions and the type of machinery and equipment operated by the firm. Assuming there was no strategic "over-emitting" behavior during the years used to determine firm baselines, the only way a firm could have influenced its permit allocations was via political means. If an individual firm was able to use political muscle to influence its permit allocation, the allocation variable is not exogenous.

The allocations schedules of the 380 firms in the 1999-2002 sample were first determined in 1994 based on historical emissions and equipment type, and then some were revised in 1995 pursuant to appeals filed with SCAQMD. According to SCAQMD, reasons for these revisions included emissions factor corrections, amendments to historical emission records, and reapportionment of fuel usage (Prager et al., 1996). The average allocation adjustment was 135,562 pounds with a standard deviation of 2,061,068 pounds.

Although the reasons given for adjusting allocation are not political in nature, it could be argued that those firms with more political clout may have been more successful at arguing for an allocation increase. Allocation adjustments can thus be thought of as a blunt proxy for the extent to which a firm was able to influence its allocation schedule. Because the majority of the observed quarterly allocation adjustments were zero and several were negative, we did not include the log of the allocation adjustment variable in our log-linear FE model. Instead, dummy variables were created to distinguish the 101 firms in the sample who had their overall allocations adjusted upwards and the 60 firms who had their allocations reduced. When these dummies are interacted with the allocation variable included in the fixed effects model, the estimated coefficient on allocation decreases slightly from 0.53 to 0.48, both are significant at the 1% level. The coefficient on the increased allocation interaction variable is 0.40 , the estimated coefficient on the decreased allocation interaction variable is -0.57 and neither are found to be statistically significantly different from zero. A Hausman test cannot reject the hypothesis that the difference in the coefficients in the complete model including the interaction terms and the reduced model are not systematic. These results suggest that the relationship between allocation and emissions is significant for all firms, regardless of whether those firms had their allocations adjusted.[17]

Finally, to the extent that firms can affect the price of permits, endogeneity concerns also arise when RTC prices are included in the model. On average over the sample used, a firm's annual allocation represents 0.2% of the total annual allocation, and no single firm's annual

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[17] Ideally, to deal with this potential endogeneity, an instrument for allocation would be used in the model. No appropriate instrument could be constructed using the available data.

allocation exceeded 9.8% of the total annual allocation. Thus, it seems reasonable to assume that these firms were price takers in the market for RTCs. However, because the market is relatively small with fewer than 500 firms, it is conceivable that firms or groups of firms could affect the price. One way to deal with this potential endogeneity is to instrument for RTC prices using lagged values. The estimated coefficients in the FE model and the FE-IV model are not found to differ significantly.. The estimated coefficient on allocation is 0.53 in the FE model and 0.54 in the FE-IV model.

8. Testing the Second Hypothesis Concerning Transaction Costs

Thus, we reject the first hypothesis that emissions are independent of the initial allocation. One explanation for the strong positive relationship between firm allocations and firm emissions is that there are transaction costs associated with learning how the RECLAIM program works, finding a trading partner, and contracting with another firm to exchange permits. If transaction costs are sufficiently high, some firms will be discouraged from taking the trouble to enter the RTC market as a buyer or seller, and will instead look upon their allocation as an emissions cap (hereby giving rise to a strong positive correlation between allocation and emissions). Thus, we want to test the stronger hypothesis that a firm's emissions are more tightly linked to its initial allocation, the greater its transaction costs. To do so, we estimate the modified model in Equation (2). If transaction costs significantly influence the relationship between allocations and emissions, we would expect $\gamma_1 > 0$.

8.1 *Measures of Transaction Costs*

We lack a simple, continuous index *T* of the relative size of transaction costs; however, we have two proxy variables for transaction costs. We use these proxies to distinguish between firms with relatively high or low transaction costs, so that our *T* is a binary variable.

Firm Size

When there are non-negligible transaction costs associated with participating in an emissions market, firm size might play a role in determining market participation. Given scale economies, smaller firms may face relatively high transaction costs in learning how the RECLAIM market works and in determining the least-cost approach to compliance. According to a recent survey of RECLAIM participants, large companies are more likely to incorporate decisions about emissions control and emissions reducing process modifications into their long term planning (EPA, 2002).

Because we lack comparable data on firm-level output or employment across firms, we use firm-level emissions from a prior period, 1994-1998, as an indicator of firm size. Firms were categorized as "small" (those firms whose average quarterly emissions NOx emissions over the period 1994-1997 fell below the median value of 4491 pounds) or "large" (average annual emissions greater than 4491 pounds) . A dummy variable was created that took on a value of one for large firms that presumably face lower transaction costs and zero otherwise.

An initial investigation of how large and small firms compare lends support to our hypothesis that the relationship between allocations and emissions is stronger among smaller firms. One way to compare how the quarterly emissions from large and small firms relate to their respective quarterly allocation is to calculate the percentage deviation of emissions from allocation:

$$\%\,deviation_{it} = \left[\frac{|\, emission_{it} - allocation_{it} \,|}{allocation_{it}} \right] \times 100$$

The average percent deviation is 81% for large firms and 61% for small firms. This result is consistent with our hypothesis that the relationship between allocations and emissions will be stronger among smaller firms. On average, large firms are net buyers and small firms are net sellers of permits.

Using the residuals from estimating the model separately for large and small firms, and the residuals from a pooled regression, we cannot reject the hypothesis that observations on small and large firms belong to the same regression model (Chow, 1960). The size dummy was interacted with the log of allocation and the interaction term was added to the original model [1]. Given our hypothesis that small firms face higher transaction costs and are thus less likely to enter the permit market, we expect the interaction term coefficient to be negative and significant. The estimated coefficient on the interaction term -0.19 , although it is not significant at the 5% level. Including the size interaction term in model (1) does not significantly affect any of the coefficient estimates.

These results should be interpreted carefully because we are using an imperfect measure of firm size in this analysis. A firm operating in a pollution intensive industry that is small in terms of annual sales or employees may emit more on average than a large firm in a less polluting industry. What we can conclude from the results presented here is that the strength of the relationship between allocation and firm-level emissions does not appear to differ significantly between big and small polluters.

Prior Participation in the NOx Market

Firms who have participated in the RECLAIM market in the past are likely to have a better understanding of how the market works and how trades are made than their less experienced counterparts. They may also have lower short-run transaction costs because they have existing trading relationships. Gangadharan (2000) found that facilities that have participated in the NOx RTC market before August 1997 many times before are more likely to trade in subsequent years.

Consequently, prior participation in the RTC market is used as a proxy for lower transaction costs. Our prior participation dummy variable equals one in year *t* if the firm had participated in the RTC market in any year prior to year t (either as a buyer or seller) in transactions that did not involve the exchange of permits of vintage t[18]. In 1999, 43% of the firms represented in the 1999-2002 dataset had bought or sold permits at non-zero prices in a previous year. This proportion increased to 69% by 2002.

Again, we calculate the percentage deviation of emissions from allocation for all firms. The average percent deviation is 200% for firms with prior participation and 120 % for firms with no prior participation. This result is consistent with our hypothesis that the relationship between allocations and emissions is stronger among firms with no prior participation.

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[18] On average, 47% of transactions occurring between 1999 and 2002 involved RTCs that had to be used in the years after the year they were purchased. If we created a dummy that equals one in year t if the firm had participated in any transactions prior to year t, it would be difficult to interpret the coefficient on the participation interaction term. One interpretation of these results is that the coefficient on the interaction term is negative and significant because the transaction costs faced by experienced firms are lower. An alternative explanation is that, as a result of buying (selling) permits of a current vintage in the past, firms have more (less) permits for the current year than they are allocated; consequently, their emissions level is more likely to differ from their allocation than a firm who has not participated in the RECLAIM market in the past. In an effort to isolate the first effect, we define the participation "treatment" as having participated in transactions in years prior to t that did not involve the exchange of permits of year t.

The participation dummy is interacted with allocation and included in a more unrestricted model[19] We hypothesize that there is a larger positive relationship between allocation and emissions among the firms who had participated previously in the RECLAIM market because they have already incurred the transaction costs associated with learning how to participate in the market. That is, we expect a negative coefficient on the interaction term with the log of the permit allocation. When the interaction term is included in the model, only the allocation coefficient is affected. The estimated β is 0.54 and the coefficient on the interaction term is -0.02. Both are significant at the 5% level.[20]

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[19] We cannot reject the hypothesis that observations on firms with prior participation and no prior participation belong to the same regression model

[20] Two other attempts were made to test for the effect of transaction costs on the relationship between allocations and emissions. First, some attempt was made to measure a firm's prior awareness of its abatement cost curve. The Bureau of the Census Pollution Abatement and Control Expenditures (PACE) Survey collected establishment level data on abatement costs for most years in 1972-1994 and 1999. Estimates of 1994 capital expenditures on pollution abatement by sic code were merged with RECLAIM data. Only 54% of firms in RECLAIM are in industrial classifications that reported abatement expenditures in the 1994 PACE survey. Using the sub-sample of firms in industries represented in the PACE survey, it was hypothesized that firms in industries reporting large pollution abatement expenditures might have more experience with and exposure to pollution abatement technologies, and thus have easier access to information about pollution control costs. Total industry abatement expenditures were interacted with the log of allocation and this variable was included in the model. A negative and significant coefficient on the interaction term would be consistent with our hypothesis. When this interaction term is included in the model, the estimated coefficient on allocation is 0.77 and significant. The coefficient on the abatement expenditure interaction term is negative but not significantly different than zero.

Second, we explored whether the strength of the relationship between allocation and emissions differ across industrial sector. For example, a firm operating in the manufacturing sector may take a different approach to making decisions about installing abatement technologies or pursuing process modifications as compared to a firm in the service or retail sectors. Sectoral differences in average firm size and average energy intensity could mean that firms in some sectors put greater emphasis on learning how to manage emissions so as to minimize costs than others. Firms were divided into eight sectors based on SICs: agriculture and mining, construction, manufacturing, transportation/communications/energy, wholesale, retail, services and public administration. Sector dummies were interacted with the allocation variable in order to test the hypothesis that allocation elasticity is equal across sectors. When these sectoral interaction terms are included in the model, none are found to be significant.

Table 3 presents the parameter estimates for a model containing interaction terms for participation and size dummies with the ln(allocation) variable. The null hypothesis that the relationship between allocation and emissions will be stronger among firms with higher transaction costs implies that the size coefficient will be positive and the participation coefficient will be negative (the relationship between allocation and emissions is stronger among small firms with no prior participation)

The parameter estimate for allocation changes significantly when these additional interaction terms are included. The estimated allocation elasticity increases from 0.53 to 0.68. While 0.53 represents the estimated average allocation elasticity for all firms in the sample, 0.68 represents the estimated average allocation elasticity for small firms with no prior experience in the RECLAIM market (i.e., firms who presumably face higher transaction costs). Summing β and the two interaction term coefficients, 0.46 is the estimated allocation elasticity for larger, more experienced firms who presumably face higher transaction costs.

The estimated coefficient on the participation/allocation interaction term is -0.02 and significant. This suggests that the relationship between allocation and emissions is significantly stronger among the inexperienced firms in the sample. The coefficient on the size/allocation interaction term is -0.2, but not significant at the 5% level.

9. Summary and Conclusions

Economists and politicians often endorse emissions trading programs as means of achieving point source emissions reduction targets at minimum cost. A particularly appealing aspect of the "cap and trade" approach is that, provided certain assumptions are met, the market will direct those with the lowest abatement costs to reduce emissions first, regardless of how permits are initially allocated. Based on our tests using data from Southern California's RECLAIM NOx program, we reject the hypothesis that emissions are independent of the initial allocation.

This failure of the Coase-like independence result is likely due to the presence of transaction costs. We tested a second, stronger hypothesis that the positive link between emissions and allocation increases, the greater a firm's transaction costs.

We used two approaches to identify firms that are likely to have relatively high transaction costs, looking at small firms and firms that had never participated in the market before. We do not find a clear effect with respect to firm size, but we observe the expected effect of higher allocation elasticities for firms that have not previously participated.

If our results can be generalized to programs other than the RECLAIM market, then these results have important policy implications. Most importantly, when designing CAT programs, how permits are allocated should be seen as more than a political balancing act. In order to ensure that firms with lower abatement costs are ultimately the ones reducing emissions in a CAT program, regulators must consider transaction costs and incomplete information (as well as the traditional political palatability and distributional concerns) when allocating permits. To some extent, this policy recommendation takes away from what made CAT programs so theoretically appealing in the first place—because transaction costs will likely exist in any permit market, allocations do matter, and an efficient market outcome is not assured regardless of allocation. That said, using a market to coordinate abatement activity affords a flexibility and responsiveness that, even in the presence of a significant allocation-emission relationship, renders CAT preferred to CAC programs.

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Figure 1: Reported Emissions and Allocation in the RECLAIM NOx Market

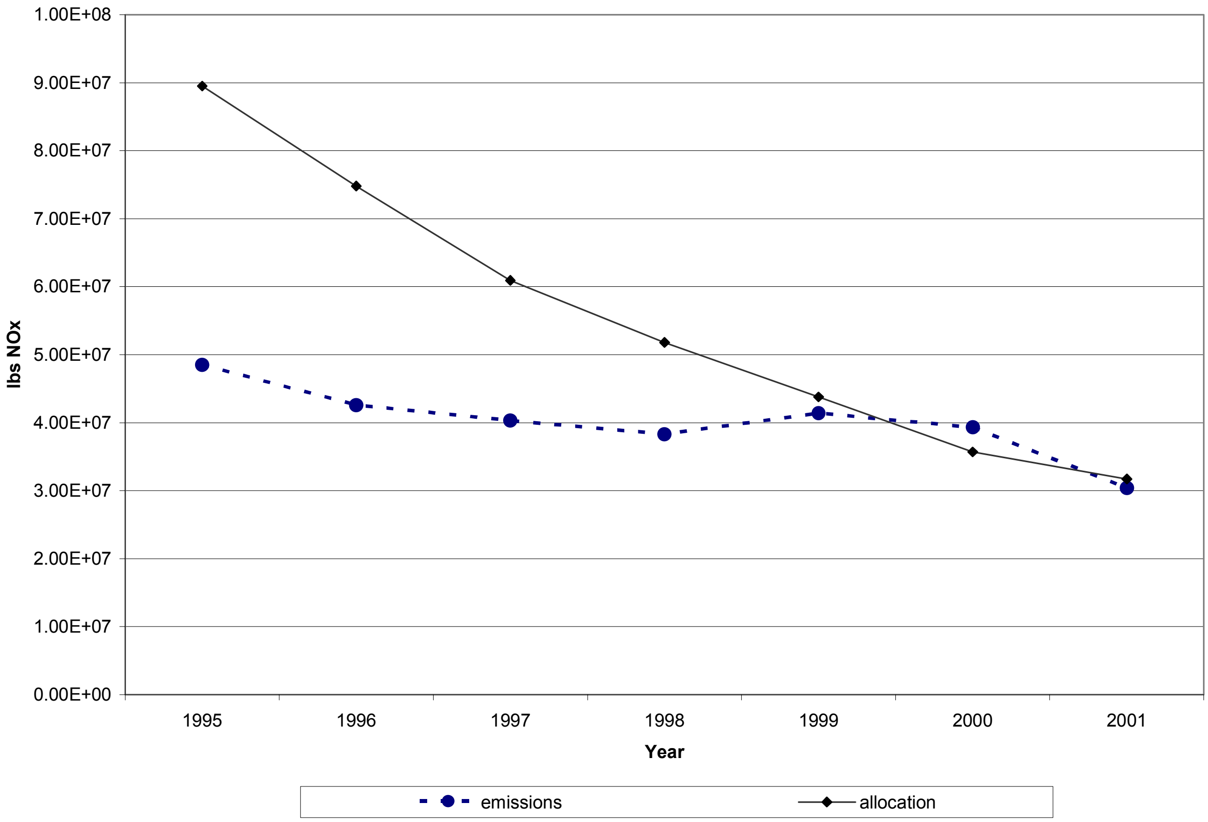

Figure 2: Current and Lagged Mean Annual RTC Prices

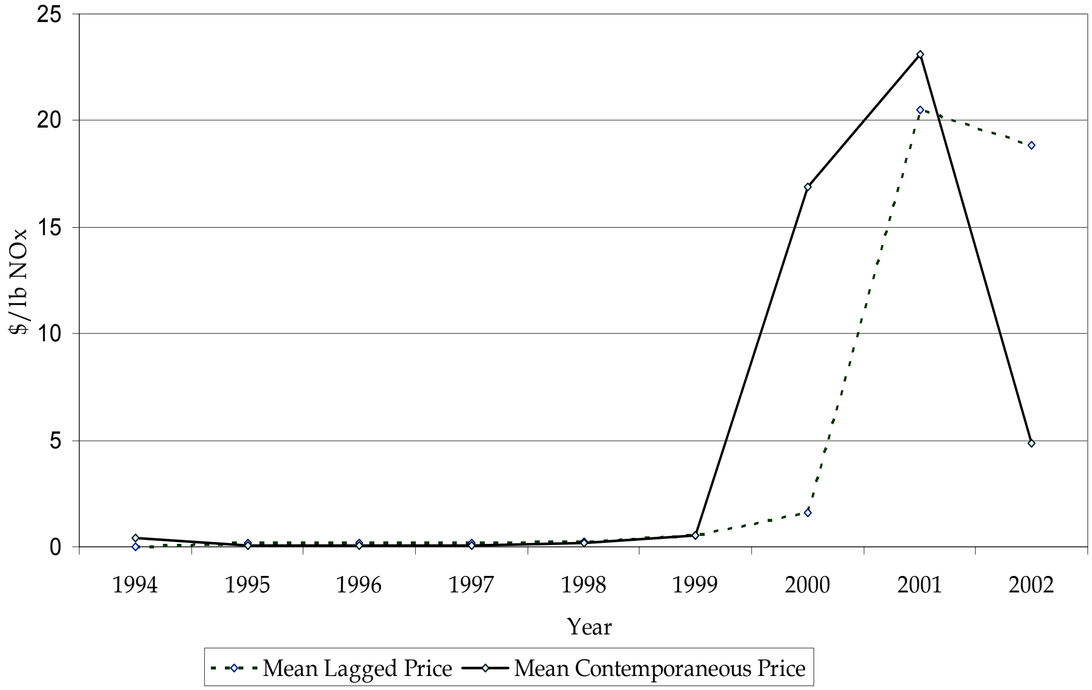

Table 1. Means and Standard Deviations (in parentheses) of Key Variables[a]

VARIABLE	1994-1998	1999-2002
Firm-Level Quarterly Emissions (pounds of NOx)	30, 285 (118, 211)	21, 729 (88, 039)
Firm-Level Quarterly Allocations (pounds of NOx)	36, 888 (123, 307)	19, 253 (67, 149)
Average RTC Price[b]	\$0.13 (\$0.11)	\$11.21 (\$11.72)
% Δ Product Price	0.27% (4.30%)	1.11% (6.94%)
Average Gas Price (\$/thousand cubic feet)	\$3.50 (\$0.81)	\$5.31 (\$2.21)
Average Southern California Electricity Price (\$/Mwh)	N/A	\$52.16 \$41.15
Number of Firms	381	380

[a] Summary statistics are calculated for those firms who have an allocation of RECLAIM RTCs.

[b] These summary statistics are calculated using all non-zero RTC prices.

Table 2. Regression of the Logarithm of Firm-Level NOx Emissions

(White Robust Standard Errors)

Variable	FE Model
ln(Allocation)	0.53* (0.16)
ln(RTC Price)	-0.03 (0.05)
ln (Lagged RTC Price)	-0.04 (0.04)
% Δ Product Price	-0.001 (0.003)
ln(Gas Price)	-0.001 (0.11)
ln(Electricity Price)	-0.02 (0.03)
Last Quarter of Cycle Dummy	-0.05 (0.03)
2000 Dummy	0.04 (0.06)
2001 Dummy	-0.05 (0.17)
2002 Dummy	-0.13 (0.17)

* Coefficient is statistically significantly different than zero at the 5% level.

Table 5:Fixed-Effect Parameter Estimates for a Model Containing Interaction Terms (Dependent Variable is log of firm-level NOx emissions, 1999-2002 Data Only)
(White Robust Standard Errors)

VARIABLE	COEFFICIENT ESTIMATES
ln(Allocation)	0.68 (0.24)
Participation * ln(Allocation)	0.03** (0.008)
Zone * ln(Allocation)	0.54** (0.24)
Size * ln(Allocation)	0.20 (0.28)
ln(RTC Price)	-0.05 (0.05)
ln (Lagged RTC Price)	-0.05 (0.05)
% Δ Product price	-0.002 (0.003)
ln(Gas Price)	-0.02 (0.15)
ln(Electricity Price)	0.05 (0.07)
Last Quarter of Cycle Dummy	-0.12** (0.03)
2000 Dummy	0.14* (0.08)
2001 Dummy	0.06 0.17
2002 Dummy	-0.06 (0.20)

* Coefficient is statistically significantly different than zero at the 5% level.