The Effect of Pollution Permit Allocations on Firm-Level Emissions

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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. This relationship between allocation and emissions is stronger among firms with relatively high transaction costs. Thus, care must be exercised in the initial allocation of permits to ensure efficiency.

keywords: emissions trading, transaction costs

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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.*
>
> *—President George Bush, upon signing the 1990 Clean Air Act Amendment*

1. Introduction

Using data from Southern California's Regional Clean Air Incentives Market (RECLAIM), we test the hypothesis that equilibrium firm-level emissions are independent of the initial allocation of pollution permits. Theoretically, 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. We also find evidence that the relationship between permit allocations and emissions is stronger among firms that are likely to face relatively high transaction costs.

Over the past three decades, governments have substantially increased the environmental regulation of industry. 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 [29]. However, 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 [28]. 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 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. Montgomery [20], 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 such as regional 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 [11]. 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 nitrogen oxide (NO_x) and sulfur oxide (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 carbon dioxide permits in anticipation of future regulation; emissions trading will undoubtedly play a central role in any international efforts to curb greenhouse gas emissions [16].

Economists have argued that a CAT approach has two substantial advantages over the traditional CAC approach. First, Hahn [10], Milliman and Prince [18], Tietenberg [27], 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 more efficient abatement technologies. Second, Montgomery [20] and Rose and Stevens [23] have argued that a CAT program reduces a regulating agency's information requirements substantially over a CAC approach because a market will allocate pollution reduction so as to minimize total cost *regardless of how permits are initially distributed*, provided that transaction costs are negligible and markets are competitive.

Because CAT programs are increasingly being relied upon to control point source pollution, it is important to understand how the theory behind emissions trading works 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, we examine whether the relationship between permit allocations and emissions is stronger among those firms that face higher transaction costs. Although we are unable to measure transaction costs directly, we can identify those firms that are more likely to face higher transaction costs, either because they are small and do not have the resources to devote to minimizing the cost of environmental compliance, or because they have limited prior experience with emissions markets and thus face a steep learning curve.

We test these hypotheses using data from Southern California's RECLAIM market for 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 summarize the necessary conditions for firm-level emissions to be independent of the initial allocation of permits. We describe the RECLAIM program in detail in Sections 3 and 4. In Section 5, we describe our estimation model. The following two sections discuss the variables and the relevant time period. We test the two main hypotheses in Section 8. The following section contains a series of robustness tests. The last section summarizes our results and draws conclusions.

2. The 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 [2] used a general equilibrium model to prove that one can expand the commodity space so as to "internalize" an externality.

Montgomery [20] established a result similar to that in Coase [7] to show that the initial allocation of permits is irrelevant to a firms' choice of emission levels 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 should be a function of the price of permits, the firm's costs of production, pollution abatement costs, and the price the firm receives for its product, but *not* 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 only 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. Stavins [26] and Montero [19] later demonstrated that the post-trading equilibrium is sensitive to how permits are initially allocated in the presence of transaction costs.

3. The Regional Clean Air Incentives Market

The RECLAIM program was designed to address serious air quality problems in the Los Angeles basin. The level of ozone, which is formed in a photochemical reaction between NOx and volatile organic compounds, in the Los Angeles basin exceeded state standards on 184 days in 1991 [11]. Adverse effects of NOx emissions include damage to lung tissue, aggravation of asthma and other respiratory problems, a reduction in the ability of plants to produce and store food, fish kills, algal blooms and reduced visibility. Hall et al. [12] estimated that health-related losses in that region due to poor environmental quality approached $10 billion per year.

The South Coast Air Quality Management District (SCAQMD)[1] 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 per year or more of either NOx or SOx were included in the program.[2] 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 conventional CAC approaches. Johnson, et al. [13] predicted

[1] 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.

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

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 [6]. 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.

Each RECLAIM trading credit (RTC) represents one pound of NOx emissions and is valid for one year. Appendix 1 describes in detail how SCAQMD calculated each firm's allocation schedule. These RTC allocation schedules, which specify how many permits the firm receives each year over the period 1994-2010, were determined and made public at the start of the program in 1994.

The total number of permits allocated each year has fallen over time so as to reduce pollution levels overall. A firm's starting (1994) allocation and year 2000 allocations were both determined by the characteristics of the equipment used by the firm (such as equipment size, hours of operation, technology type), the firm's annual NOx emissions in a prior period (1989-1992), and the amount of certified emissions reductions (ERCs) the firm had prior to 1994[3]. Firm-level allocations in the first seven years of the program were determined as a straight line rate of reduction between the firm's 1994 and 2000 allocations. From 2001 to 2003, allocations depreciated at a common rate across facilities. Allocations are not scheduled to depreciate after 2003. The annual weighted average reduction in RTC allocations for the population of 390 facilities from 1994-2003 was 8.3% [13].

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

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[3] ERCs are reductions in emissions that SCAQMD has certified as being permanent and beyond mandated reductions.

[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 fleet turnover.

emissions beyond the required amount, it can sell its excess permits in the market to other firms. RTCs cannot be banked, they must be used in the year to which they are assigned. 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.

Emissions are reported and certified quarterly. During the 30 calendar days after the conclusion of each of the first three quarters, firms must calculate their total emissions for the quarter, acquire any RTCs necessary to reconcile their allocation to their emissions, and submit a quarterly certification of emissions to SCAQMD. Firms have 60 calendar days following the last day of each compliance year to reconcile emissions and permit purchases with their allocation [24].[5]

Because regulators expected that firms would wait to purchase or sell permits until the end of the year, they feared that this behavior would lead to price spikes in the permit market during the reconciliation period following each 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 assigned to cycle 1 is allocated cycle 1 permits, but can purchase cycle 2 permits in order to offset its emissions. For example, permits of a vintage corresponding to cycle 1, 1998 can be use to offset emissions that occurred at any time in 1998. Cycle 2, 1998 permits are valid from July 1998-June 1999. A firm assigned to cycle 1 can purchase 1998 cycle 2 permits and use them to offset any emissions that occurred in July 1998-June 1999.

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

[5] SCAQMD rule 2004 states that the reconciliation period following the end of a quarter shall be used to reconcile allocations only with emissions from that quarter. A lawsuit filed in September 2003 alleges that SCAQMD has failed to conduct quarterly audits and has instead allowed a facility to be considered in compliance, provided that the facility reconciles its emissions with sufficient RTC's by the end of the year.

SCAQMD has not provided a formal auction to facilitate the trading of RTCs. Firms wishing to trade RTCs may find trading partners themselves or use one of several private brokers.[6] The fraction of RTC transactions involving private-sector brokers increased from 38% in 1994 to 75% by 2001.

4. Characteristics of the RECLAIM Market

Unfortunately, not all necessary conditions for allocative efficiency are met in the RECLAIM market. We examine transaction costs, participants' information, and the degree of competitiveness in the permit and product markets.

4.1 *Transaction Costs*

Empirical studies of CAT programs indicate that transaction costs in pollution permit markets can be significant [3],[8]. 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 brokerage services it deems necessary. A firm also bears some of the costs of monitoring and reporting its emissions to the regulating agency.

Cantor Fitzgerald required a fixed fee of $150 per trade and a variable fee of 3.5% of the transaction value in 1996 [6]. 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% to 3% of the total value of the trades [30]. Unfortunately, the EPA study did not ask questions about the

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[6] 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.

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 more long-term decisions about installing abatement equipment or pursuing other emissions-reducing innovations [30].

4.3 *Perfect Competition in Product and Permit Markets*

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 1998-2000 [5]. In other industries where regional imports and exports are limited, such as ready-mix cement, 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 distributed so that the average firm-level allocation is equal to 0.5% of the total number of permits allocated in any one year. The maximum allocation received by any one firm (as a percent of total permits allocated that year) is 9.3%. Kolstad and Wolak [15] 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 the (permit) price taking assumption has been violated only in the case of some electricity generators. The implications of imperfect competition in product and permit markets for this analysis are discussed in a later section.

4.4 *Monitoring, Compliance and Enforcement*

A RECLAIM firm is in compliance if, in the reconciliation period following the end of a quarter, it has rationalized its measured emissions during the quarter with sufficient permits of the correct vintage. If a facility is found to be out of compliance, the firm's allocation for the subsequent quarter is reduced by the total amount it exceeded its allocation. Facilities can also be fined up to $500 per violation per day.

SCAQMD estimates that the average compliance rate (the number of facilities that complied with their annual allocation) was 90% from 1994 through 1997 [30]. A 1998 SCAQMD document indicated that non-compliance prior to 1998 could be attributed to misunderstanding of the regulation or mistakes in calculation [17]. The data suggest that reported aggregate emissions in the SCAQMD region exceed allocations as early as 1998. Evidence of non-compliance is particularly strong in 2000 when electricity generators could make unusually high profits in California's wholesale electricity markets that substantially exceeded the fines associated with exceeding emission allowances.[7]

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. We assume that the firm's log-linear reduced-form emission function is

$$\ln E_{it} = \alpha_i + \beta_0 \ln A_{it} + \beta_1 T_{it} \ln A_{it} + \phi \ln Z_{it} + u_{it}, \qquad (1)$$

[7] In September 2003, two environmental groups filed a lawsuit in federal court against SCAQMD for violating the federal Clean Air Act in the administration of RECLAIM. The filed suit documents noncompliance of firms other than electricity generators in the period 1998-2001. Presumably, if the compliance rules are not enforced, the initial allocation will be less likely to affect emissions, even in the presence of transaction costs. Thus, any failure to enforce should increase the likelihood that we will not reject our hypothesis that firm-level allocations and emissions are independent (Our Children's Earth (2003). "Environmental Groups Sue SCAQMD for Violating the Clean Air Act; Pollution Trading Scheme Under Attack for Causing Smog." OCE Press Release, September 29, 2003).

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; T_{it} is a dummy variable that indicates whether firm i was more likely to have faced higher transaction costs in time t (either on account of its small size or its lack of prior experience in the permit market); Z_{it} is a vector of exogenously determined variables including the current and lagged average RTC price (to capture lagged adjustment), a proxy for the firm's average product price, and the average gas and electricity prices (input prices facing the firm). We assume that the disturbance term u_{it} is distributed with zero mean and constant variance σ_u^2 and that all the firms in the sample treat output prices, permit prices, and energy prices as exogenous.[8]

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 characteristics such as size, industry, baseline emissions, production technologies, and management characteristics. The firm fixed effects capture the determinants of allocation because the firm-level allocation schedules were determined as a function of time-invariant firm characteristics (baseline emissions, characteristics of the equipment operated by the firm prior to 1994 and ERCs/offsets held by the firm in 1994).

If the firms' unobserved abatement cost curves change from year to year, abatement cost is an important omitted variable that is not entirely captured by α_i. Because pollution control costs may also be

[8] 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. In response to a sudden increase in RTC prices in 2000, SCAQMD removed all electric generators that produce over 50 MW from the RECLAIM program. As of Jan. 11, 2001, generators pay $7.50 per pound of NOx that they emit over their RTC allocation. Because generators were able to affect both electricity and permit prices during the period we analyze here, we dropped the 27 electricity-generating facilities from the sample so as to avoid potential endogeneity problems.

affected by unobserved time-variant factors, we include time dummies in the *Z* vector to capture the effects of changes in unobserved variables (such as exogenous technical change) that influence firms equally across time. To the extent that exogenous technical change affects technologies operated by RECLAIM firms asymmetrically, the omission of the marginal abatement cost variable could bias our coefficient estimates. We also include seasonal dummies, to account for any cyclical changes in firm-level emissions, and a dummy for the last quarter of the RECLAIM cycle, for reasons we discuss in later sections.

To test our first hypothesis that equilibrium, firm-level emissions are independent of the initial allocation, we estimate a restricted version of the model in which β_1 is assumed to be 0 and test whether $\beta_0 = 0$. When we control for permit prices, product prices, energy prices, time and firm fixed effects, the coefficient on initial permit allocation, β_0, should not be statistically significantly different from zero.

We then test our second, stronger hypothesis that the effect of the initial allocation on equilibrium firm emissions is greater, the larger are transaction costs that a firm faces (or the more likely that firm is to face high transaction costs). That is, we test whether $\beta_1 > 0$.

6. Variables

Our data set contains information by firm from the first quarter of 1994, the beginning of the RECLAIM program, through the last quarter of 2001 (32 quarters). Because we are interested in the relationship between allocations and emissions, only those firms that received RTC allocations are included in this study.[9] Generators are also excluded from the sample. Appendix 2 provides a more detailed description of the data set.

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[9] Only the original firms—those present when the program began in 1994—received quarterly allocations. Any new firms entering SCAQMD that are NOx emitters must either purchase credits to cover their emissions or, in some cases, take advantage of a special reserve of RTCs earmarked for job-creating, clean companies [25].

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. On average, there are 20 (of a possible 32 quarters) quarterly emissions reports per firm (see Appendix 2).

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). From these data, we recovered the NOx permit allocation schedule for the 383 RECLAIM firms that are not electricity generators (see Appendix 2).

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—an opportunity cost—in making short-term production decisions that affect emissions. The prices they pay for future permit vintages reflect firms' expectations, which presumably influence their long-term decisions affecting emissions levels, such as whether to invest in abatement technologies. The RTC price variable used in this analysis was generated by calculating the quarterly mean of nonzero permit prices paid in transactions that occurred in quarter t for permits valid in quarter *t* (see Appendix 2). The lagged RTC price variable was generated by calculating the quarterly mean of nonzero permit prices paid in transactions occurring in time *t*-1 for permits valid in time *t*. The RTC price variable is adjusted for inflation.

6.4 Industry-Level Variables

Using the information SCAQMD provides about the identity of RECLAIM facilities, we determined the four 4-digit North American Industry Classification System (NAICS) code for each facility. The firms represented in the sample fall into 144 different industrial classifications.[10]

[10] Three facilities could not be matched with NAICS codes because they had multiple facility identification numbers and NAICS codes associated with a single address, making it impossible to match

We also obtained a measure of industry-level product price for each facility. When a firm is deciding whether to buy or sell RTCs, 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. Because we could not obtain systematic profit data, we used the Bureau of Labor Statistic's 4-digit NAICS Producer Product Indexes (PPI) as a proxy for shifts in demand facing firms.[11]

Quarterly emissions are likely to be highly correlated with quarterly energy use. Bjorner et al. [4] and Woodland [31] have demonstrated that energy prices significantly affect firm's demand for energy, particularly in energy-intensive industries. 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 NAICS code, 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 prices from the University of California Energy Institute website.[12]

6.5 *Quarter*

We include a dummy for the last quarter of the RECLAIM cycle in our reduced-form equation. RECLAIM facilities must demonstrate at the end of each quarter that their quarterly emissions did not

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the source of the emissions with an industry. After dropping these firms from the sample, we have 380 firms remaining.

[11] 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 could not be included in the analysis.

[12] The electricity price data are only available beginning in April, 1998 when California electricity industry restructuring first took effect. In the analysis conducted using pre-1998 data, electricity price is not included as a regressor in the estimation model.

exceed their allocation plus net permit purchases. To the extent that firms see their annual allocation as a binding constraint, compliance will be particularly difficult in the fourth quarter when firms have used up the majority of their allocation in the previous three quarters. Rather than go to the permit market to purchase additional permits to cover any emissions in excess of their allocation, firms may choose to reduce production and 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 one if the firm is in the last quarter of its cycle.

7. Relevant Time Period

Before conducting our hypothesis tests, we need to determine the relevant time period of the analysis. Market conditions in the early years of RECLAIM changed significantly once the aggregate allocation constraint started to bind and RTC prices increased above zero. Figure 1 plots quarterly allocations and NOx emissions as reported by all firms. The thick, solid line represents the total number of permits allocated by quarter. However, not all firms actually report emissions in a given quarter. The thin, solid line connects the quarterly allocations of only those firms that reported emissions in the corresponding quarter. The dashed line represents reported quarterly emissions. This figure illustrates that, in the early years of the RECLAIM program, firms' allocations exceeded their emissions. SCAQMD estimates that initial allocations were 40-60% above actual emissions in 1994-1996 [30]. Although *reported* emissions do not exceed the total allocation until 1999, a more complete measure of aggregate emissions would likely result in an earlier cross-over point.

Figure 2 plots the trend in average "current" and "lagged" mean annual prices.

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 by 1999.[13] The solid line in Figure 2 connects 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 five 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 by the California electricity crisis, which caused statewide demand for electricity from generators in this region to increase. Beginning in 1999, electrical generators found it profitable to increase the operation of older, less-efficient equipment. Consequently, many generators exceeded their RTC allocations significantly so that,the number of RTCs available to other firms fell and the price of RTCs rose substantially. RTC prices increased from an average price of $1.16 per pound traded in the fourth quarter of 1998 to $27.40 per pound traded during the fourth quarter of 2000 (see the Appendix 2 for how the average is calculated).

Table 1 presents summary statistics for these two periods.[14] It is only in the second period that allocations are binding and permit prices rise significantly above zero. Although the mean of quarterly firm-level emissions in the period 1998-2001 exceeded the mean quarterly allocation, the total RTC allocation over this period slightly exceeded total reported emissions because several firms did not report emissions in all quarters.

Based on Figures 1 and 2 and Table 1, we do not expect that the allocation parameter value will be constant over the entire sample period, 1994-2001. In particular, we expect the initial allocation to

[13] Miller, Michael (1994). "Firms Can Earn Credits for Keeping Emissions Down, Then Sell Them." *The San Francisco Examiner.* January 9, 1994: B1.

[14] Table 1 and the estimated model are based on 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.

have an impact on firm-level emissions only when the allocation constraint starts to bind in aggregate. Consequently, we test our hypotheses using data for the 1998-2001 period in Section 8. In Section 9, we examine what would happen if we use data for the entire period.

8. Estimation and Hypothesis Testing

We start by testing our first hypothesis that the initial allocation does not affect the equilibrium emissions. Then we examine our stronger section hypothesis that the degree to which the initial allocation affects emissions depends on the size of the transaction or information costs facing a firm.

8.1 *Testing the First Hypothesis: Firm-level Emissions are Independent of Allocation*

We estimate the fixed effects (FE) model of Equation (1).[15] Because the idiosyncratic errors are both serially correlated and cross-sectionally heteroskedastic, we use Arrellano's "clustered" robust asymptotic variance matrix estimator, generalized to the unbalanced case, to generate robust estimates of the standard errors [1],[14]. This approach involves estimating the elements of a block diagonal variance-covariance matrix allowing for error variances to differ across firms, and allowing the within-block, off diagonal elements of the matrix to be non-zero. We impose no restrictions on the nature of the within-block serial correlation.

We reject the null hypothesis that $\beta_0 = 0$ at the 0.05 confidence level (t-statistic = 2.03). That is, the initial allocation does affect equilibrium firm emissions. The estimated β_0 coefficient is 0.70, so a 1% change in allocation results in a 0.7% change in NOx emissions. Equivalently, a one pound increase in a

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[15] Because firms are required to demonstrate compliance each quarter, this analysis was conducted using quarterly data. A lawsuit filed in September, 2003 by two environmental groups alleges that SCAQMD does not enforce the quarterly compliance rules; in practice, firms must only demonstrate that they are in compliance by the end of an annual cycle (OCE, 2003). When we repeated the analysis using data aggregated to the annual level, we obtained similar results. The estimated coefficient on allocation is 0.66 and statistically significantly different than zero for the period 1998-2001. None of the other variables in the model is statistically significantly different from zero.

firm's NOx allocation in a given quarter increases its emissions by 0.73 pounds on average.[16] We cannot reject the hypothesis at the 5% level that the coefficients on the RTC price variables, product prices, and energy price are each zero. The fourth quarter dummy is statistically significantly less than zero at the 5% level, presumably reflecting end-of-year adjustments by firms to ensure that their annual emissions do not exceed their allocation.

8.2 *Testing the Second Hypothesis Concerning Transaction Costs*

Having rejected the first hypothesis that emissions are independent of the initial allocation, we now turn to our stronger, second hypothesis. 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). We test the hypothesis that the larger the transaction cost, the greater the effect of a firm's initial allocation on its emissions. That is, instead of imposing that $\beta_1 = 0$, we test whether it is statistically significantly greater than 0.

We lack a simple, continuous index *T* of the relative size of transaction costs. Instead, we use two binary variables that proxy whether a firm has relatively high or low transaction costs: firm size and prior participation in the NOx market.

Firm Size

When there are non-negligible transaction costs associated with participating in an emissions market, firm size may play a role in determining market participation. Smaller firms may face relatively high transaction costs in learning how the RECLAIM market works and in determining the least-cost

[16] Over this period, the mean firm-level quarterly emissions is 23,030 pounds and the mean quarterly allocation is 21,984 pounds.

approach to compliance because they cannot take advantage of scale economies. 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 [30].

Because we lack comparable data on firm-level output or employment across firms, we use average firm-level emissions from a prior period, 1994-1997, as an indicator of firm size. We categorize a firm as “small” if its average quarterly emissions in 1994-1997 was less than the sample median value of 4,082 pounds, and “large” otherwise.[17]

We create a size dummy variable that indicates whether a firm is small and interact it with the log of allocation. We add this interaction term to Equation (1) and test whether its coefficient, β_1, is nonzero.[18] We cannot reject the hypothesis that the coefficient on the interaction term is zero: The estimated coefficient is 0.08 with p-value of 0.80. The estimated coefficient on allocation is 0.70 and significant at the 5% level. Including the size interaction term in Equation (1) does not significantly affect any of the other coefficient estimates. We can conclude from these results 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 that 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 established trading relationships. Gangadharan [8] found that facilities that participated many times in the NOx RTC market before August 1997 are more likely to trade in subsequent years.

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[17] Because 32 firms that report emissions during the period 1998-2001 did not report emissions prior to 1998, we cannot assign them a size and hence drop them from the model.

[18] Using a Chow test, we cannot reject the hypothesis that the vectors of estimated coefficients are the same when the model is estimated separately for small and large firms.

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*.[19] In 1998, only a third of the firms represented in the 1999-2001 dataset had bought or sold permits at non-zero prices in a previous year. This proportion had increased to 59% by 2001.

The second column of Table 2 presents the parameter estimates for the full model, Equation (1), which contains the participation dummy, *T*, interacted with the allocation variable.[20] The estimated allocation elasticity increases from 0.70 to 0.71 when the participation interaction term is included. Thus, the average allocation elasticity is 0.70 for all firms in the sample, and 0.71 for firms with no prior experience in the RECLAIM market—firms that presumably face higher transaction costs. The estimated coefficient on the participation-allocation interaction term is -0.02 (the p-value is 0.09). Thus, the relationship between allocation and emissions is marginally stronger among the inexperienced firms in the sample.[21]

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[19] On average, 47% of transactions occurring between 1999 and 2002 involved RTCs that had to be used in the years after the year of purchase. Prior participation in the RTC market can affect a firm's future emissions in two ways: through lowering transaction costs, thereby increasing the chances that the firm will participate in the market again; and by altering the quantity of future emissions that the firm can offset with permits it owns. 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 vintage *t*.

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

[21] If we were to use White's heteroskedasticity-consistent standard errors, which are appropriate with serially uncorrelated errors, we would obtain smaller standard error estimates and conclude

Finally, we reject the hypothesis that the combined effect of allocation on firm-level emissions, $\beta_0 + \beta_1 * T_{it}$, is zero. The p-value is 0.04.

9. Robustness Tests

To assess the robustness of our result and whether our estimation procedure was reasonable, we examine earlier periods and conduct tests of model-specification, sample selection, homoskedasticity, lack of serial correlation, and exogeneity of the allocation and price variables.

9.1 *Determining the Relevant Time Period*

In Table 2, we assumed that the relevant time period was 1998-2001, when the allocations were binding. We now consider the entire time period, 1994-2001. To determine whether the coefficient on allocation changed over time, we add interactions of the variable of interest (log of allocation) with the seven year dummies to Equation (1) and re-estimate the model using the entire period. The allocation-time interaction terms for 1998-2002 are all statistically significantly different from zero at the 0.05 level when 1994 is the base year. A Chow test confirms that the two vectors of estimated coefficients associated with the 1994-1997 observations and the 1998-2001 observations are statistically significantly different (the estimated F-statistic is 3.2 and the associated p-value is 0.001).

We showed in Table 2 that, if we use the data only from the period when the allocation was binding, 1998-2001, we find a statistically significant relationship between allocation and firm-level emissions. As we expected, we do not find evidence that allocations matter in the earlier period, 1994-1997, when allocations were not binding: If we estimate the model using data from only 1994-1997, the estimated coefficient β_0 is -0.01 with a p-value of 0.41.

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that the allocation variable and participation-allocation interaction are statistically significant at the 1% level.

9.2 *Model-Specification Tests*

If the unobserved fixed effect α_i does not actually belong in the model, σ_α^2 = 0 and the OLS estimates are efficient. To assess whether we should include the fixed-effect terms α_i, we estimate a model that does not include fixed-effect terms but does include observable firm characteristics: two-digit NAICS dummies and baseline emissions. We estimate this modified model using OLS and then test for AR(1) serial correlation based on the OLS residuals. The allocation coefficient we estimate using OLS is 0.50 and significant. The coefficient on the participation interaction term is 0.02; it is not significant. A normally distributed test statistic was constructed and the null hypothesis, H_o: σ_α^2 = 0, was rejected [33]. Thus, we conclude that the alternative OLS model omits important time-invariant firm effects, and hence we use a firm fixed-effects model.

To test for misspecification in the functional form, we augment 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 are statistically significantly different from zero at the 0.05 level. The estimates of the original parameters do not change dramatically. The estimated coefficients on both the allocation variable and the participation interaction term are unchanged. Thus, we fail to reject the log-linear functional form for the emissions function.

9.3 *Sample-Selection Test*

The panel used to estimate model is unbalanced: Emissions data are available for 16 quarters from the beginning of 1998 through to the end of 2001. On average, firms reported emissions in 12.3 of the 16 quarters. Observations may be missing because of late reporting, malfunctioning emissions recording equipment, allocation adjustments, or plant closures. A common approach to dealing with the problem of unbalanced panel data is to use only those units that are observed over the entire sample. With only 49% of firms in the 1998-2001 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 [21].

The mean quarterly emissions for the 129 firms in the sample for which all 16 quarterly emissions reports are available is 20,040 pounds, which is 13% smaller than the overall sample mean. The mean allocation in the balanced sample is 17, 471 pounds, 20% smaller than the overall average quarterly allocation. Thus on average, the firms reporting emissions in all periods are smaller polluters than those firms that 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 (y_{it}, X_{it}) are observed. Given the difference in the mean emissions and the mean allocations for the balanced and unbalanced samples, one might hypothesize 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} or α_i [33]. To test whether the selection indicator s_{it} is independent of the idiosyncratic error u_{it}, we use a test developed by Wooldridge [32] that makes no distributional assumptions about α_i and allows for serially correlated and heteroskedastic idiosyncratic errors. Based on this test, we cannot reject the null hypothesis that s_{it} and u_{it} are independent. Consequently, we conclude that using an unbalanced panel does not affect the consistency of our estimates.

9.4 *Spherical Disturbances Test*

If we assume that

$$E\left(u_i u_i' \mid X_i, \alpha_i\right) = \sigma_u^2 I_T, \tag{2}$$

where I_T is a *T*-dimension identity matrix, then the fixed effects estimator is efficient [33]. According to Equation (2), the idiosyncratic errors have constant variance across time and across individuals, and are serially uncorrelated.

We start by testing whether the idiosyncratic errors are uncorrelated over time in the balanced sample.[22] If the right-hand-side variables are serially correlated, serial correlation in the error process will affect the standard errors in an FE model. The F-statistic (1, 891) is 5,942. Thus, we reject the null hypothesis of serially uncorrelated errors in the balanced panel, and we assume that these results hold for the complete, unbalanced panel.

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. We test for cross-sectional heteroskedasticity using a modified Wald statistic on the null hypothesis of constant variance across firms; $\sigma^2_i = \sigma^2$ for $i = 1, \ldots, N$ [9]. Using a balanced subset of the original panel, we reject the hypothesis that the disturbance variances are equal across all firms in the sample. Thus, because we find evidence of both cross-sectional heteroskedasticity and serial correlation, we use Arellano's clustered standard error estimates [1] in Table 2.

9.5 *Testing the Exogeneity of the Allocation Variable*

Until now, we have assumed that permit allocations are exogenous. The 1994-2010 RTC allocation schedules of RECLAIM firms were based on pre-1994 emissions, pre-1994 emission reductions, and pre-1994 plant and technology characteristics. It is unlikely that firms strategically "over-emitted" during the years used to determine firm baselines (1989-1992), so 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 endogenous.

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[22] One way to test whether the idiosyncratic errors are serially correlated is to obtain the estimated residuals from a fixed-effects regression and then to estimate $\hat{u}_{it} = \delta\ \hat{u}_{i,t-1}$, for $i = 1, \ldots, N$. One can then test H_o: $\delta = -1/[T - 1]$, which is equivalent to testing whether the idiosyncratic errors are serially uncorrelated (Wooldridge, 2002).

The allocations schedules of the 380 firms in the 1998-2001 sample were first determined in 1994 based on historical emissions and equipment type, and then some were revised in 1995 in response to appeals filed with SCAQMD. According to SCAQMD, these revisions reflect corrections to estimated emission rates, amendments to historical emission records, and reapportionment of fuel usage [6], [22]. The average allocation adjustment was 135,562 pounds with a standard deviation of 2.06 million pounds. In the sample, 101 firms had their allocations increased, and 60 firms had their allocations decreased.

Although the reasons cited for adjusting allocation are not political in nature, 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. We create a series of five dummy variables that indicate whether the firm had previously participated in the Reclaim market, and whether the firm had their allocations adjusted up or down: participated-adjust up, participated-not adjusted, participated-adjust down, no prior participation-adjusted up, and no prior participation-adjusted down (the base group is no prior participation and no adjustment). We interact each of these dummy variables with the allocation variable and re-estimate our FE model. [23] The estimated coefficient on allocation (that is, the effect for the no prior participation and no adjustment group of firms) decreases from 0.70 to 0.67, but remains statistically significant at the 5% level. None of the interaction terms are statistically significant. The coefficient on the interaction of allocation and the participated-not adjusted dummy is -0.02, but is no longer statistically significantly different from zero individually. We cannot reject the hypothesis that the coefficient in this model and our original model are identical. We conclude that the relationship between allocation and emissions is statistically significant regardless of whether a firm's allocations have been adjusted.

There is another reason why the allocation variable might be endogenous: We have omitted a variable, marginal abatement cost, that may be correlated with allocation. The rate at which a firm's

[23] We could not use an instrument to deal with potential endogeneity because no appropriate instrument is available.

allocation declined between 1994 and 2000 was determined by technology-specific emission adjustment factors. These factors were based on information collected by SCAQMD, prior to 1994, regarding hours of operation, equipment size, heating capacity and other technology characteristics. By including firm fixed effects in Equation (1), we control for time-invariant, inter-firm differences in technology and abatement costs. By including time dummies in the estimation model, we control for the effect of trends in technological change and abatement costs that affect firms uniformly. However, to the extent that innovations in abatement technology affected firms differently over the period 1999-2001, and to the extent that these inter-firm differences were correlated with the technology specific emissions adjustment factors used by SCAQMD regulators in 1994, the allocation variable will be correlated with the error term, and our coefficient estimates will be biased. We take two different approaches to evaluating how likely it is that a correlation between allocation and unobserved, asymmetric technological innovation is driving the relationship between allocation and firm-level emissions.

Our first approach exploits a policy change in 2001. After that date, firm-specific allocation reductions ceased, although allocations of all firms continued to decrease at a uniform rate. Thus, even if allocation is related to emissions only because it serves as a proxy for unobserved, asymmetric changes in marginal abatement costs, this relationship should end in 2001. To test this, we add an interaction term—a dummy for 2001 multiplied by log(allocation)—to Equation (1). If allocation is a proxy for the marginal abatement cost, we would expect the coefficient on the interaction term to be negative and statistically significant. Instead, we find that the coefficient on the interaction term is positive and not statistically significant. Thus, we conclude that the relationship between allocation and firm-level emissions does not change statistically significantly beginning in 2001.

Our second approach takes advantage of the random assignment of firms to one of two cycles, so that half the firms' allocation cycle ends in the second quarter and the other half's cycle ends in the fourth quarter. As Table 2 shows, firms appear to reduce their emissions more in the last quarter of their allocation cycle, as their allocated permits are running out. If allocation and firm-level emissions are truly independent, we should not find this end-of-cycle effect. To explore this result further, we estimate an equation that differs from Equation (1) in two respects. First, instead of including a firm fixed effect, we include an industry fixed effect. That is, we control for fixed differences across firms that vary only by industry. Second, we include two time-invariant, firm-level covariates to control for inter-firm heterogeneity: a firm's baseline emissions, and the rate at which a firm's allocation decreases.

When we control for baseline allocation, the rate at which allocation decreases, and industry fixed effects, we can compare the emissions of similar firms with different cycle assignments. By including quarter dummies, in addition to an end-of-cycle dummy, we can interpret the coefficient on the latter as the effect of the ending of an allocation cycle on emissions, independent of any seasonal effects. If firm-level emissions are independent of allocation, the ending of an allocation cycle should not affect firm level emissions.

Both the estimated coefficient on allocation, 0.4, and the estimated coefficient on the last quarter of an allocation cycle dummy, -0.7, are statistically significantly different from zero at the 5% level (using Arrelano's "clustered" standard error estimates). For example, a firm assigned to cycle 1 emits statistically significantly less in the fourth quarter compared to a cycle 2 firm in the same industry with a similar allocation schedule. Thus, again we find that emissions are positively related to allocation in a manner that has nothing to do with changes in the marginal abatement cost.

9.6 Testing the Exogeneity of the Permit Price Variables

In Section 4, we discussed the possibility that the permit and some product markets are imperfectly competitive. Having eliminated the electricity generators from the sample, we are less concerned about violating assumptions of price taking behavior in permit or product markets. On average, a firm's annual allocation represents 0.5% of the total annual allocation, and no single firm's annual allocation exceeded 9.3% 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 use an instrumental variables (IV) estimator where RTC prices lagged two to six periods are the instruments for the current RTC prices. The estimated coefficient on allocation is 0.72 in both the FE model and the FE-IV model. A Hausman test fails to reject the exogeneity hypothesis.

10. 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.

We hypothesized that this failure of the Coase independence result is due to the presence of transaction costs. We test a second, stronger hypothesis that the positive link between emissions and allocation increases, the greater a firm's transaction costs. We use two approaches to identify firms that are likely to have relatively high transaction costs: small firms and firms that had not previously participated in the market. We do not find a clear effect with respect to firm size, but we find some evidence of higher allocation elasticities for firms that have not previously participated in the market for NOx RTCs.

This relationship may not persist in the RECLAIM market. Increasingly, RECLAIM firms are applying for permits to install NOx abatement equipment. As that equipment comes on line and as more firms gain permit trading experience, the relationship between allocations and emissions will likely weaken.

However, if this relationship persists in the RECLAIM market or if it can be found in other permit markets, such as the national SO_2 market or the market for NOx in the northeastern US, then great care must be used in initially allocating permits. 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. 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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Appendix I: SCAQMD's Allocation Methodology

SCAQMD's methodology to calculate a facility's RTC schedule is described in more detail in SCAQMD's Rule 2002. The starting allocation for each facility was determined using the following formula:

$$Starting\ Allocation = \sum_{k=1}^{K_i} [A_k \times \ B1_k] + ERCs + External\ Offsets,$$

where K_i is the number of regulated NOx sources operated by Firm i; A_k measures the throughput of the k^{th} source or process unit, for the maximum throughput year from 1989-1992, in pounds of NOx, and $B1_k$ is the relevant starting emission factor for the k^{th} subject source or process unit operated by the firm.. For example, if the i^{th} firm only has one source of NOx (K_i=1), A_1 would be the maximum annual emissions from that source over the period 1989-1992. Prior to 1994, starting NOx emission factors (B1), as well as Tier I emission factors (B2), were established for all types of equipment being operated by RECLAIM sources; equipment was categorized based on hours of operation, equipment size, heating capacity and permitting information. The K_i products of baseline throughput times the starting emission factors are summed to determine the starting allocation for the i^{th} firm.

Emission Reduction Credits (ERCs) are reductions in emissions that SCAQMD views as being real, permanent, and surplus (beyond mandated reductions). Any ERCs held by RECLAIM facilities in 1993 were converted to RTCs and added to the starting allocation for that facility. These converted ERCs had a zero rate of reduction between 1994 and 2000. An external offset is similar to an ERC in that it is an emission reduction approved by SCAQMD for use to mitigate an emission increase, but the emission reduction is made at a facility other than the facility creating the emission increase. External offsets held by facilities in 1993 could be converted to RTCs and added to the starting allocation pursuant to approval by SCAQMD. These converted external offsets also depreciate at a 0% rate until 2000.

The total number of permits allocated each year has fallen over time so as to reduce pollution levels overall. Firm-level allocations between 1994 and 2000 were determined by a straight line rate of reduction between the firm's starting allocation and the firm's year 2000 allocation. The latter was determined using the following formula:

$$Year\ 2000\ Allocation = \sum_{k=1}^{K_i} [A_k \times B2] + converted\ ERCs + converted\ Offsets,$$

where $B2$ is the Tier I emission factor corresponding to the subject source or process unit. Converted ERCs and offsets represent the quantity of ERCs and offsets that were converted to RTCs in the calculation of the starting allocation. All of the information used to determine 2000 allocations was available in 1994.

Firm-level allocations between 2000 and 2003 were determined by a straight line rate of reduction between the 2000 allocation and the year 2003 allocation. The 2003 allocations were determined in 1994 by applying a percentage inventory adjustment to reduce each facility's year 2000 allocation so that the sum of all RECLAIM facilities' 2003 adjustment was equal to an emissions reduction target established in 1991. Allocations cease to depreciate after 2003.

Appendix II

In the past, SCAQMD provided a modem-accessible bulletin board on which it posted for each firm in the RECLAIM program a facility identification number, address, zone, and cycle assignments. We use this information to link data from other sources to those we obtained from SCAQMD.

A.1 *Quarterly Emissions*

For monitoring and reporting purposes, RECLAIM sources are divided into four categories: major sources, large sources, NO_x process units, and designated equipment. A firm can have anywhere from 1 to 144 monitored sources. Major sources, which account for 14% of RECLAIM NO_x sources, are required to install a continuous emissions monitoring system to measure emissions directly. Large sources (approximately 20% of RECLAIM NOx sources) have the option to be monitored by a continuous process monitoring system (which uses emissions factors or rates to estimate total emissions). The NO_x process units and designated equipment (approximately 57% and 9% of NOx sources respectively), are allowed to impute their emission using measures of fuel consumption, processing rate, or operating time in conjunction with an emission factor or emission rate.

On average, there are 22.3 quarterly emissions reports per firm (of a possible 33 quarters), and 12.3 quarterly emissions reports per firm over the 16 quarters focused on in the analysis (January 1998-December 2001).

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 are 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.[24]

A.2 *Quarterly Allocations*

A firm's allocation for a given year is calculated by summing the RTCs, emission reduction credits (ERCs) 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. Annual allocations are then divided equally into quarters. Any adjustments that were made by SCAQMD after the allocations were initially determined are incorporated into our measure of allocation.

When firm allocations were being determined, SCAQMD asked each firm to choose a year in the period 1989-1992 to serve as a baseline for that firm's allocation schedule. Unfortunately, the firm-level baseline emissions data were not available from SCAQMD. In the OLS regression, we use each firm's first annual allocation as a proxy for its baseline emissions.

A.3 *RTC Prices*

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. In our analysis, we used the quarterly mean of non-zero prices, weighted by transaction volume. Because 61% of the registered trades are recorded as $0 price transactions, if we had calculated the mean permit prices using the complete transaction data set, we would have been underestimating what it cost a firm to purchase permits from another firm. Quarterly means of non-zero transactions are more meaningful indicators of expected prices for firms planning to participate in the RECLAIM market.

[24] This description is based on personal correspondence with George Haddad, a SCAQMD engineer, in 2002.

There are three reasons why RTCs are traded at a price of zero:

(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.

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 the true, unbundled price variability. This measurement error may bias coefficient estimates toward zero.

A.4 Input Prices

Quarterly emissions are likely to be highly correlated with quarterly energy use, which is in turn likely to be correlated with energy prices, 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.

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

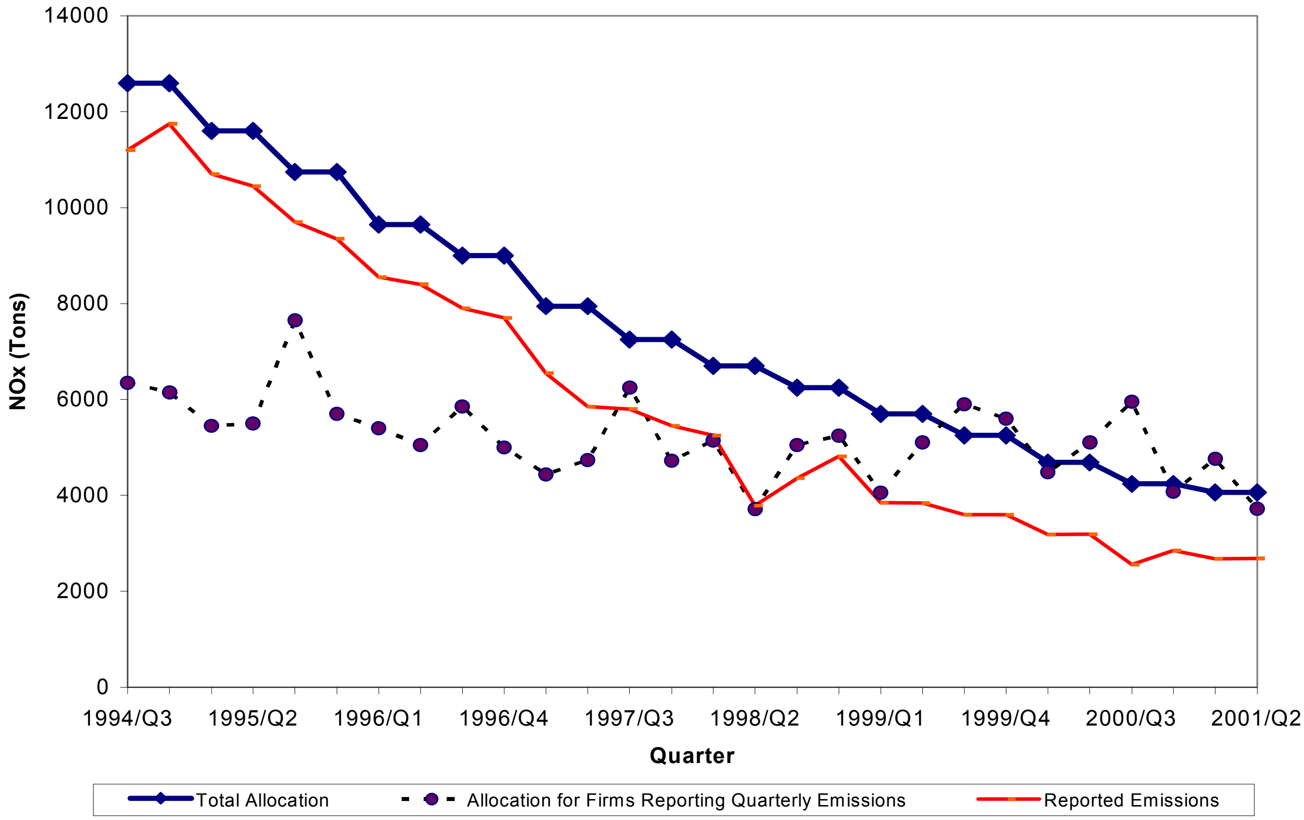

Figure 2: Current and Lagged Mean Annual RTC Prices

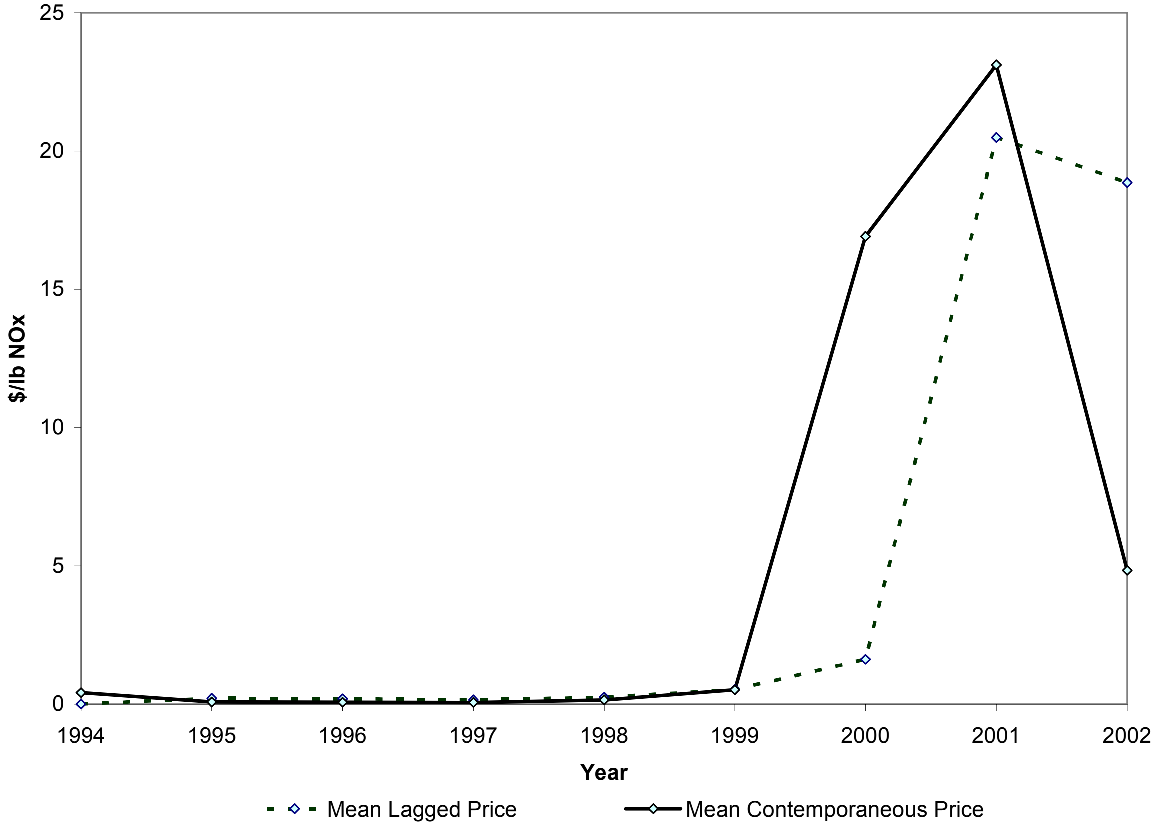

Table 1: Means (Standard Deviations) of Key Variables[a]

VARIABLE	1994-1997	1998-200
Firm-Level Quarterly Emissions (pounds of NOx)	31,652 (122,863)	23,030 (91,951)
Firm-Level Quarterly Allocations (pounds of NOx)	39,488 (130,81)	21,984 (76,698)
Average RTC Price[b] ($/lb)	0.09 (0.10)	9.00 (11.60)
Δ Product Price	0.75% (4.2%)	0.4% (6.5%)
Average Gas Price ($/thousand cubic feet)	3.50 (0.81)	4.97 (2.30)
Average Southern California Electricity Price ($/Mwh)	N/A	51.16 (42.15)

Note: There are 380 firms in this sample.
[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: 1998--2001
(Arrelano's Clustered Standard errors)

VARIABLE	RESTRICTED MODEL	UNRESTRICTED MODEL
ln(Allocation)	0.70** (0.35)	0.71** (0.35)
Participation × ln(Allocation)	—	-0.02* (0.01)
ln(RTC Price)	-0.05 (0.04)	-0.05 (0.04)
ln (Lagged RTC Price)	0.07 (0.06)	0.08 (0.06)
% Δ Product Price	0.00 (0.00)	0.00 (0.00)
ln(Gas Price)	0.06 (0.13)	0.05 (0.13)
ln(Electricity Price)	0.09 (0.07)	-0.08 (0.07)
Last Quarter of Cycle Dummy	-0.07** (0.03)	-0.07** (0.03)
Quarter 1 Dummy (Jan-March)	0.09 (0.06)	0.09* (0.05)
Quarter 2 Dummy (April-June)	0.06* (0.04)	0.06* (0.04)
Quarter 4 Dummy (Oct.-Dec)	-0.03 (0.05)	-0.03 (0.05)
1999 Dummy	-0.05 (0.07)	-0.02 (0.06)
2000 Dummy	-0.18 (0.15)	-0.14 (0.15)
2001 Dummy	-0.47* (0.27)	-0.43 (0.27)
Number of Observations	3, 304	3,304
Number of Firms	263	263
F statistic	2.26**	2.6**
Adjusted R^2	0.85	0.85

** We reject the hypothesis that the coefficient is zero at the 5% level.
* We reject the hypothesis that the coefficient is zero at the 10% level.