Distributing Pollution Rights in Cap-and-Trade Programs:
Are Outcomes Independent of Allocation?*

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Abstract

According to the Coase theorem, if property rights to pollute are clearly established and emissions permit markets nearly eliminate transaction costs, the permit market equilibrium will be independent of how the permits are initially distributed among firms. Testing the independence of firms' permit allocations and emissions is difficult because of endogeneity and omitted variable bias. We exploit the random assignment of firms to different permit allocation cycles in Southern California's RECLAIM Program to test for a causal relationship between facility-level emissions and initial permit allocations. Our primary finding is that a null hypothesis of zero effect cannot be rejected.

JEL Classifications : D21, D23, H11, Q50, Q53, Q58

1   Introduction

Market-based pollution permit trading programs have moved to the front and center of industrial environmental regulation. One of the most appealing qualities of the "cap-and-trade" (CAT) approach to regulating industrial emissions is that a permit market should, in theory, direct firms with the lowest abatement costs to reduce emissions first, regardless of how emissions permits are allocated across firms (Dales, 1968; Montgomery, 1972). The independence of a firm's emissions in equilibrium and how emissions permits are initially distributed is a necessary condition for this result.[1] Researchers have been unable to directly evaluate this independence in practice because of the likely endogeneity of firm-level permit allocations with respect to emissions and the lack of an appropriate instrument.[2] We exploit an unusual design feature of Southern California's Regional Clean Air Incentives Market (RECLAIM) to test for a causal relationship between firms' permit allocations and nitrogen oxide emissions.

In theory, provided a series of conditions are met, permit market outcomes will be independent of the initial distribution of emissions permits in a cap-and-trade program (Coase, 1960). This independence confers important political and practical advantages. If the initial distribution of permits plays no role in determining emissions and abatement outcomes in equilibrium, emissions permits can be freely allocated to pursue political objectives (such as establishing a constituency for the market-based regulation) without compromising the economic efficiency properties of permit

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[1] Additional conditions include zero transaction costs, full information, and perfectly competitive markets.

[2] In programs such as the Nitrogen Oxide Budget Program, the endogeneity of permit allocations is explicit. A firm's permit allocation in one period is determined by production decisions made by the firm in the previous period. In other programs, such as the Acid Rain Program, permits were grandfathered based on historic emissions levels and operating characteristics. Under these circumstances, permit allocations may be endogenous in an econometric sense. Ordinary least squares estimates of the effect of permit allocations on emissions will be biased if the factors that determine permit allocations are highly correlated with subsequent emissions.

market outcomes.[3] The use of free permit allocations to compensate industrial stakeholders for some portion of compliance costs incurred has played an essential role in securing political support for CAT programs. Furthermore, if the initial distribution of permits is not critical, the information required to efficiently implement a CAT program is reduced, as compared to more traditional command-and-control approaches such as emissions and technology standards.

The theory literature has identified several conditions under which the independence of the initial distribution of emissions permits and facility emissions might fail to hold. Stavins (1995) demonstrates that the permit market equilibrium can be sensitive to the initial allocation of permits in the presence of transaction costs. In his model, increasing (decreasing) marginal transaction costs imply a negative (positive) relationship between permit allocations and firm-level emissions in equilibrium. Montero (1997) extends Stavins' work to incorporate uncertainty. When firms face transaction costs in the permit market and are uncertain about the likelihood that their permit trades will be approved, firm-level emissions are more likely to be increasing with initial permit allocations. Finally, Hahn (1984) shows that the initial distribution of permits can have efficiency implications if permit markets are imperfectly competitive.

Given our increasing reliance on CAT programs as the primary means of addressing a range of environmental problems (including acid rain, urban ozone, and climate change), it is important that we understand how these programs work in practice. Notably, the courts have begun to question whether emissions in equilibrium are in fact independent of how permits are initially allocated, arguing that "the market would only bear out that assumption if the transaction costs of trading emissions were small, which is hardly likely." (*North Carolina v. EPA*, No. 05-1244

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[3]Several economists have explored how permit allocation can be used to enhance the political feasibility of emissions trading programs. See, for example, Bovenberg and Goulder (2001), Bovenberg et al. (2005), Dinan and Rogers (2002).

(D.C. Cir. Jul. 11, 2008)).[4] This line of argument has potentially important implications for the design and implementation of market-based environmental regulation.

Previous empirical studies of cap-and-trade-programs encumbered with transaction costs and regulatory uncertainty have found evidence consistent with autarkic compliance (Gangadharan, 2000; Montero et al., 2002). However, a direct test for a causal relationship between the number of emissions permits allocated to a firm and the quantity of emissions the firm chooses to emit has been confounded by the likely endogeneity of firm-level permit allocations with respect to emissions. We can use instrumental variables techniques to consistently estimate how changes in initial permit allocations affect emissions if we have an instrument that is strongly correlated with facility-level permit allocations and uncorrelated with the disturbance term in the emissions equation. Southern California's RECLAIM program provides a rare case where such an instrument is available.

RECLAIM was the first emissions trading program to incorporate a broad range of industries and sectors; it has the longest history of any locally designed and implemented CAT program. Several features of the RECLAIM program make it particularly well suited to a study of the relationship between firm level allocations and emissions. First, facility-level permit allocations, which were determined at the outset of the program, vary significantly across facilities and across time. Second, transaction costs and regulatory uncertainty are well documented in the RECLAIM market (Gangadharan, 2000; Schubert and Zerlauth, 2000; US EPA, 2002). Consequently, we might expect to find a relationship between facility-level emissions and the initial permit allocation in this program (Montero, 1997; Stavins, 1995). Finally and most importantly, facilities regulated

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[4]On July 11, 2008, the U.S. Court of Appeals for the D.C. Circuit ruled unanimously against the Clean Air Interstate Rule which was intended to be the largest, most comprehensive CAT program in U.S. history. In its written opinion, the court openly questioned the assumption that emissions in equilibrium would be independent of the initial allocation (*North Carolina v. EPA*, No. 05-1244 (D.C. Cir. Jul. 11, 2008)).

under RECLAIM were randomly assigned to one of two permit allocation cycles. We use this random assignment to instrument for facility-level permit allocations in an empirical test of the independence of facility-level emissions and permit allocations in RECLAIM.

The main empirical findings are as follows. First, when we use an ordinary least squares fixed effects (OLS-FE) estimator that does not account for the potential endogeneity of permit allocations, we find a statistically significant, positive relationship between facility-level emissions and permit allocations. If we interpret these results as evidence of a causal relationship, we would conclude that a 10 percent increase (decrease) in the number of permits allocated to a facility increases (decreases) quarterly emissions by 4-5 percent. However, when we instrument for facility-level permit allocations using random assignment to permit allocation cycles, we no longer find any evidence of a statistically significant relationship. These findings are robust to a variety of specifications. For our most robust specifications, the OLS-FE estimate lies outside the 95 percent confidence interval implied by our instrumental variables estimator. Based on these results, we fail to reject the hypothesis that firm-level emissions in equilibrium are independent of how RECLAIM permits were initially allocated.

Section 2 introduces a simple theoretical framework that helps to motivate the need for instruments. Section 3 provides an overview of the RECLAIM program. Section 4 discusses the RECLAIM emissions permit allocation process in some detail. Section 4 describes our empirical strategy. Section 5 presents the results. We assess the robustness of our findings in Section 6. Section 7 concludes.

2   Theoretical framework

A simple partial equilibrium model helps to highlight the econometric issues that can confound attempts to identify a causal relationship between the initial permit allocation and firms' emissions decisions. We adopt a factor demand approach to modeling emissions. We assume profit maximizing firms operating in perfectly competitive input and output markets produce a single output q using inputs $\mathbf{x} = [x_1, ... x_k]$. We further assume that production technologies can be represented by a strictly concave, twice differentiable production function $q(p, \mathbf{w}; z)$, where p is the output price, $\mathbf{w}$ is a vector of input prices, and z are fixed, exogenous variables such as technology operating characteristics.

For expository purposes, we focus on the simple case of two variable inputs: emissions e and a generic input x.[5] Firms' emissions are regulated under a CAT program. A firm's emissions permit allocation A is pre-determined; permits are distributed for free at the outset of the program. To remain in compliance, firms must purchase permits to offset their uncontrolled emissions. Firms act as price takers in the permit market; the permit price is τ. The indirect profit function for a representative firm is given by:

$$\pi = Pq(e, x; z) - w_x x + \tau(A - e). \tag{1}$$

This profit function is assumed to have the usual properties: π_i is increasing in the product price P, non-increasing in input prices w, and convex in P.

Input supply and factor demand functions are implicitly defined by the first-order conditions for profit maximization. We are particularly interested in the emissions function $e(P, \tau, w; z)$. Note that the firm's profit maximizing choice of emissions will be independent of its initial permit

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[5]It is straightforward to generalize this model to the $k > 2$ case.

allocation A. After totally differentiating the system of first-order conditions with respect to emissions and the exogenous variables, we can use Cramer's rule to derive expressions for the partial derivatives of the emissions function:

$$\frac{\partial e}{\partial \tau} = \frac{Pq_{xx}}{|H|}; \quad \frac{\partial e}{\partial P} = \frac{Pq_{ex}q_x - Pq_{xx}q_e}{|H|}; \quad \frac{\partial e}{\partial w_x} = \frac{-Pq_{ex}}{|H|} \tag{2}$$

The second-order conditions for profit maximization imply that $|H| > 0$. By assumption, $q_{ee}(e, x; z) < 0$ and $q_{zz}(e, x; z) < 0$. Thus, a firm's profit maximizing choice of emissions is decreasing in τ. Emissions are most likely to be increasing in P.[6] The response of firm-level emissions to changes in w_x will depend on whether x and e are substitutes or complements.

There are two reasons why we might observe correlation between facility-level permit allocations and emissions. First, this correlation might be indicative of a causal relationship. Previous theoretical work has identified conditions under which the independence of A and e might fail to hold. To illustrate a particularly important case, we introduce transaction costs into the model.[7] Following Stavins (1995), let t denote the quantity of permits traded by the firm:

$$t = (e - A).$$

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[6]The firm will increase its emissions in response to an increase in the product price P if $Q_{ez}Q_z > Q_{zz}Q_e$. Although we cannot conclude that the firm will always increase emissions when the price it receives for its product increases, the circumstances under which Q_{ez} will be sufficiently negative such that the firm reduces emissions when the product price increases are unlikely for most common production functions.

[7]Stavins (1995) and Montero (1997) investigate how, in theory, the post-trading equilibrium can be sensitive to how permits are initially allocated (for free) to facilities. Stavins develops a theoretical model of a cost minimizing firm whose emissions of a uniformly mixed flow pollutant are subject to cap-and-trade regulation. Transaction costs are assumed to be a function of the number of permits sold. He concludes that, if marginal transaction costs are increasing (decreasing), firm-level emissions are increasing (decreasing) with firm-level permit allocations. Montero (1997) later demonstrates how, in the presence of uncertainty or transaction costs, the permit market equilibrium can be sensitive to the allocation of permits, even when marginal transaction costs are constant.

We define a common transaction cost function $T(t)$, for which $T'(t) > 0$ and for which $T''(t)$ can be positive, negative, or zero valued. The firm's indirect profit function is now:

$$\pi = Pq(e, z) - \omega_x x + \tau A - \tau e - T(t). \tag{3}$$

The expressions for the partial derivatives summarized by [2] are unaffected by the introduction of transaction costs to the model. However, if T_{eA} is non-zero, emissions will no longer be independent of the initial permit allocation :

$$\frac{\partial e}{\partial A} = \frac{T_{eA} P q_{xx}}{|H|}. \tag{4}$$

If marginal transaction costs are increasing (decreasing) with t, facility-level emissions will be negatively (positively) correlated with permit allocations. Theory suggests that, in markets where both transactions costs and regulatory uncertainty are present, we might be more likely to find a positive relationship between firm-level emissions and permit allocations (Montero, 1997; Ben-David et al., 2000).

Correlation between facility-level permit allocations and emissions need not imply a causal relationship. In fact, the standard approach to allocating permits to facilities introduces spurious correlation between these two variables. Policy makers typically allocate more permits to facilities that have historically accounted for a larger share of emissions and/or facilities who they expect will face higher abatement costs over the course of the program. Put differently, the factors that determine a facility's initial permit allocation (i.e. pre-determined operating characteristics, production processes, and/or anticipated abatement potential) are likely to be correlated with facility-level emissions.

In our analysis, facility-level abatement costs are a potentially important confounding factor. Anticipated compliance costs played an important role in determining the trajectory of a RE-CLAIM facility's permit allocation through time. Facilities with higher expected abatement costs received more permits. If expectations were somewhat correct, facility-level permit allocations will be positively correlated with abatement costs. A firm's emissions are also likely to be positively correlated with abatement costs. Let the variable input x in [1] represent emissions abatement inputs. These inputs could include, for example, maintenance activities and/or operations changes that allow the firm to reduce its emissions rate per unit of output while holding other inputs constant. If emissions and abatement inputs are technical substitutes, emissions will increase with abatement costs. Our challenge lies in distinguishing a causal relationship between emissions and permit allocations from a spurious one.

One solution to this identification problem would involve allocating emissions permits randomly across facilities. This would assure that variation in initial permit allocations is exogenous, and that permit allocations are uncorrelated with omitted, unobserved factors that determine emissions in equilibrium. Although an ideal research design, random allocation of permits across stakeholders is unlikely to be politically viable or desirable in any meaningful policy context.

In the absence of experimental data, we exploit a natural experiment afforded by an unusual design feature of Southern California's RECLAIM program. RECLAIM facilities were randomly assigned to one of two compliance cycles. This random assignment has generated truly exogenous variation in facility-level permit allocations, albeit in limited quantities. We use this exogenous variation to test for a relationship between facility-level permit allocations and emissions.

3 The Regional Clean Air Incentives Market

The RECLAIM program was adopted in 1993 to address severe air quality problems in the Los Angeles basin. Ozone concentrations in the Los Angeles basin exceeded state standards on 184 days in 1991 (Hall, 1996).[8] To confront these and other air quality issues, regulators began to consider market-based regulatory alternatives.

The South Coast Air Quality Management District (SCAQMD) covers a 10,740 square mile area of southern California including all of Orange county and parts of Los Angeles, Riverside, and San Bernadino counties. The SCAQMD introduced the RECLAIM program in 1994 to bring the region into compliance with state and federal air quality emissions standards at minimum cost. The majority of facilities in the SCAQMD emitting four tons per year or more of nitrogen oxide (NOx) were included in the NOx trading program.

At the outset of the program, RECLAIM included 392 facilities owned and operated by both the private sector and government agencies (Prager et al., 1996; Schubert and Zerlauth, 1999).[9] Of these, 72 percent are in manufacturing; 13 percent in communications, transportation or utilities; 2 percent in construction; 3 percent in the service sector; 6 percent in wholesale; 2 percent in retail; and the remaining 2 percent are government facilities.

The RECLAIM program caps the total quantity of permitted NOx emitted by facilities in the program over the period 1994-2010. A RECLAIM trading credit (RTC) represents one pound of NOx emissions and is valid for one year. RTCs cannot be banked, they must be used in the

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[8]Adverse effects of ozone exposure 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, and reduced visibility.

[9]In the early years of the program, several 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).

vintage year to which they are assigned. Permits were allocated to RECLAIM facilities at no cost. RTC allocation schedules, which specify how many permits each facility receives over the duration of the program, were determined and made public in 1994. Section 3 provides a detailed description of how SCAQMD allocated permits to facilities in RECLAIM.

To remain in compliance, a firm has several options including reducing production, increasing operating efficiency, installing abatement technology, or purchasing permits.[10] If a firm reduces its emissions below its permit allocation, it can sell excess permits in the market to other firms.[11] Studies and surveys carried out prior to 2003 indicate that, in the first ten years of the program, most facilities achieved compliance through short-run changes in production processes, fuel substitution, and other short-run emissions management options versus major capital investments in abatement equipment (SCAQMD, 2000; Schubert and Zerlauth, 1999; US EPA, 2006).

Emissions are reported, and compliance is certified, quarterly. A compliance "cycle" lasts twelve months. During the 30 calendar days after the conclusion of each of the first three quarters of a cycle, firms must acquire any RTCs necessary to reconcile their allocation to their emissions and submit a quarterly certification of emissions to SCAQMD. Facilities are subject to penalties for quarterly shortfalls.[12] Firms have 60 calendar days following the last day of each compliance cycle (i.e. the fourth quarter) to reconcile emissions with their permit allocation and purchases (SCAQMD, 1993b; US EPA, 2006)[13].

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[10]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. 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.

[11]By 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.

[12]Facilities that fail to hold sufficient RTCs are required to surrender permits in future periods to cover the shortfall and can be subject to large civil financial penalties.

[13]SCAQMD rule 2004 states that the reconciliation period following the end of a quarter shall be used to reconcile

3.1 Transaction costs

The theoretical literature suggests that a firm's emissions might not be independent of its permit allocation if participating in the permit market incurs transaction costs. Transaction costs are well documented in RECLAIM (Schubert and Zerlauth, 2000; US EPA, 2006). Gangadharan (2000) provides evidence to suggest these costs have discouraged participation in the RECLAIM market.

Transaction costs in RECLAIM manifest in a variety of ways. Prior to entering the RTC market, a firm must learn how the market works and determine what it would cost to reduce emissions internally. If a firm decides that it wants to participate in the RTC market, it must find a trading partner, negotiate a transaction and hire any legal, insurance, and brokerage services it deems necessary. Facilities also incur a transaction fee, split equally between the buyer and seller, that helps to fund the administration of the RECLAIM program.[14]

When the RECLAIM program was introduced, no institutional arrangements were made to facilitate trading. Initially, firms wishing to trade RTCs had to find their own trading partners. However, shortly after the program was introduced, an electronic auction program was developed by Ace Markets Inc. and various firms began offering brokerage services. The fraction of RTC transactions involving private-sector brokers increased from 38 percent in 1994 to 75 percent by 2001. Several surveys of RECLAIM market participants have collected information about transaction costs. Early on, brokers reported charging a fixed fee of $150 per trade and a variable fee of 3.5 percent of the transaction value (Burnside and Eichenbaum, 1996). In a more recent survey, market participants estimated that total broker fees amounted to 1 percent to 3 percent

allocations only with emissions from that quarter. A lawsuit filed in September 2003 alleged that SCAQMD has, in some instances, failed to conduct quarterly audits. The case settled in favor of the plaintiffs (Communities for a Better Environment and Our Children's Earth Foundation vs. SCAQMD et al., Case No. 03-06985 WMB (CTx)).

[14]As of 2006, this fee was $100.75 per transaction (US EPA, 2006).

of the total value of the trades (US EPA, 2002).

3.2 Regulatory uncertainty

In a recent, comprehensive RECLAIM program evaluation, regulatory uncertainty was identified as a key issue that has allegedly undermined the success of RECLAIM(US EPA, 2006). The theory literature has demonstrated how the initial permit allocation can affect permit market outcomes in the presence of regulatory uncertainty. Here, we briefly discuss several sources of uncertainty surrounding compliance and enforcement in RECLAIM.

First, questionable brokerage practices in RECLAIM have created considerable uncertainty about compliance approval. One of the major RTC brokers, the Automated Credit Exchange, has been sued repeatedly for failing to deliver RTCs that were paid for by their clients.[15] Furthermore, 17 substantive amendments to the RECLAIM program rules since 1994 have exacerbated uncertainty about how the regulation will be interpreted and enforced (EPA, 2006).[16]

Emissions monitoring and enforcement practises have also created considerable uncertainty about compliance approval. If emissions data for a RECLAIM facility are missing, the regulator computes the facility-specific maximum possible emissions for the period over which reports are missing. If the regulator concludes ex post that a facility did not have sufficient permits to cover its reported or imputed emissions, the firm's subsequent allocation is reduced by the total amount of the violation. Non-compliant facilities can also face stiff monetary penalties, although the penalties are not automatic and are negotiated on a case by case basis (Stranlund and Chavez, 2000).[17]

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[15] Jacob, Chip. "Smoke and mirrors." *Pasadena Weekly*. Thursday Dec. 12, 2002. 14-18.

[16] For example, following the electricity crisis of 1999-2000, the structure of the program was fundamentally changed when electricity generators were removed entirely from the RTC market.

[17] SCAQMD estimates that the average compliance rate (the number of facilities that complied with their annual

4 Allocating emissions permits in RECLAIM

Our identification strategy depends on a detailed and accurate characterization of the RECLAIM emissions permit allocation process. In this section, we first provide a detailed discussion of how permits were allocated in RECLAIM. We then turn to the data and illustrate precisely how the random assignment of RECLAIM facilities to one of two "compliance cycles" generates exogenous variation in facilities' permit allocation schedule.

The SCAQMD reports that it used a modified grandfathering approach to RTC allocation.[18] Original RECLAIM participants were allocated a stream of permits at no cost.[19] Facility-specific permit allocation schedules from 1994 to 2010 and beyond were established at the outset of the program. Over the first ten years of the program, facility-specific permit allocation schedules follow a stairstep pattern, ratcheting down every twelve months. The rate at which a facility's quarterly permit allocations decrease over time was determined by factors that are likely to be highly correlated with factors that determine future emissions trajectories.

Before the RECLAIM program got underway, regulators were concerned that firms might wait until the final reconciliation period following the end of each annual compliance cycle to make final adjustments to their RTC holdings. They feared that this behavior would create unnecessary price volatility in the permit market. To avoid this problem, regulators chose to randomly assign

allocation) was 90% from 1994 through 1997 (US EPA, 2002). A 1998 SCAQMD document suggests that non-compliance prior to 1998 is likely due to misunderstanding of the regulation or mistakes in calculation (Lieu, 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.

[18] The RTC allocation methodology is described in detail in SCAQMD Rule 2002 (SCAQMD,1993).

[19] Any new firms entering SCAQMD who are NOx emitters must either purchase permits to cover their emissions or, in some cases, take advantage of a special reserve of RTCs earmarked for job-creating, clean companies (Schwarze and Zapfel, 2000).

facilities to one of two staggered twelve month compliance cycles. Facilities assigned to group one (two) experience a discrete drop in quarterly permit allocations in January (July) of each year. Thus, although two technically identical facilities receive the same number of permits over the duration of the RECLAIM program, the temporal pattern of their permit allocation is determined in part by random cycle assignment.[20]

4.1   Determining facility-specific permit allocation schedules

Two parameters define the downward linear trajectory of a facility's quarterly permit allocations over the first seven years of the RECLAIM program. First, a facility's historical fuel consumption was multiplied by an emissions coefficient that was based on pre-existing regulations and "Reasonable Available Technology" rules in order to determine quarterly allocations in the first permit allocation cycle ($P1$).[21]   The second parameter ($P2$) measures the facility's quarterly allocation in 2000. This was based on facility-specific "technologically feasible abatement volumes". The SCAQMD assessed each facility's operating characteristics and production equipment in order to determine relative abatement potential. Fewer permits were allocated to those facilities with ex ante expected greater emissions abatement potential (Schubert and Zerlauth, 1999; SCAQMD,1993).

More formally, the permit allocation trajectory for facility i in quarter t can be summarized

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[20]Facilities can use permits associated with both cycles for compliance. For example, cycle 1 permits of 1998 vintage can be used to offset any emissions occurring in the 1998 calendar year. Cycle 2, 1998 permits can be used to offset pollution emitted in July 1998-June 1999.

[21] To determine "historic emissions", each facility was allowed to chose the year with the highest annual production level (and therefore with the highest level of emissions) between 1989 and 1992. Initial facility-specific allocations were also adjusted to reflect the number of certified emissions reductions (ERCs) the firm held prior to 1994.

as follows:

$$A_i(t) = P1_i - \left(\frac{P1_i - P2_i}{28}\right)t, \qquad (5)$$

where t indexes quarters over the first seven years of the program ($t = 1...40$).

Figure 1 presents a stylized illustration of the permit allocation schedule for a representative facility over the first seven years of the RECLAIM program (i.e. the period during which there was inter-facility variation in the rates at which permit allocations decreased over time). The square (triangular) symbols represent the quarterly allocation schedule that this facility would receive were it assigned to cycle one (two). Note that random cycle assignment does not affect the total number of permits the firm receives over the duration of the program, nor does it affect the average rate at which the facility's quarterly permit allocations decrease over time. Random cycle assignment does affect the timing of the discrete drops in quarterly permit allocations over time. In the first six months of each calendar year, the facility will be allocated more permits if it is assigned to cycle 2 versus cycle 1.

Permit allocation schedules ceased to decrease at facility specific rates after 2000. Between 2001 to 2003, allocations were reduced at a common rate across facilities. Under the original rule, allocations ceased to depreciate after 2003.[22]

Figure 2 uses quarterly data from the RECLAIM program to illustrate how permit allocations decreased over time in aggregate.[23] The broken line represents the total number of RTCs allocated to RECLAIM facilities in each quarter. The grey line plots quarterly reported NOx emissions. The

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[22]In January, 2005, the AQMD Governing Board adopted several changes. Amendments included further reductions in RTC allocations. These reductions were phased in beginning in 2007.

[23]SCAQMD maintains a detailed database tracking all NOx permits and quarterly, facility-level emissions. From these data, we recovered the NOx permit allocation schedules for 360 RECLAIM facilities. Some of the facilities that received permit allocations were ultimately excluded from the RECLAIM program. We exclude these facilities in our analysis. Appendix 1 includes a detailed description of these data.

solid black line represents the quarterly RTC allocations to only those firms that reported emissions in the corresponding quarter (not all firms report emissions in each quarter). The discrete increase in both emissions and permit allocations in July 1994 signals the entry of facilities assigned to cycle 2. The average rate of decline in quarterly permit allocations changes as the program transitions from facility specific rates to a uniform rate in 2000-2001.

The aggregate cap on emissions was not binding in the early years of the program, although a substantial number of individual facilities did emit in excess of their allocation in these years (U.S. EPA, 2002). At the outset of the program, SCAQMD regulators anticipated that the aggregate cap would start to bind in 1996 or 1997 (Schubert and Zerlauth, 1999). Figure 2 suggests that this "cross-over" likely occurred in 1998 or 1999. Finally, it is worth noting that the RECLAIM program encountered non-compliance problems during California's electricity crisis in 1999-2000. During this period, several facilities were unable to acquire sufficient permits to offset their emissions (SCAQMD, 2001). In 2001, electricity producers were categorically excluded from the RECLAIM program (SCAQMD, 2001).

4.2   Random assignment to compliance cycles

The random assignment of facilities to compliance cycles is particularly critical to our identification strategy. Here, we present evidence to support the SCAQMD's claim that the compliance cycle assignment process was random.

Under random assignment, we would expect that unobserved firm characteristics, and observed permit allocation parameters, would be distributed similarly across the two cycles. Table 1A reports summary statistics for observed facility-specific allocation trajectories by compliance cycle. The $P1$ values and the rates at which quarterly allocations decrease (in percentage terms)

over the first seven years of the program are distributed similarly across compliance cycles.

The summary statistics presented in Table A1 appear to be consistent with random assignment. Table 1B summarizes the results of 1000 simulations of random assignment of RECLAIM facilities to compliance cycles. The observed moments of the distribution of allocation parameters in cycle 1 and 2, respectively, are all within one standard deviation of the simulated moments.

4.3   An empirical look at RECLAIM permit allocations

The SCAQMD maintains a database tracking all RECLAIM permit allocations, transactions, and reported quarterly emissions. In this section, we use permit allocation data from the 1994-2000 (i.e. the period during which permit allocations decreased at facility-specific rates) to estimate a model of permit allocation. This exercise helps to illustrate the effect of random cycle assignment on facility-specific permit allocation schedules.

The number of permits allocated to facility i in time period t is given by:

$$A_{it} = \beta_1 P1_i + \beta_2 (P1_i - P2_i)t + \delta_q + \delta_{C2,1} Cycle2\_1_i + \delta_{C2,2} Cycle2\_2_i + \varepsilon_{it}. \tag{6}$$

The first two arguments in [6] map directly to equation [5]. Thus, we expect $\beta_1 = 1$ and $\beta_2 = 1/28$. The δ_q are quarter indicators ($q = 1..4$). These variables allow a facility's quarterly allocations to deviate systematically from the linear trajectory defined by [5] (just as the step functions plotted in Figure 1 deviate from a line defined by $P1$ and $P2$).

The inclusion of two $Cycle2$ dummy variables allows the average quarterly deviations to differ across compliance cycles.These variables are used to illustrate the effect of random cycle assignment on permit allocation schedules. The binary variable $C2\_1_i$ equals one in the first six months of each calendar year for all facilities assigned to compliance cycle 2; otherwise, $C2\_1_i = 0$. If cycle

assignment has a significant effect on permit allocations, we expect $\delta_{C2,1} > 0$. The binary variable $C2\_2_i$ equals one in the second half of each calendar year for all cycle 2 facilities; otherwise $C2\_2_i = 0$. We expect $\delta_{C2,2}$ to be close to zero (because permit allocation parameters do not differ significantly across cycles).

Equation [6] is estimated using both level and log values. Results (reported in Table 2) are consistent with the allocation methodology described above. Both specifications fit the data almost perfectly ($R^2 > 99$ percent)[24]. In both cases, the estimates of β_2 are statistically indistinguishable from $1/28 \approx 0.036$ and estimates of β_1 are close to one. The estimate of $\delta_{C2,1}$ is positive and statistically significant; we fail to reject the null of $\delta_{C2,2} = 0$.

These results indicate that random assignment to cycle 2 increased a facility's permit allocation by 13 percent, on average, in the first half of each calendar year over the period 1994-2000. The average effect of a cycle 2 assignment on quarterly permit allocations is estimated by $\delta_{C2,1} - \delta_{C2,2}$. In levels, this estimate is 4095 lbs of NOx which is equivalent to 13 percent of the average quarterly allocation. In the log specification, the point estimated effect of random cycle assignment is 0.13.

5   Estimation framework

The factor demand model introduced in section 2 helps to motivate our approach to testing for a causal relationship between facility-level emissions and permit allocations. We model emissions as an input to production. Emissions are assumed to be a function of output prices, input prices,

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[24]Unexplained variation in permit allocations that is not explained by the model is likely due to rounding error or very small, undocumented modifications to facility-level permit allocation schedules.

and possibly permit allocations.[25]   We begin with the following reduced form model :

$$e_{it} = \alpha_{1i} + \phi_1 A_{it} + \beta' W_{it} + u_{1it}. \tag{7}$$

Quarterly, facility-level emissions (measured in lbs of NOx) are represented by e_{it}; the firm's quarterly permit allocation (also measured in pounds of NOx) is A_{it}. W_{it} is a vector of input and output prices, including the RECLAIM permit price, energy prices, wages, and producer price indices that vary across industries. The "1" subscript denotes the specification number.

We estimate the model using both level and log-transformed values of the dependent and independent variables. When log-transformed values are used, the ϕ coefficient measures the average response, in percentage terms, in facility-level emissions to a percentage change in permit allocation. For ease of interpretation, we emphasize the log specification, although results are qualitatively the same across specifications. A detailed description of the data we use is included in the Appendix.

With panel data, we can control for omitted, time-invariant factors that might be correlated with both permit allocations and emissions (such as facility size, historic emissions, operating and management characteristics) provided that these effects are additive in terms of e_{it}. The facility-level fixed effects α_{1i} are included for this purpose. The disturbances u_{it} are allowed to be correlated across time within facilities.

There are a number of ways in which this OLS fixed effects specification (OLS-FE) might violate the classical assumptions of a standard regression framework. First, if we estimate this model using data from all RECLAIM facilities, some elements of the price vector may be endogenous.

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[25]Data limitations prevent us from estimating the entire system of input supply and factor demand equations. We focus exclusively on the emissions function.

Electricity producers were able to affect both electricity and permit prices during the period we study. These facilities were removed from RECLAIM after the electricity crisis in 2000.[26] In our main results, we exclude the 27 electricity generators from the analysis so as to avoid potential endogeneity problems. We conduct robustness checks, summarized in Section 6, which indicate that this exclusion does not substantively affect our empirical findings.

Omitted variable bias poses a more difficult challenge. Unfortunately, we do not observe abatement costs. RECLAIM firms report using a variety of short-run abatement strategies, including increased maintenance, improvements in combustion efficiency, and fuel substitution (US EPA, 2006). The costs of these options likely varied both across time and across facilities. Moreover, facility-level permit allocation trajectories were defined as a function of ex ante expected abatement potential. To the extent that ex ante expected abatement potential is correlated with ex post realized abatement costs, permit allocations will be endogenous.

If intertemporal variation in abatement costs (and other potentially significant omitted variables) affects emissions symmetrically across firms, the inclusion of time period fixed effects will mitigate omitted variables bias. We estimate a second specification that includes a set of 39 quarter-year dummies:

$$e_{it} = \alpha_{2i} + \delta_t + \phi_2 A_{it} + u_{2it}, \tag{8}$$

where the δ_t are time period dummies ($\delta = 1..39$). These time dummies capture the average effects

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[26]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 electricity generators from the RECLAIM program. Beginning of Jan. 11, 2001, these facilities had 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, we drop the 27 electricity-generating facilities from the sample so as to avoid potential endogeneity problems. In robustness tests, we re-estimate the models using a data set that includes the generators. Our results are unchanged.

of omitted, time-variant factors.

5.1 Instrumental variables estimation

Neither empirical specification controls for confounding factors that vary both across facilities and across time. Because we are unable to measure facility-specific abatement costs with any degree of precision, this important variable is omitted from our estimation models. If temporal trends in abatement costs vary across facilities, an important source of omitted variation will be captured by the error term u_{it}. Moreover, because permit allocations are likely to be correlated with abatement costs, this regressor will be correlated with the error term.

Instrumental variables (IV) estimation allows us to estimate ϕ consistently and free of omitted variables bias provided that we can find an instrument that is distributed independently of u_{it} and strongly correlated with A_{it}. The RECLAIM program constitutes a rare case where such an instrument is available. We use the exogenous component of variation in facility-level permit allocations (i.e. that which is generated by random cycle assignment) to identify a causal effect of permit endowments on facility-level emissions. More precisely, we use the $Cycle2\_1$ variable introduced in section 4 to instrument for permit allocations.

A good instrument is distributed independently of the disturbance term u_{it} and strongly correlated with the endogenous regressor A_{it}. Our instrument satisfies both criteria. First, because the assignment of facilities to compliance cycles assignment was random, our instrument should be uncorrelated with u_{it}. Results presented in section 4.2 support the exclusion restriction.

Point estimates, hypothesis testing, and confidence intervals based on our IV estimator will be unreliable if our instrument is only weakly correlated with the endogenous regressor. Concerns about the weakness of our instrument can be alleviated by looking at the reduced form regression

of quarterly permit allocations on our instrument and the other exogenous variables in the model. Note that this first stage regression equation is a reduced form of [6].

Table 3 presents the first stage regression results for both specifications of the empirical model. The relationship between permit allocations and our cycle 2 instrument is positive and highly statistically significant.[27] The F-statistics on the excluded instrument are very large suggesting a strong basis for inference.

6   Are emissions independent of permit allocations?

We begin with the fixed effects estimates of specifications 1 and 2. We then re-estimate these equations using an IV approach, and show that the two sets of estimates lead to different conclusions about whether emissions are independent of permit allocations.

6.1   Non-IV, OLS estimates

The first two columns of Table 3 presents our OLS-FE estimates. Specification 2 is estimated using data from all RECLAIM facilities that receive permit allocations and report emissions. Wage data and/or product price indices are unavailable for 27 percent of RECLAIM facilities. Consequently, the data set used to estimate specification 1 is less complete. We use a clustered, robust asymptotic variance matrix estimator, generalized to the unbalanced case, to generate robust estimates of the

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[27] As one would expect, the estimated effect of the instrument (i.e. the $Cycle2\_1_{it}$ indicator) on log of quarterly permit allocations is equal to that which we estimate in Table 2 when the same data sets are used to estimate the two models. When wage data and producer price indices are used as regressors, almost 100 facilities are dropped from the sample due to data limitations. When specification 2 is estimated using the data available to estimate specification 1, the estimated coefficient on the cycle 2 instrument is 0.10 (p-value <0.00).

standard errors (Arrelano, 1987).

The estimated coefficient on the quarterly permit allocation variable is 0.40 in the first specification, 0.46 in the second. In both cases, we can reject the null hypothesis that the allocation coefficient is zero at the 0.01 level. If we were to interpret this as evidence of a causal relationship, we would conclude that a ten percent increase (decrease) in a firm's NOx allocation in a given quarter increases (decreases) its emissions by 4-5 percent on average.

Coefficients on fuel prices and wages are negative, suggesting that energy and labor inputs are technical complements for emissions. With the exception of electricity prices, none of the input or output price coefficients are statistically significant at the 0.05 level. However, energy prices, wages, and permit prices are highly correlated time series variables. When we estimate alternative specifications that include only one of these input price variables, the coefficient is negative and statistically significant (the allocation coefficient is not significantly affected). The coefficient on the national producer price indices is positive but not statistically significant, possibly because these indices are noisy measures of the prices received by these RECLAIM facilities.

6.2   IV estimates

The last two columns of Table 3 report the corresponding IV estimates, where we treat ln A_{it} as endogenous. The IV estimates of the allocation coefficient differs substantially from the OLS-FE estimates. We cannot reject the null hypothesis that the allocation coefficient is zero at the 0.05 level. In specification 2, the OLS-FE estimate of this coefficient does not lie within the 95 percent confidence interval of the IV estimate.

When interpreting these estimation results, we need to be clear about the margins on which our instruments are working. An ideal instrument would manipulate all dimensions of the endoge-

nous right-hand-side variable for all observations. The random assignment of facilities to RTC allocation cycles does not do this. Instead, it generates exogenous variation around an endogenous, facility-specific downward trend. Consequently, we are limited to an analysis of the average effect of short run variation in quarterly permit allocations on emissions. Fortunately, this kind of analysis is particularly useful in the context of RECLAIM. Over the period we study, most of the firms in the program reportedly achieved compliance through short-run changes in production processes and fuel use when necessary, versus through major capital investments in abatement equipment (US EPA, 2006; Schubert and Zerlauth, 1999). If these short-run changes in emissions were sensitive to quarterly permit allocations, we should be able to detect this dependence in our analysis of the relationship between exogenous variation in quarterly allocations and observed, facility-level emissions.

In summary, we find a strong correlation between emissions and the endogenous component of permit allocation schedules—i.e. the portion that is based on anticipated abatement cost trends and facility-specific operating characteristics. However, we find no significant relationship between facility-level emissions and the exogenous variation in facilities' permit allocations generated by random cycle assignment. These findings are consistent with- but not proof of- the hypothesis that facility-level emissions in RECLAIM are independent of the initial distribution of permits.

7   Robustness tests

To assess the robustness of our results, we estimate alternative model specifications and investigate the possibility of selection bias.

7.1 Estimating the model with data aggregated annually

In some respects, aggregating data quarterly seems most appropriate. Facilities are required to certify compliance quarterly. Furthermore, quarterly data captures short-run behavior in more detail, and in particular, makes it easier to detect any end-of-cycle effects on facility-level emissions. However, RECLAIM facilities can use permits allocated to them for use in a particular cycle at any time in the 12 month compliance cycle. Therefore, an analysis of quarterly data could potentially fail to detect a relationship between a facility's permit allocation and its annual emissions.

We reestimate the model using annual data (omitting the quarterly dummy variables, but including year and facility-level fixed effects). Aggregation reduces the number of observations by more than 75 percent because we can only use observations for a given facility and year if the facility has reported emissions in all four quarters.

Table 5 summarizes results from estimating the model using annual data. Interactions between the year dummy variables and the compliance cycle 1 indicator are used to instrument for permit allocations. These instruments prove to be somewhat weak. In the first stage, the F statistic on the exclusion of the instruments is 3.43. When the model is estimated using data aggregated annually, the OLS-FE coefficient estimates are very similar to the quarterly estimates. The allocation coefficient estimate is 0.55 and it is statistically significant at the one percent level. The IV point estimate of the allocation coefficient is -0.44 with a standard error of 1.08. In summary, these results are entirely consistent with our analysis that used quarterly data, although we encounter problems with weak instruments when we use annual data.

7.2   Alternative Model Specifications

We further evaluate the robustness of our findings by estimating the model using untransformed data (versus log values of the dependent and independent variables). We also re-estimate the model with the a data set that includes the electricity generators. Results summarized in Table 5 indicate that our key findings are robust to these changes. In both cases, the OLS estimated coefficient on allocation is highly statistically significant and positive, whereas the IV estimate is negative and statistically insignificant.

7.3   Alternative Time Periods

Over the period 2001-2003, facility-level RTC allocations ratchet down at a common rate versus a rate that reflects facilities' anticipated abatement costs, operating characteristics, and past emissions. If the statistically significant OLS-FE estimate of the permit allocation coefficient is picking up spurious correlation between omitted variables that determine facility-specific permit trajectories and emissions (versus a causal relationship between permit allocations and emissions), this effect should disappear when all facilities' allocations are decreasing at the same rate. This is, in fact, what we find.

We re-estimate the model using data from 2001-2003. Whereas the coefficient estimates for the control variable coefficients (i.e. fuel prices, permit prices, product prices) are not substantially affected, the point estimate of the allocation coefficient drops to -0.13 (from 0.46). The IV estimate is -0.68 with a standard error of 0.63. Unfortunately, using only data from these three years reduces the number of observations by over 70 percent; estimates are very imprecise. Although we cannot conclude anything from such noisy estimates, these results are consistent with the hypothesis that the statistically significant allocation coefficient obtained when facility-level permit allocations are

regressed on emissions is picking the effect of omitted variables versus the direct effect of variation in RTC allocations on emissions.

7.4 Sample-selection

The panel we use to estimate the model is unbalanced. Emissions data are available for 40 quarters from the beginning of 1994 through 2003. A typical facility reported emissions in 26 of these quarters. Observations may be missing because of late reporting, malfunctioning emissions recording equipment, allocation adjustments, plant closures, or bad record keeping.

Because the true form of the sample selection effect is unknown, we cannot assume that fixed effects in the linear panel data model eliminate sample selection bias. One approach to dealing with the problem of unbalanced panel data is to use only those units that are observed over the entire sample. With less than 11 percent of firms in the sample reporting emissions for all quarters, this approach is impractical.

Thus, we use an alternative approach. If we observe the left-hand side variables for facility i, we set a binary indicator variable $s_{it} = 1$, and otherwise we set s_{it} equal to 0. If the disturbance term u_{it} is uncorrelated with s_{it}, the IV estimator is consistent, even if there is correlation between s_{it} and X_{it} or α_i (Wooldridge, 2002). Semykina and Wooldridge (2005) propose a variable addition test that can be used to detect endogeneity in the sample selection process even if there is heteroskedasticity and autocorrelation in the error terms in both the selection and primary equations. We use their approach to test for the independence of u_{it} and s_{it}. We first estimate a probit model of selection into our sample. From this we compute inverse Mill's ratios. The differenced ratios are included as regressors in our estimation equation. The coefficient on the Mills ratio is not statistically significantly different from zero. This suggests that incomplete reporting does not

significantly bias our results.[28]

8 Summary and conclusions

A particularly appealing aspect of the "cap-and-trade" approach to regulating industrial emissions is that, provided certain assumptions are met, the market will direct those firms with the lowest abatement costs to reduce emissions, regardless of how permits are initially allocated. This important hypothesis has been difficult to directly test because of the likely endogeneity of facility-level permit allocations with respect to emissions.

In Southern California's Regional Clean Air Incentives Market (RECLAIM), identical facilities experienced discrete drops in their quarterly allocation schedules at different points in the calendar year if they were randomly assigned to different permit allocation cycles. We test whether this exogenous variation in quarterly permit allocation schedules affects facility-level emissions.

Notably, when we do not instrument for facility-level permit allocations, we find evidence of a strong correlation between emissions and allocations. This correlation could indicate a direct, causal relationship between permit allocations and emissions, or spurious correlation between emissions and omitted factors that determine permit allocation schedules. Our analysis lends support to the latter hypothesis. Our IV estimates (which are presumably free of omitted variables bias) are not statistically significant. Furthermore, when we re-estimate the model using data from a short period during which changes in facility-level allocations were not determined by anticipated abatement cost trends and facility-specific operating characteristics, the OLS estimate of the allocation coefficient is very close to zero. Based on these results, we fail to reject the hypothesis that nitrogen oxide emissions at RECLAIM facilities were independent of how emissions permits

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[28]The p-value associated with the estimated Mills ratio in the primary equation is 0.06.

were allocated across firms.

Given the structure of the natural experiment we have to work with, we are limited in the conclusions we can draw from this analysis. In particular, we cannot determine whether facilities' long-run compliance decisions were affected by the number of permits they expected to be allocated over the course of the program, nor can we investigate whether an inequitable allocation of permits across program participants has facilitated the exercise of market power. These caveats notwithstanding, our findings are consistent with the hypothesis that permit market outcomes are independent of how permits are initially distributed. This hypothesis is an important and increasingly controversial foundation underpinning market-based pollution permit trading programs.

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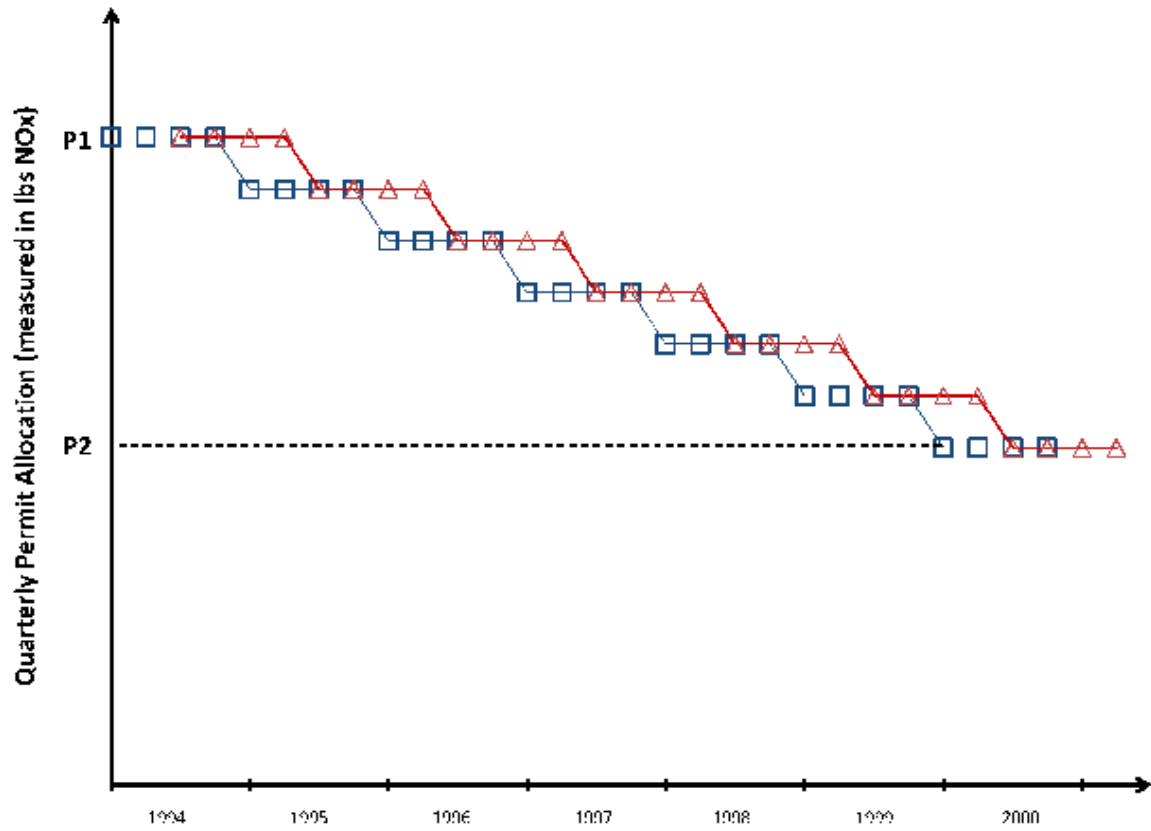
Figure 1 : Permit Allocation Schedule for a Representative RECLAIM Facility

Notes: This is a stylized illustration of a representative facility's emissions permit allocation schedule. Two quantities, P1 and P2, define the facility-specific linear trajectory of permit allocations. These parameters are determined by pre-determined operating and emissions characteristics. The square (triangular) symbols represent the number of permits the facility would receive in a given quarter conditional on its being assigned to compliance cycle one (two). Quarterly permit allocations decrease at the end of each twelve month compliance cycle but remain constant within a cycle. If the facility is assigned to cycle one, the compliance cycle is coincident with the calendar year. If the firm is assigned to cycle 2, the compliance cycle runs July-July.
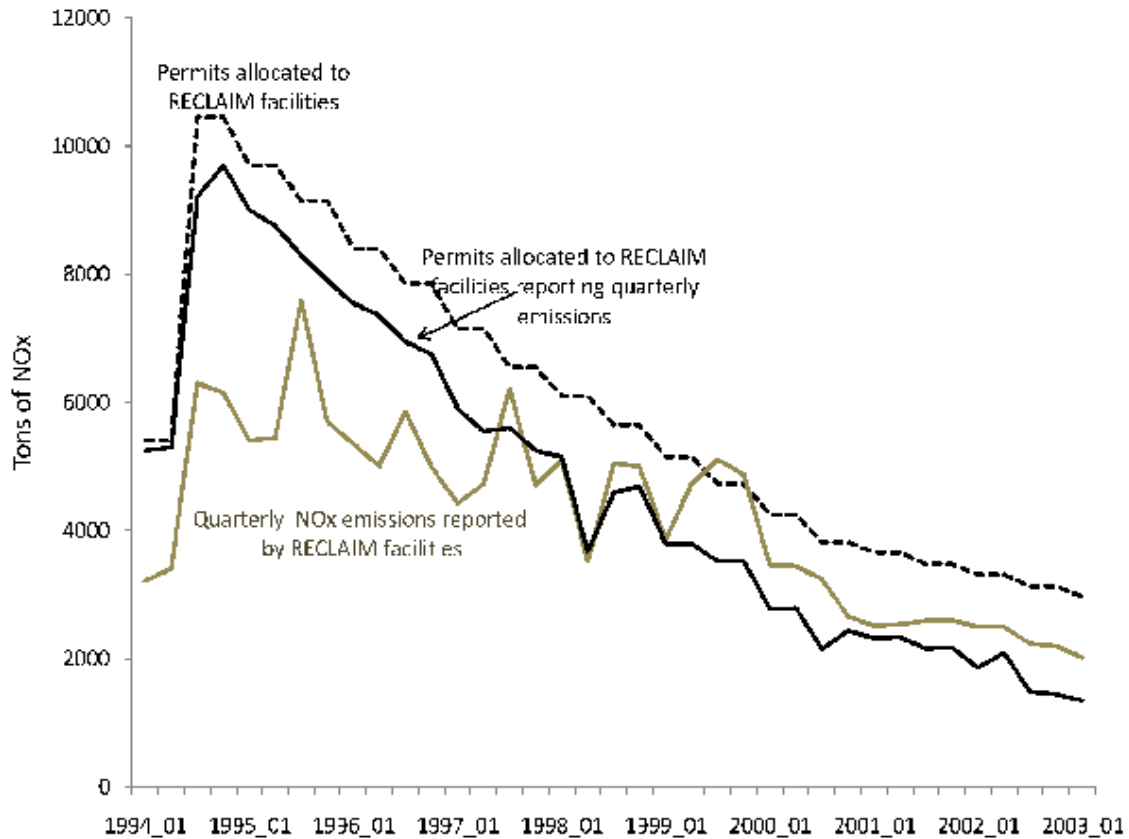
Figure 2: Quarterly NOx Emissions and RTC Allocations in RECLAIM: 1994-2003

Notes: This figure plots quarterly emissions and RTC allocations over the period 1994-2003. Permits and emissions are measured in US tons of NOx. The broken line plots the total quantity of RTCs allocated to the 360 facilities that report quarterly emissions. The solid black line plots the number of permits allocated to all facilities reporting emissions in a given quarter. The grey line plots the total NOx emissions reported in each quarter. The sudden increase in both emissions and permit allocations in mid-1994 occurs because facilities assigned to cycle 2 did not enter the RECLAIM program until July of 1994. Note that total NOx emissions exceeded the aggregate allocation during the California electricity crisis (1999-2000). Several facilities were unable to acquire sufficient permits to offset their emissions during this period.

Table 1A : Linear Permit Allocation Trajectory Parameters by Compliance Cycle

VARIABLE	Allocation cycle 1	Allocation cycle 2
$P1$ Quarterly allocations in the first cycle (lbs of NOx)	46,515 (124,404)	47,534 (169,945)
% reduction in quarterly allocations over 1994-2000	47.2% (32.1%)	47.6% (27.9%)
Number of facilities	158	202

Notes: This table reports summary statistics for parameters that describe facility-specific permit allocation schedules by compliance cycle. Standard deviations are in parentheses.

Table 1B : Linear Permit Allocation Trajectory Parameters by Compliance Cycle: Simulated Random Assignment (R=1000)

VARIABLE	Allocation cycle 1	Allocation cycle 2
Mean of $P1$	47,258 (8,890)	46,954 (6,954)
Standard deviation of $P1$	148,069 (32,603)	149,197 (25,419)
Mean % reduction	47.5% (1.7%)	47.4% (1.4%)
Standard deviation of % reduction	30.0% (1.4%)	30.0% (1.0%)
Number of facilities	158	202

Notes: This table reports results from 1000 simulations of random assignment of facilities to compliance cycles. For each simulation, the mean and standard deviation of the two permit allocation parameters (i.e. initial allocation P1 and the The observed summary statistics reported in Table 2A lie well within one standard deviation of the simulated moments.

Table 2 : **Exogenous and Endogenous Variation in Observed Permit Allocation Schedules: 1994-2000**

Explanatory Variable	Dependent Variable: Quarterly permit allocation	
	Level Specification	Log Specification
$P1_i$ Initial quarterly allocation	1.06 (0.01)**	1.01 (0.00)**
$(P1_i - P2_i) * t$	-0.04 (0.00)**	-0.03 (0.00)**
δ_1 (Quarter 1 indicator)	-3478.32 (682.42)**	-0.10 (0.04)*
δ_2 (Quarter 2 indicator)	-2345.36 (538.49)**	-0.07 (0.04)
δ_3 (Quarter 3 indicator)	-1658.74 (543.13)*	-0.02 (0.04)
δ_4 (Quarter 4 indicator)	-307.78 (468.00)	-0.00 (0.04)
Cycle2_1$_i$ (Average effect of cycle assignment; January-June)	4646.16 (838.92)**	0.13 (0.01)**
Cycle2_2$_i$ (Average effect of cycle assignment; July-December)	551.38 (490.33)	0.00 (0.01)
Adjusted R^2	0.99	1.0
F test on exclusion of C2_1 Prob > F	30.6 0.00	82.5 0.00

Notes: Dependent variable in the first specification is quarterly permit allocation. The second specification uses log values of permit allocations and allocation trajectory values P1 and P2. The unit of observation is the facility.

Robust standard errors are clustered at the facility level.

**indicates significantly different from zero at 99 percent confidence

*indicates significantly different from zero at 95 percent confidence

Table 3 : Facility-level Permit Allocations and Random Cycle Assignment (First-Stage Reduced Form)

EXPLANATORY VARIABLE	OLS-FE SPECIFICATION	
	(1)	(2)
Cycle 2 * Jan-June indicator (instrument)	0.07 (0.01)**	0.13 (0.01)**
RTC price	-0.05 (0.01)**	-
Natural gas price	-0.05 (0.01)**	-
Electricity price	-0.62 (0.04)**	-
Wage index	-0.37 (0.03)**	-
Producer price index	-0.37 (0.23)	-
Quarter–year dummy variables	N	Y
Number of observations	4884	9600
Number of facilities	266	360
F-test on exclusion of instrument	134.63	281.46
Prob > F	0.0	0.0

Notes: Dependent variable is log of quarterly permit allocation. The unit of observation is a RECLAIM facility. All prices and price indices are also measured in logs. Robust standard errors are clustered at the facility level.
** indicates significantly different from zero at 99 percent confidence
* indicates significantly different from zero at 95 percent confidence

Table 4 : Facility-level Permit Allocations and Emissions

Explanatory Variable	OLS-FE		IV-FE	
	(1)	(2)	(1)	(2)
Quarterly permit allocation	0.40 (0.13)**	0.46 (0.13)**	-0.08 (0.36)	-0.42 (0.28)
RTC price	0.01 (0.01)	-	-0.01 (0.02)	-
Natural gas price	-0.06 (0.04)	-	-0.09 (0.04)*	-
Electricity price	-0.93 (0.04)**	-	-1.23 (0.32)**	-
Wage index	-0.11 (0.10)	-	-0.30 (0.19)	-
Producer price index	0.21 (0.35)	-	0.04 (0.34)	-
Quarter- year dummy variables	N	Y	N	Y
Number of observations	4785	9261	4785	9261
Number of facilities	261	358	261	358

Notes: Dependent variable is log of quarterly permit allocation. The unit of observation is a RECLAIM facility. Permit allocations, prices, and price indices are also measured in logs. Robust standard errors are clustered at the facility level.
** indicates significantly different from zero at 99 percent confidence
* indicates significantly different from zero at 95 percent confidence

Table 5 : Robustness Testing

	Main results	Annual data	Include electricity producers	Levels	2001-2003 data
OLS-FE estimate	0.46 (0.13)**	0.55 (0.16)**	0.35 (0.13)**	0.61 (0.06)**	-0.13 (0.51)
IV-FE estimate	-0.42 (0.28)	-0.44 (1.08)	-0.21 (0.27)	-0.43 (0.30)	-0.68 (0.51)
First stage estimate	0.13 (0.01)**		0.13 (0.01)**	4409 (1073)**	0.11 (0.00)**
F test on exclusion of instrument(s)	281.5	3.43	342.4	16.9	764.7
degrees of freedom	1, 359	8, 336	1, 378	1, 359	1, 242
Prob > F	0.00	0.00	0.00	0.00	0.00

Notes: The unit of observation is a RECLAIM facility in all specifications. Robust standard errors are clustered at the facility level in all specifications. In the specification that uses annual data, we use interactions between cycle assignment and year dummies to instrument for allocation. Random cycle assignment affects the number of permits a facility receives in a given year.
** indicates significantly different from zero at 99 percent confidence
* indicates significantly different from zero at 95 percent confidence

9 Appendix

We submitted a SCAQMD public records request to obtain facility-level information about facility location, compliance cycle assignment, operating characteristics, emissions, and RTC allocations. We linked these data with price data from other sources (including the Bureau of Labor Statistics and the Energy Information Administration). Our data set contains facility-level information from the first quarter of 1994, the beginning of the RECLAIM program, through the end of 2003 (40 quarters). Because we are interested in the relationship between allocations and emissions, only those firms that received RTC allocations are included in this study.[29]

Quarterly emissions data

All RECLAIM facilities are required to submit quarterly emissions reports to SCAQMD. On average, there are 26 quarterly emissions reports per firm (of a possible 40 quarters for cycle 1 facilities, and a possible 38 quarters for cycle 2 facilities).

There may be measurement error in the emissions data for smaller pollution producers. For monitoring and reporting purposes, RECLAIM sources are divided into four categories: major sources, large sources, NOx process units, and designated equipment. A firm can have anywhere from 1 to 144 monitored sources. Major sources, which account for 14 percent of RECLAIM NOx sources, are required to install a continuous emissions monitoring system to measure emissions directly. Large sources (approximately 20 percent 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 NOx process units (57 percent of NOx sources) and designated equipment (9 percent), 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.

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 tons/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.[30]

Quarterly permit allocations data

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[29]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 (Schwarze et al., 2000).

[30]This is based on personal correspondence with George Haddad of SCAQMD (2002).

SCAQMD maintains a database tracking all NOx permits. This database contains initial RTC allocations, allocation adjustments, retirements, and trades (measured in pounds) by vintage. From these data, we recovered the NOx permit allocation schedule for 374 RECLAIM facilities. A firm's allocation for a given permit vintage is calculated by summing the RTCs, emission reduction credits (ERCs) and non-tradable credits (NTC's) that it was allocated for that year. For Group 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.

RTC price data

We obtained RTC transaction information, including the identification of buyers and sellers, the date, price, quantity, zone, and vintage of permits traded, from SCAQMD and two private-sector brokers (ACE and Cantor Fitzgerald),. Over half of registered trades are recorded as $0 price transactions. There are three reasons why RTCs are traded at a price of zero:

1. 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.

2. 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.

3. In some cases, a single parent company owns multiple RECLAIM facilities. If a company transfers RTCs between two of its RECLAIM facilities,this transaction is recorded as a $0 trade.

In our analysis, we used the quarterly mean of non-zero prices, weighted by transaction volume, adjusted for inflation. If we had calculated the mean permit prices using the complete transaction data set, we would underestimate the average cost of purchasing a permit from another firm.

The common practice of bundling trades introduces additional complication. 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.

Energy price data

RECLAIM firms report using a variety of fuel types including natural gas, diesel, coal, propane, butane and electricity (SCAQMD, 2001). Because firm-specific information regarding fuel use or energy contracts was unavailable, we use natural gas and electricity prices as a proxy for energy

prices in general. Weighted average natural gas prices were constructed using data from Southern California natural gas bidweek markets (available as part of Platts' GASdat product). Quarterly weighted average electricity prices were constructed using data reported in the Energy Information Administration's *Electric Power Monthly*. 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.

Industry-level variables

Using the information SCAQMD provides about the identity of RECLAIM facilities, we determined the four-digit North American Industry Classification System (NAICS) code and four-digit Standard Industrial Classification (SIC) code for each facility. This allows us to merge our data set with industry-specific wage data and producer price indices.

Because we could not obtain facility-level data on revenues or product prices, we used the Bureau of Labor Statistic's four-digit NAICS Producer Product Indices (PPI) as a proxy for shifts in product demand facing firms. There are several industrial classification categories for which producer price series are unavailable, including finance, insurance, real estate, entertainment, and public administration categories.

The Bureau of Labor Statistics also provides quarterly average wage data by industry classification. We use these data to proxy for labor input prices. Here again, there are some industrial classifications that could not be merged with wage data. Facilities in these industries were omitted from the data used to estimate model specifications that include wages as a regressor.