Redistribution, Delegation, and Regulators' Incentives: Evidence from the Clean Air Act

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Abstract

Taking advantage of the structure of the 1990 Clean Air Act Amendments (CAAA), we study the tradeoff between efficiency and equity associated with different levels of discretionary power when delegating regulatory authority to lower levels of government. Exploiting an instrumental variables approach, we provide evidence that the benefits of the 1990 CAAA were highly localized and accrued disproportionately to poorer households. Further, under the current structure of the 1990 CAAA, it costs at most about $1.30 for every $1 worth of air quality improvements transferred from richer to poorer areas, suggesting that the program does not entail a large tradeoff between efficiency and equity.

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I. Introduction

The merits of decentralization and delegation of regulatory authority from higher to lower levels of government remains a controversial issue. Proponents of decentralization argue that with decentralization comes increased efficiency in the provision of local public goods and services (Oates 1972, Brennan and Buchanan 1980). Opponents, however, fear that with decentralization there is a potential for regulatory capture by local interest groups, which can lead to undesirable distributional outcomes (Laffont and Tirole 1991, Bardhan 2002). Because of these concerns, when delegating regulatory authority to lower levels of government, the federal government often imposes detailed rules on how local governments have to implement a regulation or program. Central to this debate is the tradeoff between efficiency and equity associated with different levels of discretionary power given to lower levels of government. However, very little is known about the empirical magnitude of these tradeoffs for most government programs.

The implementation of the Clean Air Act, the most ambitious federal environmental legislation to date, provides a unique opportunity to learn about the tradeoff between efficiency and equity associated with different levels of discretionary power when delegating regulatory authority. Learning about this tradeoff in the context of environmental policy is particularly important given growing concerns related to environmental justice and mounting evidence of the regressivity of environmental policy (Depro and Timmins 2009, Shadbegian and Gray 2009, Banzhaf 2011, Fullerton 2011, Bento 2013). First enacted in 1970, the Clean Air Act established standards for the ambient concentrations of criteria pollutants with the goal of improving air quality and protecting human health. The implementation of the Clean Air Act has been delegated to local authorities, and the federal government outlines in great detail the requirements needed for a county to be in attainment with the regulation. Following amendments in 1990, the Clean Air Act began regulating particulates less than 10 micrometers in diameter (PM_{10}), for which the negative health effects were deemed particularly severe. When delegating regulatory authority under the Clean Air Act, the federal government stipulated that counties were designated to be out of attainment with the standard if *at least* one of the monitors within the county had concentrations of PM_{10} exceeding the standard.

In this paper, we take advantage of this monitor-level requirement and county non-attainment designations under the 1990 Clean Air Act Amendments (CAAA) to study the tradeoff between efficiency and equity associated with delegation of regulatory authority. By forcing local authorities to pay particular attention to the most polluted areas, this monitor-level requirement may limit the discretionary power of local regulators in meeting the federal standard. We provide convincing evidence that the air quality improvements induced by the 1990 CAAA were highly localized, as local regulators had incentives to target the areas around non-attainment monitors as a strategy to bring their counties in attainment with the federal standard. For houses located within five miles of a non-attainment monitor, our estimate of the elasticity of house prices with respect to PM_{10} reductions is about -0.6. In contrast, for houses located further away, we do not detect any appreciation attributable to the 1990 CAAA. Rental prices also appear to have increased in a localized fashion, although the capitalization of air quality improvements is substantially smaller and less consistent than for housing prices. The maximum elasticity of rents with respect to PM_{10} reductions is about -0.2. As a consequence, a large portion of the benefits from the 1990 CAAA accrued to lower income homeowners, as these were the homeowners located in the areas that experienced the largest improvements in air quality.

Our central estimate of the overall benefits of the 1990 CAAA is $43.9 billion, with areas traditionally out of attainment, such as Los Angeles, benefiting as much as $6 billon. In turn, we argue that the implicit cost associated with the monitor-level requirement for a county to be in attainment, measured by lost capitalization resulting from a hypothetical program structure where delegation comes with greater discretionary power afforded local authorities, is relatively low. For Los Angeles County, for example, our estimate of the maximum lost capitalization is only $1.8 billion - about 30% of the estimated benefits of the program under its current structure. The increased capitalization under the hypothetical program relative to the actual structure of the 1990 CAAA comes from the redistribution of pollution from relatively dirtier areas to cleaner areas with greater capitalization potential. Together, these results are suggestive of a relatively small tradeoff between efficiency and equity associated with detailed requirements the federal government imposes on local authorities when delegating regulatory authority.

To measure the tradeoff between efficiency and equity associated with different levels of discretionary power when delegating regulatory authority under the 1990 CAAA, we proceed in three steps. First, we estimate the changes in housing prices and rental rates between 1990 and 2000 induced by the declines in PM_{10} induced by the 1990 CAAA. Second, we use these estimates to calculate the overall benefits of the 1990 CAAA as well as the distribution of those benefits across geographic locations and among homeowners and renters at different points in their respective income distributions. Third, we calculate the implicit cost of the monitor-level attainment requirement for a county to be in attainment by comparing the capitalization that resulted from the 1990 CAAA against a hypothetical capitalization obtained by allocating emissions reductions to areas with the highest capitalization potential. This hypothetical capitalization is intended to reflect the behavior of a local authority whose only objective is to maximize the local tax base. Based on these hypothetical capitalizations, we also calculate the costs of transferring \$1 dollar worth of emissions reductions from richer to poorer areas through the current structure of the CAAA that requires a monitor-level requirement for a county to be in attainment, and contrast it against more traditional ways to redistribute funds across space and different socio-economic groups.

Our main empirical challenge is to estimate the causal effect of declines in PM_{10} on housing prices and rents. To do this, we have assembled a unique dataset that includes annual readings of PM_{10} concentrations by monitor, county and monitor attainment designations, and tract-level census data on housing prices and rents as well as a host of socio-economic characteristics. Seminal work by Chay and Greenstone (2005) that examined the capitalization of total suspended particulates (TSPs) air pollution into housing values for the 1970s noted the need for an instrumental variables approach in order to overcome biases from confounding factors that are simultaneously correlated with pollution and housing prices. In their work, which is conducted at the county level, county attainment designations under the 1970 Clean Air Act serve as an instrument for changes in pollution. In the spirit of Chay and Greenstone (2005), we also adopt an instrumental variables approach. However, our analysis is conducted at the monitor level (as opposed to county) and our instrument differs from theirs in two important dimensions. First, we rely on both monitor and county attainment designations as instruments for PM_{10}. We use monitor attainment designations as an instrument because it better matches the behavior of local regulators and is a good predictor for the spatial variation in the drops of PM_{10} within non-attainment counties with multiple monitors. As documented in Aufhammer et al. (2009), faced with a standard that requires all monitors in a county to meet a minimum threshold level of air quality, regulators target dirtier areas as a strategy to bring counties into attainment. Our use of monitor attainment designations is also motivated by the non-linearities of the damage functions for major air pollutants (Dockery et al. 1993). Second, instead of a simple binary instrument that only captures attainment status, we use a more sophisticated instrument that reflects the persistence of non-attainment status to capture differential responses depending on the severity of violations. Finally, the spatially disaggregated nature of the analysis allows for the calculation of the tradeoffs between overall benefits and distribution of the benefits for different socio-economic groups of homeowners and rents that result from different structures of delegation of the 1990 CAAA.

Our work contributes to a growing literature that examines the impact of delegation of regulatory authority for the provision of local public goods and services (Gordon 1983, Fisman and Gatti 2002, Bardhan 2002). Earlier work in this literature has typically examined the efficiency implications associated with delegation of regulatory authority. We add to this literature by illustrating how the structure of regulatory programs designed by the federal government and enforced by local authorities can generate remarkably different distributional impacts, and by calculating the implicit costs of inducing certain distributional goals.

This paper also contributes broadly to the literature on the distributional impacts of environmental policies (Fullerton 2011, Banzhaf 2011, Bento 2013). The general view is that environmental policies are typically regressive, with costs falling disproportionately on the poor and benefits appropriated largely by wealthier households. More closely related to our work are studies that have examined the distributional impacts of the CAAA. Earlier work by Gianessi et al (1979) provides suggestive evidence that the costs of the 1970 Clean Air Act were mildly regressive. Consistent with Gianessi et al. (1979), Robinson (1985) demonstrates that if one assumes all industries have the ability to pass the costs of regulation on to consumers, the 1970

Clean Air Act's costs were borne disproportionately by lower income households. More recently, a series of studies that measured the distribution of the benefits of the 1990 CAAA have relied on locational equilibrium models and examined the distribution of benefits for a limited number of metropolitan areas, emphasizing within metropolitan areas differences in the distribution of benefits that result from general equilibrium adjustments in housing prices (Sieg et al. 2004, Tra 2010). Other studies examined the aggregate impacts on specific subgroups of the population, such as renters and homeowners (Grainger 2012). In contrast with nearly all prior work in this area, our analysis provides spatially disaggregated econometric estimates of the distribution of benefits of the 1990 CAAA nationwide, which are crucial to illustrating how alternative structures of delegation of regulatory power under the program alter the distribution of benefits. Additionally, because of the substantial heterogeneity in incomes within homeowner and renter populations, exploring the distribution of benefits for each group in a geographically disaggregated fashion allows for a more complete analysis of the incidence of the benefits of the program.

The rest of the paper is organized as follows. The next section provides an overview of air quality regulation and describes local regulator behavior in response to the 1990 CAAA. Section III describes the data we use in this study and provides some descriptive statistics. We describe our identification strategy and detail our empirical model in Section IV. After we present our regression results in Section V, we discuss the distributional implications of our findings in Section VI. In Section VII, we explore the tradeoffs between efficiency and equity associated with different levels of discretionary power. Section VIII concludes.

II. Environmental Regulation and the Clean Air Act Amendments

A. Brief Historical Facts about Particulate Matter Regulation under the CAAA

Particulate matter (PM) is a term used for a class of solid and liquid air pollutants. PM originates from a variety of mobile and stationary sources, including automobiles, trucks, and, power plants. With the 1970 Clean Air Act, which was an extension of the original 1963 Clean Air Act, the EPA was authorized to enforce a National Ambient Air Quality Standard (NAAQS) for total suspended particulates (TSPs), which include PM less than 100 microns in diameter. A nationwide network of air pollution monitors allowed the EPA to track TSPs, and two types of standards were used to determine whether pollution levels were sufficiently dangerous to warrant regulatory action. As the U.S. EPA (2005) states, "primary standards set limits to protect public health, including the health of 'sensitive' populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings." For each standard, the EPA considered both a 24-hour average and an annual average. Between April 30, 1971 and July 1, 1987, the primary standard for TSPs was 260 $\mu g/m^3$ for the 24-hour average and 75 $\mu g/m^3$ for the annual average. Meanwhile, the secondary standard for TSPs was 50 $\mu g/m^3$ for the 24-hour average and 60 $\mu g/m^3$ for the annual average (National Archives and Records Administration 1987).

In addition to adding provisions for regulating ozone depletion, addressing acid rain, and establishing new auto gasoline reformulation requirements, the amendments to the Clean Air Act passed in 1990 began regulating particulates less than 10 micrometers in diameter (PM_{10}), for which the negative health effects were deemed particularly severe. While particulates larger than

10 micrometers in diameter can generally be filtered in the nose and throat, those less than 10 micrometers in diameter cannot and may cause health problems if sufficient quantities settle in the bronchi and lungs. The new primary standard under the 1990 CAAA required that the three-year geometric average of PM_{10} concentration for each monitor in a county be less than 50 $\mu g/m^3$. It further required via a secondary standard that the 24-hour average concentrations at a monitor not exceed 150 $\mu g/m^3$. This change was implemented because a growing body of scientific evidence indicated that the greatest health concern from particulate matter stemmed from PM_{10}, which can penetrate into sensitive regions of the respiratory tract.[1]

If any monitor within a county exceeds the primary annual standard for one year or the primary 24-hour standard for more than a single day per year, the county is considered to be in violation of the standard. In that case, the EPA can designate a county "non-attainment." A non-attainment county is required to submit to the EPA a state implementation plan (SIP), which outlines the county's strategy to reduce air pollution levels in order to be compliant with the NAAQS. If pollution levels continue to exceed the standards or if the county fails to abide by its SIP, the EPA may impose sanctions on the county in violation. These sanctions may include the withholding of federal highway funds and the imposition of technological "emission offset requirements" on new or modified sources of emissions within the county (National Archives and Records Administration 2005).

B. Local Regulator Behavior

For a county to be deemed out of attainment, pollution readings from only one monitor within that county need to exceed the primary or secondary standards. As such, in counties with

[1] For a concise analysis of the health effects from exposure to PM_{10}, see Hall et al. (1992). For analyses of the impacts of air pollution on infant health, see Currie and Neidell (2005) and Chay and Greenstone (2003).

more than one monitor, local regulators are likely to allocate a disproportionate amount of their effort toward reducing PM_{10} levels near monitors out of attainment (or monitors close to non-attainment), as these monitors put the county as a whole at risk of falling out of attainment. Further, it is well documented in the epidemiological literature that the relationship between mortality and particular matter is non-linear. Dockery et al. (1993) estimate convex damage functions, providing further rationale for prioritizing particularly dirty areas for clean up.

Auffhammer et al. (2009) provide evidence of strategic behavior among local regulators. They show that the average drop in PM_{10} near non-attainment monitors located in non-attainment counties relative to attainment monitors in non-attainment counties was a sizable 5.43 $\mu g/m^3$ per year. They interpret their results as evidence that regulators target non-attainment monitors for more aggressive action, and thereby minimize future expected costs for the county as a whole.

Additional discussions with EPA and South Coast Air Quality Management District officials confirm such behavior. At the local level, policymakers have various ways to enforce the regulations either directly through the CAAA or indirectly through related policies that will tend to result in uneven reductions in air pollution across space. For example, officials may step up inspections and enforcement at polluting facilities in dirty areas. Plants may be required to install equipment to reduce particulate and officials may use permitting rules to ensure that facilities meet guidelines for regulated emissions. Additionally, construction companies may be encouraged to wet the areas in which they are working to avoid dust. Also to limit dust, in and around landfills, dirt roads are kept wet and vehicles must clean their wheels before going back onto the street again. In addition, some areas impose direct regulations on the oxygenated content of fuels, more stringent zoning regulations that make it harder for polluting facilities to locate in these areas, traffic alleviating policies and smart growth strategies to reduce emissions from transportation, and paving of side roads. In this paper, we leverage spatial heterogeneity in monitoring and enforcement efforts within counties to measure the distribution of the benefits of the 1990 CAAA and to assess the implicit cost of imposing a monitor-level requirement for a county to be in attainment.

III. Data and Descriptive Statistics

This section briefly discusses the sources and relevant features of the air quality, regulatory, and housing and population datasets we use in the analysis. We refer the reader to Appendix A for additional details about the data.

A. Air Quality Data

The PM_{10} concentrations were obtained from the Air Quality Standards (AQS) database, which is maintained by the EPA. For each monitor, the database includes the annual mean concentrations, the highest concentration recorded in any 24-hour period, the geospatial coordinates of the monitor, and several reliability measures. For the purposes of our analysis, we restrict attention to monitors with reliable readings.[2] Further, we require that monitors have at least one reliable reading in each of the following sets of years: 1989-1990, 1991-1996, and 1999-2000. This enables us to match concentration levels with decennial census data and construct instruments from mid-decade observations.[3] The reliability and timing requirements place significant demands on the set of monitors, and as a result, our final sample consists of 375 monitors located in 230 counties. While only a small fraction of counties in the U.S., these 230

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[2] See Appendix A for more details on the requirements for reliability.

[3] If a monitor has a valid observation from 1990 (2000), then that observation is attached to the 1990 (2000) census data. If a monitor does not have a valid observation from 1990 (2000), but does from 1989 (1999), then the 1989 (1999) observation is attached to the 1990 (2000) census data.

counties are located in densely populated areas and contain approximately one-third of the total U.S. population.[4] Observed changes in pollution in our sample are also consistent with recent work using a broader sample of monitors. Based on our sample, the average concentrations of PM_{10} declined by 19% in the 1990s, which is consistent with the findings of Auffhammer et al. (2009), who rely on a much larger sample of monitors.

We obtained the county attainment designations from the annual code of federal regulations (CFR). Since the primary and secondary standards are identical for PM_{10}, we have a single indicator variable for each county and year. While the EPA designates each county in the U.S. as attainment or non-attainment, not all counties contain air quality monitors that meet our time and reliability requirements, which are necessary to be included in our sample.[5]

For the purpose of our analysis, we also assign attainment status to each monitor using the EPA's rules. If in year *t* a monitor's annual PM_{10} concentration is greater than 50 $\mu g/m^3$ or its 24-hour concentration exceeds 150 $\mu g/m^3$ more than once, then that monitor is designated non-attainment in year *t+1*.

B. Demographic and Housing Characteristics around Monitors

The demographic and housing data come from the GeoLytics Neighborhood Change Database. This dataset aggregates decennial census microdata to normalize tract boundaries such that the data are directly comparable across time periods. For the years 1990 and 2000, we

[4] Appendix Figure 1 shows the geographic distribution of the 375 monitors that are included in our sample. Appendix Table 1 shows that 1990 PM_{10} levels are higher on average for included monitors relative to the broader population of monitors. However, the decadal changes are insignificantly different across each group. Further, in robustness tests, we relax the monitor reliability requirements.

[5] Appendix Figure 2 displays the 1990 attainment status for each county in our sample. The spatial distribution of non-attainment counties confirms widely held beliefs of which areas are most polluted. The southwestern U.S. (particularly Los Angeles), mountain cities like Denver and Salt Lake, and rust belt cities (Chicago, Detroit, Cleveland, and Pittsburg) are all in the non-attainment group. While some counties are persistently non-attainment through the 1990s, individual monitors show much more variation.

obtained tract-level data for the median owner-occupied housing value, median rental rate, housing characteristics, and socioeconomic characteristics. A complete list of these variables appears in Appendix Table 2.[6]

Using Geographic Information Systems (GIS), we matched each monitor to a single census tract. We then calculated the distance between each tract in the data and the closest tract containing a monitor. Figure 1 plots non-parametric relationships between a tract's distance to the closest air quality monitor in our sample and selected demographic and housing characteristics of that tract, including median housing price, median rent, share of housing units owner occupied, median family income, population density, share college educated, share white, and the unemployment rate in 1990. Figure 1 highlights systematic variation across space for each socioeconomic variable; as the distance from a monitor increases, median housing and rental values, the share of units owner occupied, median incomes, share college educated and share white all increase, whereas population density and unemployment rates decrease. Figure 1 underscores the fact that the monitors are placed in tracts that are systematically different than other tracts and the county as a whole. This is a direct consequence of the EPA's requirement that monitors be located in densely populated areas.[7]

For the purposes of our empirical analysis, we construct concentric ring buffers around each monitor at distances of 0-1, 1-3, 3-5, 5-10 and 10-20 miles. The rings are constructed such that county lines and lines equidistant with other monitors in the same county truncate the rings. The number of tracts, or partial tracts, included in a ring initially increases with distance, but then declines, reflecting the facts that tracts are larger in rural areas and that at larger radii, rings

[6] We omit tracts that have missing values for the variables of interest or report anomalous house price changes; for further details, see the appendix.

[7] See http://epa.gov/airquality/montring.html#montypes. Plots for 2000 characteristics are similar to those for 1990, indicating that the characteristics of neighborhoods close to and further from monitors are fairly stable over time.

bump into county lines and lines equidistant with other monitors.[8] Consistent with Greenstone and Gallagher (2008) and Banzhaf and Walsh (2008), we aggregate housing and socioeconomic data for all tracts falling within a given ring, using weights equal to each tract's land area within the relevant ring multiplied by its population.[9] Cumulatively, the rings cover 92% of total county population (see Appendix Table 3).

C. Variation in Pollution within and across Areas

Figure 2 shows PM_{10} reductions between 1990 and 2000 for monitors in attainment located in counties in attainment, for monitors in attainment located in counties out of attainment, and for monitors out of attainment.[10] The decline in concentrations for in-attainment monitors located in attainment and non-attainment counties is 5.1 $\mu g/m^3$ and 7.0 $\mu g/m^3$, respectively. The out-of-attainment monitor group experiences substantially larger declines in concentrations over the decade, 15.4 $\mu g/m^3$ on average. This pattern highlights the substantial within-county variation in pollution driven by the CAAA and its attainment designations. As we would expect, and as Auffhammer et al. (2009) show, PM_{10} reductions are localized and center around monitors responsible for inciting regulatory action. That the EPA's non-attainment designations were generally effective in reducing pollution levels is consistent with past work documenting the enforcement of air quality standards under the 1990 CAAA (Henderson 1996, Nadeau 1997,

[8] We illustrate the construction of the rings for the Chicago metro area in Appendix Figure 3.

[9] When tracts are aggregated to a ring level, median house value and median family income lose their "median" nature, but instead are weighted averages of medians.

[10] A monitor is classified as non-attainment if it exceeds either of the EPA standards at some point during 1992-1997. A monitor is classified as county non-attainment if it is located in a county that is non-attainment at some point during 1992-1997, but is not non-attainment itself. All but one monitor designated as non-attainment are located in non-attainment counties.

Becker and Henderson 2000). We will further explore the spatial scale of pollution reductions associated with non-attainment designations in the empirical analysis.[11]

Table 1 breaks out demographic and housing characteristics, including 1990 levels as well as changes between 1990 and 2000, for tracts with monitors in attainment in counties that are in attainment, monitors in attainment that are in counties out of attainment, and monitors that are out of attainment. Consistent with Figure 2, the first row shows that monitors out of attainment had higher initial PM_{10} levels in 1990 as well as greater reductions in PM_{10} between 1990 and 2000. It also shows that the initially dirtiest areas near non-attainment monitors typically had lower initial house values and income levels as well as higher shares of minorities and unemployment rates. These results, together with Figure 1, underscore the extent to which demographic and housing characteristics vary as a function of distance to the closest monitor, variation we exploit in the empirical analysis to help identify the distribution of benefits of the pollution reductions induced by the 1990 CAAA.

IV. Empirical Approach

In this section, we outline our econometric approach to estimating the implicit value of air quality derived from housing market data. We rely on the hedonic model developed by Rosen (1974), which characterizes a market for heterogeneous goods and allows one to assign prices to the attributes of those goods. We estimate regressions using spatially disaggregated data in order to examine how the capitalization of air quality improvements varies across space, which, as

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[11] In a series of tests, we examined how pollution levels and changes in pollution across monitors varied with distance between monitors. In Appendix Table 4, we find a strong positive correlation between PM_{10} levels in 1990 that diminishes only slightly as we move away from the monitors; however, it is still strong and positive for monitors even 50 miles apart. More important for our empirical analysis, the correlation in changes in pollution between 1990 and 2000 fades more quickly with distance, with the correlation falling from close to 0.7 for monitors within one mile of one another to around 0.40 for monitors 20-40 miles apart. The precise correlation depends on which monitors we include in the sample and what time period we consider, but the pattern is the same regardless.

discussed in the previous section, has important implications for the incidence of the 1990 CAAA.

Our analysis takes place at the monitor level, with demographic and housing information based on rings of different radii around each monitor. We separately estimate our models for owner-occupied house values and for rents; given a large fraction of renters are low-income households, determining the impact of air quality changes induced by the 1990 CAAA on rents is important in evaluating its overall distributional consequences.

Our basic specification is

$$\Delta p_i = \theta \Delta PM_i + \Delta \mathbf{X}_i \boldsymbol{\beta} + \varepsilon_i , \tag{1}$$

where p_i is the natural log of either median owner-occupied housing value or median rent in area i, PM_i is the concentration of PM_{10} in area i, and $\mathbf{X}_i$ is a vector of area i's housing and neighborhood characteristics.[12] In (1), prices, PM_{10} concentrations, and the vector of controls are differenced between 2000 and 1990. This first-difference approach controls for both observable

[12] The matrix **X** includes the following variables, all differenced between 2000 and 1990: total housing units, percent of housing units occupied, percent of housing units owner occupied, percent of housing units heated by coal, percent of housing units heated by wood, percent of housing units without a kitchen, percent of housing units with full plumbing, percent of owner-occupied units with two bedrooms, percent of owner-occupied units with three bedrooms, percent of owner-occupied units with four bedrooms, percent of owner-occupied units with five or more bedrooms, percent of owner-occupied units that are single detached units, percent of owner-occupied units that are single attached units, percent of owner-occupied units that are mobile homes, percent of owner-occupied units that were built 5-10 years ago, percent of owner-occupied units that were built 10-20 years ago, percent of owner-occupied units that were built 20-30 years ago, percent of owner-occupied units that were built 30-40 years ago, percent of owner-occupied units that were built 40-50 years ago, percent of owner-occupied units that were built 50 or more years ago, percent of renter-occupied units with two bedrooms, percent of renter-occupied units with three bedrooms, percent of renter-occupied units with four bedrooms, percent of renter-occupied units with five or more bedrooms, percent of renter-occupied units that are single detached units, percent of renter-occupied units that are single attached units, percent of renter-occupied units that are mobile homes, percent of renter-occupied units that were built 5-10 years ago, percent of renter-occupied units that were built 10-20 years ago, percent of renter-occupied units that were built 20-30 years ago, percent of renter-occupied units that were built 30-40 years ago, percent of renter-occupied units that were built 40-50 years ago, percent of renter-occupied units that were built 50 or more years ago, median family income, percent of residents with less than a high school degree, percent of residents with a college degree, percent of residents who are Black, percent of residents who are Latino, percent of residents under the age of five, percent of residents over the age of 65, percent of residents that are foreign born, percent of households that are headed by a female, percent of residents that live in the same house as five years ago, percent of residents that are unemployed, percent of residents that are employed in manufacturing, percent of residents that are below the poverty line, percent of residents that receive public assistance, population density, and local home price indices. Sample means for these variables at the tract level are provided in Appendix Table 2.

and unobservable time invariant characteristics of areas that might be correlated with house prices and air quality, such as climate and topographical features, transportation infrastructure, and population density. In this time differenced specification, θ measures capitalization.

As Table 1 suggests, monitor non-attainment areas differ along several observable dimensions from monitor in-attainment areas, irrespective of whether the non-attainment monitors are in non-attainment counties or not. In particular, monitor non-attainment areas have relatively low house prices, low median incomes, low shares of residents that are white, high unemployment rates, and low shares of houses with three or more bedrooms.[13] To the extent that these characteristics are time-invariant, a differencing approach will sweep out these effects. However, changes in unmeasured characteristics of locations that are correlated with PM_{10} and also independently affect p might still bias estimates of θ. For example, expansions in local transportation infrastructure or increases in overall economic activity could affect both pollution levels and housing prices. We would generally expect such correlations to bias the coefficient on pollution toward zero.

We exploit the 1990 CAAA and its implications for local regulator behavior to address the simultaneity that would otherwise exist between house prices and pollution. Our identification strategy builds on that of Chay and Greenstone (2005), who instrument for changes in pollution at the county level between 1970 and 1980 using county non-attainment status in the mid-1970s. However, following more recent work examining the more localized externalities associated with environmental improvements (e.g., Gamper-Rabindran et al. 2011), we exploit heterogeneity within counties in pollution levels and socio-economic characteristics as well as in officials'

[13] With regard to the changes between 1990 and 2000 reported in Table 1, changes in PM_{10} conform to our expectations, but surprisingly, changes in median house values do not. While aggregate data at the county level show that house prices appreciated more in non-attainment counties, house prices at the tract level do not appreciate in line with changes in PM_{10}. This lack of correlation points to the importance of including other covariates that affect house values in our specification.

behavior. Figure 2 highlights the substantial degree of within-county variation in pollution reductions, which is in part driven by local regulator efforts to bring dirtier monitors in line with the EPA's standards. Our IV strategy therefore uses monitor attainment status as an instrument for localized pollution reductions.[14] We also consider overidentified models that use both monitor attainment status and county attainment status as instruments. Further, to capture heterogeneity in the persistence of non-attainment and its potentially differential impact on the extent of air quality improvements, our instruments are constructed as ratios of years out of attainment. Specifically, our monitor (county) instrument is the ratio of years that the monitor (county) is out of attainment to the number of years for which there is a record during the time span 1992-1997. With the county instrument, the denominator is always six years; for the monitor instrument, due to some monitors not having valid data for all years, the denominator can vary from one to six years.[15]

The first stage and reduced form equations of the IV analysis can be written as

$$\Delta PM_i = \varphi N_i + \Delta \mathbf{X}_i \mathbf{\Pi} + \mu_i \tag{2}$$

$$\Delta p_i = \gamma N_i + \Delta \mathbf{X}_i \Omega + v_i , \tag{3}$$

where the instrument N_i is equal to the ratio of non-attainment years during the time span 1992 to 1997. When we use only monitor attainment status as an instrument, the model is just identified, and $\theta_{IV} = \gamma/\varphi$. For θ_{IV} to be a consistent estimate of the effect of changes in PM_{10} on prices, it must be the case that non-attainment status affects changes in PM_{10} and that, conditional on other observable neighborhood and housing characteristics, non-attainment status only affects house

[14] Non-attainment could result from violation of either the annual standard or the 24-hour standard.

[15] While we include in our sample only monitors that have valid PM_{10} readings in both 1990 and 2000, our ratio instrument avoids further selection issues that might arise if we were to require monitors to have a reading one or more particular years during the 1990s. As discussed in Section V.D., the results are similar when we use alternative instruments as well as when we relax reliability requirements for monitors in the sample.

prices through its impact on PM_{10}.[16] As Figure 2 suggests, and as we show more rigorously in Section V.A., the first condition clearly holds. While we cannot conclusively show that the exclusion restriction holds, we include an extensive set of controls and conduct a battery of robustness tests aimed in part at mitigating concerns that any shocks to prices between 1990 and 2000 are not orthogonal to shocks to PM_{10}.[17]

We apply the reduction in pollution measured at the monitor level to each ring, although based on the reduced-form results presented below and the observed gradient in magnitude of pollution changes, there is reason to believe that declines in pollution tend to be larger closer rings than in further away rings. Given this, we would expect estimates of φ in equation (2) to be upper bounds on the true reduction in pollution experienced in more distant rings. In turn, we would expect the IV estimates of θ in equation (1) to be biased downward in absolute value for the rings further away, meaning that the magnitude of the estimated effects could be larger than we find.[18]

One concern is that if house price trends across regions are correlated with patterns of air quality improvements, it could bias our estimates of the effects of pollution reductions on home values. To address this issue, we include as a control local home price indices from Freddie Mac, and specifically the conventional mortgage home price index (CMHPI). We use MSA-level

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[16] Regulatory action in response to non-attainment could affect other pollutants besides PM_{10}, such as ozone. Changes in PM_{10} are more likely to be capitalized into housing markets given it is visible to the unaided human eye, unlike most other air pollutants.

[17] One concern would be if measures aimed at reducing pollution to achieve or maintain attainment independently affect house prices. For example, paving dirt roads can reduce PM_{10} and, by increasing neighborhood accessibility, might also independently affect house prices. Most of our sample monitors are located in urban areas such that road paving is not a major source of PM_{10} reductions, but measures to reduce pollution from industrial sites could have similar effects. However, we believe that with our extensive set of covariates (including, for example, manufacturing employment), we effectively control for such possible channels.

[18] To the extent that people were cognizant of possible increases in the stringency of pollution control measures prior to 1990 and anticipated future air quality improvements in their local areas, we might expect prices to have capitalized those improvements by 1990. While we do not believe that the general public was aware of attainment status and likely future changes in air quality owing to the 1990 CAAA, if there were some capitalization of anticipated pollution reductions by 1990, it would lead us to underestimate the impact of the 1990 CAAA.

indices when available and state-level indices otherwise.[19] In effect, our estimates reflect the effects of changes in PM_{10} on changes in prices beyond those that would be expected given regional price trends. In robustness tests, we also consider pre-treatment trends in neighborhood conditions to address concerns that neighborhoods in and out of attainment were on different initial trajectories.

V. Results

A. First-Stage Results

We begin with an analysis of the first-stage estimates of the relationship between non-attainment and pollution reductions. The results for the 0-1 mile ring appear in Table 2. The first-stage is identical for owners and renters, as the regressions include the same controls. We show results from a just identified model using the fraction of years between 1992 and 1997 that the monitor is out of attainment as an instrument (column (1)) as well as results from an overidentified model using both the fraction of years between 1992 and 1997 that a monitor is out of attainment as well as the fraction of years between 1992 and 1997 that a county is out of attainment (column (2)).

Consistent with the descriptive statistics in Table 1, the results in column (1) show that relative to areas with monitors always in attainment, areas with monitors out of attainment experience an 11.9 $\mu g/m^3$ decline in PM_{10}. Given the mean value of the monitor-level instrument is 0.4, the average monitor in the non-attainment group experiences a decline in PM_{10} of 4.7 $\mu g/m^3$. The overidentified model in column (2) reveals that both monitor non-attainment and

[19] Results using home prices deflated by these local indices are very similar to our main estimates; these results are available upon request. In robustness tests that appear in Appendix Table 5, we also consider regressions with region fixed effects, which additionally control for any unobserved trend in home prices at the region level. The results are very similar to the main estimates.

county non-attainment are associated with declines in PM_{10}. Again echoing Table 1, the results imply that the largest drops in PM_{10} occur near non-attainment monitors that are located in counties out of attainment, while smaller drops occur near attainment monitors that are located in counties out of attainment. The coefficient estimates in the just-identified and overidentified models are highly significant, and with F-statistics of 19 and 15, respectively, the instruments appear to be highly relevant. The corresponding first-stage regressions for each ring beyond 1 mile are estimated as well and are presented in Appendix Table 6. Results are very similar, but change slightly due to different values of the control variables.

B. Reduced-Form Results

The reduced-form relationships between non-attainment status and changes in house prices and rents appear in the top panels of Tables 3 and 4. We show results for prices and rents within rings of 0-1 mile, 1-3 miles, 3-5 miles, 5-10 miles, and 10-20 miles around monitors, and present specifications with only the monitor instrument and specifications with both instruments.

For homeowners (Table 3), there is a striking pattern across rings in each model, with house price growth strongly positively related to non-attainment within close rings but increasingly less related to non-attainment in more distant rings around monitors. This is consistent with there being reductions in pollution near non-attainment monitors that are confined to relatively small areas. Indeed, based on the reduced-form estimates, it appears that reductions in pollution near non-attainment monitors occur up to 5 miles from the monitor. If, on the other hand, the reductions in pollution were more evenly distributed over a wide area, we would expect to see a stronger relationship between non-attainment status of a monitor and house prices even in more distant rings around the monitor. However, the results suggest that non-attainment status matters only for tighter rings around the monitor.

If it were the case that homeowners in more distant rings value air quality improvements less than homeowners close to monitors, the results could still be consistent with more evenly distributed pollution reductions. However, as Figure 1 shows, residents of more distant rings are on average much richer than those in closer rings, and past research suggests that if anything, richer homeowners value air quality improvements more than poorer homeowners (Fullerton 2011).

The reduced-form results for renters in the top panel of Table 4 show a different pattern than those for homeowners. With the exception of the 1-3 mile ring, where rents are positively related with non-attainment status, there appears to be very little relationship between non-attainment and rents.

C. Second-Stage Results

In the bottom panels of Tables 3 and 4, we present the second stage results from our IV analysis for homeowners and renters for each ring around monitors and for just-identified and overidentified models.[20] We apply the reduction in pollution measured at the monitor level to each ring, although based on the reduced-form results, there is reason to believe that declines in pollution tend to be larger in smaller rings than in larger rings. Given this, we would expect estimates of φ in equation (2) to be upper bounds on the true reduction in pollution experienced in more distant rings. In turn, we would expect the IV estimates of θ in equation (1) to be biased downward in absolute value for the larger rings.

[20] For the interested reader, Appendix Table 7 presents cross-section and first-difference regression results.

Focusing on the homeowner results for the 0-1 ring around monitors and using the just-identified model (Table 3, column (1)), the IV estimates imply that a one unit decrease in PM_{10} increases house prices by a statistically significant 0.92%. The estimate in the overidentified model (column (2)) is similar at 1.33% (which is also statistically significant). The implied elasticity of house prices with respect to PM_{10} reductions is about -0.6. This is roughly twice as large as Chay and Greenstone's (2005) estimate of the elasticity of house prices with respect to reductions in total suspended particulates (TSPs).

The IV estimates of the impacts of pollution reductions on house prices get smaller, albeit not statistically different from one another, as we consider larger rings of up to five miles around monitors. Using estimates from the just-identified model, the increase in home values on average in response to a one unit decline in PM_{10} measured at the monitor is 0.82% for houses 1-3 miles from the monitor and 0.67% for houses 3-5 miles from the monitor. Echoing the reduced-form results, we do not detect any significant capitalization of air quality improvements in housing prices in the 5-10 mile ring or 10-20 mile ring.

Based on these results, we can calculate the implied marginal willingness-to-pay (MWTP), the annual dollar amount a household would pay to face one unit less of PM_{10}. To convert house prices to annual expenditure, we assume an 8% interest rate and a 30-year mortgage.[21] The implied MWTP for a one-unit reduction in PM_{10} (in dollars) based on our preferred estimates are stable at around $120-$130 for rings within 5 miles of the monitor. These results are suggestive of highly localized capitalization of the improvements resulting from the 1990 CAAA and are consistent with other estimates based on different data sets and identification strategies. For example, Bayer et al. (2009) find a MWTP of $149 ($1982-84) using decennial census data and

[21] We choose 8% because it is roughly the average 30-year mortgage rate that prevailed during the 1990s. See http://www.mortgagenewsdaily.com/mortgage_rates/charts.asp.

an IV strategy based on long-range pollution transport. Bajari et al. (2012) use sales data from a single city and estimate a MWTP of \$94. Lang (2012) uses a panel of individual housing units and a similar identification strategy as the present paper and finds a MWTP of \$212, suggesting aggregation bias is minimal.

Meanwhile, the IV estimates in Table 4 suggest that, with the exception of the 1-3 mile ring, there is no discernible impact of changes in air pollution on rents. For the 1-3 mile ring, the just-identified IV estimates imply that a one unit decrease in PM_{10} increases rents by a statistically significant 0.32%. The implied elasticity of rents with respect to pollution reductions is -0.2. Notably, for renters in the 1-3 mile ring, the implied MWTP is substantially lower than for homeowners at only \$27. These results, which are broadly consistent with Grainger (2012), imply that, for the 1-3 mile ring, capitalization of air quality improvements in rents is only 40% of that in housing prices.[22]

D. Further Tests and Robustness Checks

We conducted a series of robustness checks for our main results, including tests for sorting, analyses using alternative instrument definitions, analyses using different sets of monitors, and analyses incorporating pre-1990 trends. In additional tests that appear in the appendix, we also consider checks on the robustness of our results to potential errors introduced by changing neighborhood boundaries between 1990 and 2000, alternative ring definitions, additional controls for regional time trends, topographical differences across areas that might affect pollution concentration, and analyses that exclude California.

[22] Though more disaggregated, our results are consistent with those of Grainger (2012), who also examines the effects of the 1990 CAAA on homeowners and renters separately. In Appendix Table 8, we find qualitatively similar results as his using alternative instruments and different specifications, although there are minor discrepancies due to differences in sample construction.

Sorting – A potential concern in interpreting our estimates as the MWTP for air quality improvements and in evaluating the distributional and welfare implications of the 1990 CAAA more broadly is that households may relocate in response to changes in pollution. Households could have sorted prior to 1990, such that those with the greatest distaste for air pollution lived in the areas that were initially the cleanest, or also potentially in response to the pollution changes induced by the 1990 CAAA during the 1990s, such that those living in neighborhoods with large changes in pollution by 2000 were different than those living in the same neighborhoods in 1990. In this section, we examine the extent to which sorting pre- and post-1990 may have occurred and how it affects the interpretation of our results.

In a test to determine first whether there was sorting prior to 1990, we estimate a correlated coefficient model (Garen 1984). This model was applied by Chay and Greenstone (2005) to explore if there was evidence for locational sorting by households based on their preferences for air quality prior to the enactment of the 1970 Clean Air Act. The correlated coefficient model is similar to two stage least squares; the first stage is identical to equation (2), but the second stage can be written as

$$\Delta p_i = \eta(\Delta PM_i) + \psi\hat{\mu}_i + \delta(\Delta PM_i)\cdot\hat{\mu}_i + (\Delta \mathbf{X}_i)\Gamma + \omega_i . \tag{4}$$

In equation (4), the endogenous change in air quality is included, along with the residual term from the first stage and their interaction. The coefficient on the change in PM_{10} is interpreted as the valuation of exogenous changes in air quality. The coefficient on the residual from the first stage is interpreted as the bias resulting from the endogeneity of PM_{10}. The coefficient on the interaction term is an indication of heterogeneous valuation. If the estimate of δ is positive, it suggests that areas experiencing a large reduction in PM_{10}, which in the context of the 1990 CAAA are the dirtier areas, would value an unexpected decline in PM_{10} more than areas experiencing small reductions in PM_{10}. A positive coefficient would also indicate diminishing marginal returns to air quality improvements. Meanwhile, a negative estimate of δ would indicate increasing marginal returns to air quality improvements, which can be interpreted as evidence of preference-based sorting prior to the changes in PM_{10} occurring.

The results from estimating the correlated coefficient model appear in Table 5. The coefficient on the change in PM_{10} is consistent with the second-stage results of Table 3, which show estimated capitalization rates as large and significant for areas close to monitors, but declining in magnitude and significance as distance grows. The coefficients on the residual are positive and similar in magnitude to the coefficients on PM_{10}, indicating that the endogeneity bias is large and would greatly affect results not using an IV strategy.[23] The coefficient on the interaction between PM_{10} and the residual, the main coefficient of interest, is positive, but small and statistically insignificant for all models. This provides weak evidence of diminishing marginal utility with increasing air quality and no evidence of preference-based sorting. To the extent that there was little sorting based on preferences for air quality prior to 1990, it is arguably unlikely that any substantial re-sorting occurred in the mid-1990s in response to the pollution reductions induced by the 1990 CAAA.

Consistent with the lack of sorting in response to 1990 CAAA-induced changes in air quality, the descriptive statistics in Table 1 suggest that the characteristics of neighborhoods close to non-attainment monitors changed little between 1990 and 2000. As an additional test for whether there were systematic changes in households residing in affected neighborhoods, we estimated the effect of pollution reductions on the change in the fraction of households that moved in the past five years, population density, the number of housing units, and the fraction of housing units

[23] Evidence of this can also be seen in the OLS results in Appendix Table 7.

that are owner occupied. In each case, we instrumented changes in PM_{10} with our measure of monitor non-attainment. One would expect to see differential rates of neighborhood turnover in areas experiencing particularly large changes in pollution induced by the policy if there were re-sorting. One might also expect to see changes in the size of the population and housing stock in these areas.

The results of these additional robustness tests appear in Table 6. The results suggest that areas experiencing relatively large policy-induced reductions in air pollution did not see particularly large changes in turnover rates, population density, housing units, or housing tenure. In additional tests reported in Appendix Table 9, we also find little change in the age or racial composition of affected neighborhoods. While not conclusive given that there may be more subtle changes that we cannot detect in our data, these results imply that the sorting and supply responses to pollution reductions induced by the 1990 CAAA were not large. Hence, as we discuss further in the welfare analysis, it is unlikely that areas experiencing substantial reductions in air pollution were disproportionately gentrified during the 1990s, which in turn suggests that the incidence of the program's impacts was greater among low-income populations.

Additional Robustness Checks – In Table 7, we show results for a number of other robustness tests for homeowners.[24] First, we examine the extent to which pre-treatment trends in neighborhood conditions affect the results. To the extent that neighborhoods that experienced large reductions in pollution levels were already on an upward trajectory, we might attribute further improvements to changes in air quality, when in fact they might have occurred even in the absence of the 1990 CAAA and regulator efforts to reduce local pollution. In Panel A of Table 7, we show results in which we include as controls differences between 1980 and 1990 in

[24] Similar tests for renters are provided in Appendix Table 10.

log median income, share black, log population, and log housing units.[25] We lose close to 20% of the observations due to missing data in 1980, when the country was not fully tracted. Nonetheless, the results are remarkably similar with the inclusion of these pre-treatment trends; the IV estimates continue to suggest that a one-unit drop in PM_{10} leads to just over 1% growth in home prices over the decade in areas close to a non-attainment monitor, and that appreciation is declining with distance.

We also consider how our restrictions on the set of monitors included in the analysis affects the main results. Results using relaxed reliability restrictions appear in Panel B of Table 7. The sample size grows by about 60% when we include monitors whose readings were flagged by the EPA as unreliable. In part because of the noisiness of these readings, the strength of our first-stage changes little despite the increase in sample size. Meanwhile, the magnitudes of the estimated impacts of reductions in PM_{10} on home values are very similar to the main results. A one-unit reduction in PM_{10} increases home values by 1-1.5% in neighborhoods within three miles of a non-attainment monitor, but by less than 1% in neighborhoods further from three miles from a non-attainment monitor.

Next, we experimented with alternative measures of non-attainment for our instrument. In particular, instead of monitor and county non-attainment as instruments, we used the difference between annual PM_{10} concentrations in 1991 and the actual standard as an instrument. This captures the extent to which a monitor exceeds the minimum levels, which is predictive of the magnitude of subsequent changes in pollution levels. As Panel C of Table 7 shows, the second-stage estimates of the effect of PM_{10} changes on house prices are slightly smaller than in our

[25] Information on home values is not available for tracts in 1980.

main results, but again qualitatively similar and still statistically significant for the 1-3 mile and 3-5 mile rings. [26]

We also considered a variety of other robustness checks that, for the sake of space, we present in the Appendix. First, the results change little when we restrict attention to tracts whose boundaries do not change substantively between 1990 and 2000, which suggests that our estimates are not being driven by any errors introduced in normalizing the geography (Appendix Table 12). Similarly, if instead of using partial tracts when rings overlap, we restrict attention to whole tracts, the results are very similar (Appendix Table 13). We also find very similar estimated effects when we include region fixed effects, which allow for differential trends in house prices across regions (Appendix Table 5). In additional tests, we exploit information about elevation, which affects air pollution concentration, as well as distance from monitors to tract centroids; qualitatively, the results are similar in each case (Appendix Tables 14 and 15).

In principle, one could take advantage of the cutoff rule determining attainment status to conduct a regression discontinuity (RD) analysis in which one only considers a subset of the geographic areas with pollution levels within a narrow window around the threshold. In comparison to our IV approach, an RD design would allow for the possibility that the instruments are not orthogonal to the error term in the second stage for the full sample. Given the limited number of areas in our final sample, though, we do not have sufficient power to limit the sample to the extent needed to conduct an RD. However, if we drop from the analysis California, which has many monitors with PM_{10} levels that far exceed the cutoff for non-attainment status, our results are very similar. These results appear in Appendix Table 16.

[26] The first-stage estimates for this instrument appear in Appendix Table 11.

VI. Who Appropriated the Benefits from the 1990 CAAA?

Earlier work on the distributional impacts of environmental policy typically found that environmental policy is regressive, with the costs largely falling on lower income households and the benefits appropriated by higher income groups (Banzhaf 2011, Fullerton 2011, Bento 2013). In documenting the incidence of environmental policies, Fullerton (2011) argues that willingness to pay (WTP) proportional to income is an adequate measure. Therefore, we use the estimates presented above to calculate WTP and WTP proportional to income. Further, as Chay and Greenstone (2005) note, while the gradient of the hedonic price function provides the average MWTP for a one-unit decline in air pollution, the calculation of WTP requires identification of the MWTP function. An approach to obtaining this function is to make strong assumptions on its shape. Freeman (1974) showed that if preferences are homogeneous and linear with respect to air quality such that the MWTP for clean air is constant, it becomes straightforward to calculate WTP. Like most of the prior literature, we rely on these assumptions to calculate WTP. Finally, when considering the incidence of the benefits from air quality improvements in housing markets, a logical starting point is to consider the aggregate impacts on homeowners and renters (Grainger 2012). This is because, at least on average, renters are poorer than homeowners. However, as Appendix Figure 4 clearly demonstrates, there is a large amount of income heterogeneity among homeowners; in fact, in 1990, one third of homeowners had household income levels below the mean household income among renters.[27] Therefore, a more disaggregated approach that considers this heterogeneity allows for a more complete picture of the incidence of benefits of the program.

[27] Authors' calculations based on the 1990 Decennial Census 1% Public-Use Microdata Sample.

In the first four rows of Table 8, we provide summary information on median income levels, median house values, the number of owner-occupied units, and the total value of housing in the 0-1, 1-3, and 3-5 mile rings. Because improvements were localized and only statistically significant up to the 3-5 mile ring, we do not report results for larger rings. The sixth row presents WTP proportional to income, which declines from 1.13% in the 0-1 mile ring to 0.99% in the 1-3 mile ring and 0.85% in the 3-5 mile ring. The higher values for closer rings indicates that the net benefits of the pollution reductions are larger as a fraction of income for those households residing in those areas than for households living in more distant rings. To the extent that those areas close to monitors were on average poorer, the benefits of the policy appear to be progressive, although the differences across rings within five miles of monitors are not large.

Table 8 presents these statistics exclusively for homeowners because, with the exception of the 1-3 mile ring, rents were for the most part unaffected, which alleviates one common source of regressivity of environmental policies. The IV estimates for renters suggest that, in general, either renters do not value air quality improvements or landlords are unable to increase rents (allowing renters to appropriate most of the improvements in air quality). Therefore, renters are either unaffected by the program or have actually experienced welfare gains. The exception is the renters in the 1-3 mile ring. For these individuals, if they do not value air quality improvements, they would experience a welfare loss due to the increase in rents. On the other hand, if they value the improvements by as much as homeowners, they would have actually appropriated most of the benefits since rents increased less than housing prices.

Panel A of Figure 3 provides another perspective on the relationship between WTP proportional to income and median family income. The dotted line shows density of tract median household income across all tracts in our sample; the average median family income is around

$50,000, although as the figure makes clear, there is some right skew to the distribution. The solid line shows estimates of proportional WTP as a function of tract median family income. Proportional WTP is clearly declining in median income over the range of tracts where the bulk of households live (up to around $100,000). There appears to be some nonlinearity in proportional WTP above $100,000, but there are very few households in that range.

In Panel B of Figure 3, we show how proportional WTP varies with initial levels of PM_{10}. Not surprisingly, the highest proportional WTP tends to be in areas with the greatest initial levels of air pollution. While relatively few households live in these areas (as the kernel density suggests), the benefits relative to income tend to be highest there. This underscores an important consequence of the structure of the CAAA: by requiring that local officials ensure that PM_{10} levels do not exceed certain thresholds at the monitor level, it effectively ensures that areas with the highest proportional WTP are the primary beneficiaries of the program.

In addition to WTP proportional to income, we present in the final two rows of Table 8 estimates of average appreciation per house (based on estimates that control for neighborhood characteristics) in each ring associated with reductions in pollution as well as aggregate capitalization within each ring. Consistent with WTP proportional to income, appreciation per house is largest in the closest rings, where we see average increases in house values of around $5,000. However, total capitalization is greatest in rings that are somewhat more distant from monitors. This is largely a reflection of higher initial house values and a larger number of owner occupied units in more distant areas (see the second and third rows of Table 8). This implies that although some poorer households living close to monitors benefit greatly from the reductions in pollution induced by the 1990 CAAA, a larger number of households living further from monitors also benefit, but each to a smaller extent.

VII. Redistribution and the Implied Costs of Strict Delegation

A. Conceptual Framework

In the spirit of the literature on regulatory capture (Laffont and Tirole 1991, Fisman and Gatti 2002, Bardhan 2002), here we outline a simple framework for measuring the implicit cost of the monitor-level requirement for attainment status as well as simulate alternative regulatory regimes that would allow for different allocations of pollution reductions across space. Consider a federal regulatory agency that is considering delegating the implementation of a regulation or program to a local authority. When delegating the implementation of the regulation, the federal agency can give more or less discretionary power to the local authority by setting specific requirements. More requirements typically lead to less discretionary power and imply higher economic costs. Whenever there is a potential for local regulatory capture, if the local authority has discretionary power in the implementation of the program, the local authority may deviate from the goals set by the federal agency. In our context, the federal agency's goal is exclusively to protect human health. Therefore, in light of the evidence on the non-linear health benefits of pollution reductions (Dockery et al. 1993), the federal agency wants to ensure that pollution reductions happen in the initially dirtiest areas. In contrast, the local authority may have broader goals. Local air quality management agencies are typically composed by elected and appointed county officials. When making decisions about where to reduce pollution, these officials may trade off the goal of protecting human health against other local goals. For example, a local authority may be tempted (potentially due to influence from by vested interest groups) to clean up relatively rich areas in an attempt to increase the local community's tax base.

To measure the implicit cost of the monitor-level requirement for attainment status, we compare the capitalization that resulted from the program against a hypothetical capitalization calculated through an alternative allocation of emissions reductions with the exclusive intent of maximizing total capitalization. We see this hypothetical capitalization as the one resulting from the behavior of a local government that only values maximizing the property tax base and ignores any non-linearities in the benefits of cleanups. The difference between the hypothetical and actual capitalization therefore represents an upper bound of the cost of imposing a monitor-level requirement in attainment.[28]

B. Overall Benefits

Based on the estimates in Tables 3 and 4, Panel A of Table 9 displays the total benefits that resulted from the 1990 CAAA. For homeowners alone, the total benefit amounted to \$20.5 billion between 1990 and 2000.[29] This value drops to \$19.1 billion if one assumes that renters in the 1-3 mile ring paid the rent increase but did not value the improvement in air quality. If, in contrast, we assume that renters value the improvements as much as homeowners, even when renters in the 1-3 mile ring pay higher rental prices, the total benefit of the program is \$30.1 billion.

Given that our sample does not comprise the whole country, we scale up the benefits using a back-of-the-envelope calculation. The \$30.1 billion estimate is based on the 57 counties in our sample that are designated non-attainment at some point during the 1990-2000 period. The EPA

[28] Implicitly, we are assuming that the costs of emissions reductions are identical across different areas within a county. In practice, even within a county, there could be heterogeneity is costs of abatement if the emissions in different areas of a county come from different sources.

[29] This calculation reflects the localized nature of the improvements, which were statistically significant up to the 3-5 mile ring. If we also include capitalization in the 5-10 mile ring, where the effects of pollution reductions were positive but not statistically significant, the total benefit for homeowners would be \$30.4 billion.

designated another 26 counties non-attainment that are not included in our original sample. Assuming similar rates of capitalization, the implied total benefit of the program to entire U.S. would increase by 46% and would be $43.94 billion. As a point of comparison, Chay and Greenstone (2005) found that the improvements in air quality induced by the mid-1970s TSPs non-attainment designation were associated with a $45 billion aggregate increase in housing values in non-attainment counties between 1970 and 1980. Notably, though, unlike Chay and Greenstone (2005), who conducted their analysis at the county level, our benefit measure reflects the relatively localized nature of environmental improvements owing to the 1990 CAAA.

C. Implied cost of the monitor-level requirement for attainment status

To calculate the implied cost of the monitor-level requirement for attainment status, we first calculate a hypothetical capitalization by considering the total reductions in PM_{10} in our sample of monitors due to the 1990 CAAA and allocating these reductions based on capitalization potential. In effect, under this scenario, the federal government reallocates the aggregate drops in pollution attributable to the program to areas of the country where it would have the greatest impact on the aggregate value of the housing stock. While obviously not realistic, this exercise will illustrate our general approach to estimating the implicit cost of the monitor-level requirement for attainment status.

In our sample of 375 monitors, 120 are either in non-attainment or belong to non-attainment counties. We assign exogenous changes in PM_{10} to these monitors based on the first-stage IV results shown in Table 2. The average reduction in PM_{10} attributed to the 1990 CAAA is 3.55 $\mu g/m^3$ per monitor, corresponding to a total nationwide reduction of 426.1 $\mu g/m^3$. Under the counterfactual, we think of this as our budget of PM_{10} reductions, which can be allocated to any monitor. We define capitalization potential as the total housing value multiplied by the corresponding capitalization coefficient from Table 3 summed over all rings around each monitor (up to and including the 3-5 mile ring). Then monitors are ordered from largest to smallest capitalization potential, and in that order, PM_{10} levels in 2000 are lowered to equal Portland, Oregon's lowest observed 2000 PM_{10} level of 16.6 $\mu g/m^3$ until the budget of total reductions is exhausted. We choose Portland because it has low PM_{10} levels and is a relatively large city, and thus represents an attainable level of pollution. Abstracting from heterogeneity on the costs of abatement, this hypothetical exercise would lead to a capitalization for homeowners of $86.2 billion (reported in Panel B of Table 9). This implies an upper bound to the cost of the monitor-level requirement of complying with federal standards is $65.7 billion. Thus, under this hypothetical (and unrealistic) scenario, the implied upper bound cost of the monitor-level requirement in attainment status is very large and, in fact, bigger than the actual overall benefits of the 1990 CAAA. This reflects the fact that the regulator in this case has many places across the U.S. where he or she could reduce emissions. Under this hypothetical scenario, much of the PM_{10} reductions would take place in wealthy portions of large cities such as Los Angeles and Chicago, as well as wealthy suburban areas like Orange County, California, Fairfield County, Connecticut, and Bergen County, New Jersey, areas that were usually but not always substantially cleaner to begin with. Indeed, as the second column in Table 9 shows, the percent decline in PM_{10} for monitor non-attainment areas would fall drastically from 12.2% to 5.5% if we were to permit the federal government to reallocate pollution reductions across the entire country.

Perhaps more realistic is a similar hypothetical capitalization exercise that instead requires that redistribution of emissions reductions takes place within a county. This hypothetical scenario preserves the structure of delegation under the 1990 CAAA, but effectively removes the incentive for local regulators to target monitors that exceed minimum pollution levels. Two of the non-attainment counties, Los Angeles, California and El Paso, Texas, are particularly useful to illustrate important implications of this scenario. We have chosen these two counties as they both have six monitors with heterogeneity in monitor attainment. Further, the sources of pollution differ in each county, with a relatively large share of particulates coming from mobile sources (e.g., vehicles) rather than stationary sources (e.g., manufacturing plants) in Los Angeles as compared to El Paso.

Panel C of Table 9 displays calculations for this hypothetical scenario for El Paso and Los Angeles. The benefits of the 1990 CAAA to these two counties were \$0.26 billion and \$6 billion respectively. Due to differences in initial pollution levels and housing prices and the correlation between the two across neighborhoods within each county (see Appendix Table 17), removing the monitor-level requirement for attainment status leads to drastically different outcomes in these counties. In the case of El Paso, where most of PM_{10} emissions come from stationary sources located in areas with lower housing values, removing the monitor-level requirement for attainment status would translate into a drop in the percent decline in PM_{10} for monitor non-attainment areas from 8.6 to zero. That is, if the goal of the local authority is exclusively to allocate pollution reductions based on maximizing appreciation, removing the monitor-level requirement leads to a redistribution of emissions reductions such that all the pollution reductions occur in attainment as opposed to non-attainment areas. In contrast, in Los Angeles, PM_{10} emissions come from both stationary and mobile sources, with a non-trivial proportion of emissions coming from automobile use. As a consequence, the correlation between housing values and pollution in Los Angeles is a relatively low -0.25, whereas in El Paso the correlation is -0.87 (see Appendix Table 17). Hence, when we remove the monitor-level requirement for attainment status in Los Angeles, we see a relatively small drop in the percent decline in PM_{10} for monitor non-attainment areas (from 9.7 to 8.2). This is because, while non-attainment monitors located in areas with lower housing values would experience smaller reductions in PM_{10} (as in El Paso), non-attainment monitors located in areas with higher housing values would continue to experience large drops. Thus, in Los Angeles, removing the monitor-level requirement would redistribute emissions reductions from poorer to richer non-attainment areas as well as to richer attainment areas. While these calculations assume the worst case behavior for the local regulator and abstract from heterogeneity in abatement costs, they nonetheless point to the critical role that the monitor requirement for attainment status plays in making the benefits of the program more progressive.

Panel C of Table 9 also indicates that the cost of the monitor-level requirement for attainment status is relatively small when we require that any redistribution take place within a county. For El Paso, the cost is \$0.12 billion, or about 42% of the estimated benefits of the program under the current regime. For Los Angeles, the cost is \$1.8 billion, or about 30% of the estimated benefits of the program under the current regime. These costs are particularly small relative to the implied cost based on the scenario presented in Panel B.

Based on these hypothetical capitalizations, we also calculate the costs of transferring \$1 dollar worth of emissions reductions from a richer to a poorer area. These are \$1.32 for El Paso and \$1.23 for Los Angeles.[30] Alternatively, regulators could have removed the monitor-level requirement and instead compensated victims of pollution exposure in non-attainment areas while allocating pollution reduction to areas of greater capitalization potential. Such

[30] For example, for El Paso, 1+(0.38-0.26)/0.38 = 1.32.

compensation could be financed through taxes, at a cost of approximately $1.40 per dollar transferred, assuming a labor tax with a marginal excess burden of 0.4 (Browning 1987). Surprisingly, redistributing funds in space from attainment to non-attainment areas through the monitor-level requirement is relatively cost-effective. More generally, the monitor-level requirement for attainment status appears to be less distortionary when the correlation between housing values and initial pollution levels is low, as is the case in Los Angeles, or when the variance of housing values is small, as is the case in El Paso.

VIII. Conclusion

Taking advantage of the structure of the 1990 CAAA, this paper examines the tradeoff between efficiency and equity associated with different levels of discretionary power in the delegation of regulatory authority from higher to lower levels of government. Our central finding is that alternative structures of delegation of a program can produce remarkably different distributional impacts.

In the context of the 1990 CAAA, which penalized counties if readings from individual air quality monitors exceeded specified thresholds, local regulators had an incentive to clean up initially dirtier areas where a disproportionate number of poor households live. As a consequence, the benefits of the air quality improvements were highly localized, with benefits accruing primarily to households located within five miles of non-attainment monitors. The implied elasticities of house prices and rents with respect to the PM_{10} reductions are about -0.6 and -0.2, respectively.

Using our estimates, we explored the implicit costs associated with the current structure of the 1990 CAAA by considering hypothetical scenarios in which we allow for local authorities to reallocate pollution reductions to areas with the goal of maximizing the tax base. A surprising finding is that these implicit costs appear to be quite low. In Los Angeles, for example, it costs no more than $1.23 for every $1 of benefit transferred from a richer to a poorer area under the current program. Further, the monitor-level requirement for attainment status appears to be less distortionary when the correlation between housing values and initial pollution levels within a county is low, which is typically the case when pollution comes primarily from mobile sources or when there is little variation in house values across neighborhoods.

More generally, the insights provided in this paper may serve as a starting point for thinking about the structure of delegation of regulatory authority in other domains where these tradeoffs between efficiency and equity are a concern, including programs aimed at improving school quality, reducing neighborhood crime, or revitalizing blighted communities.

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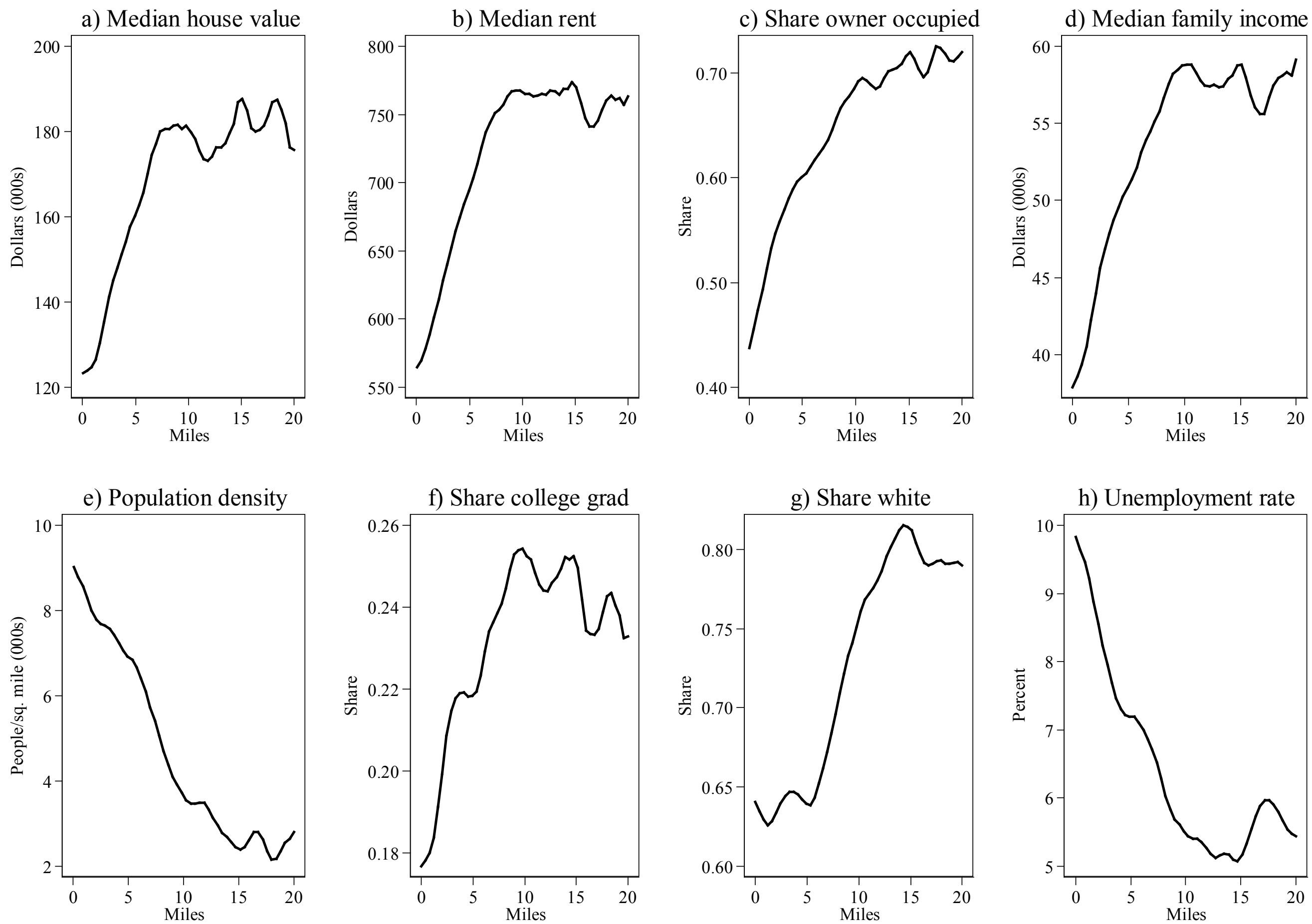
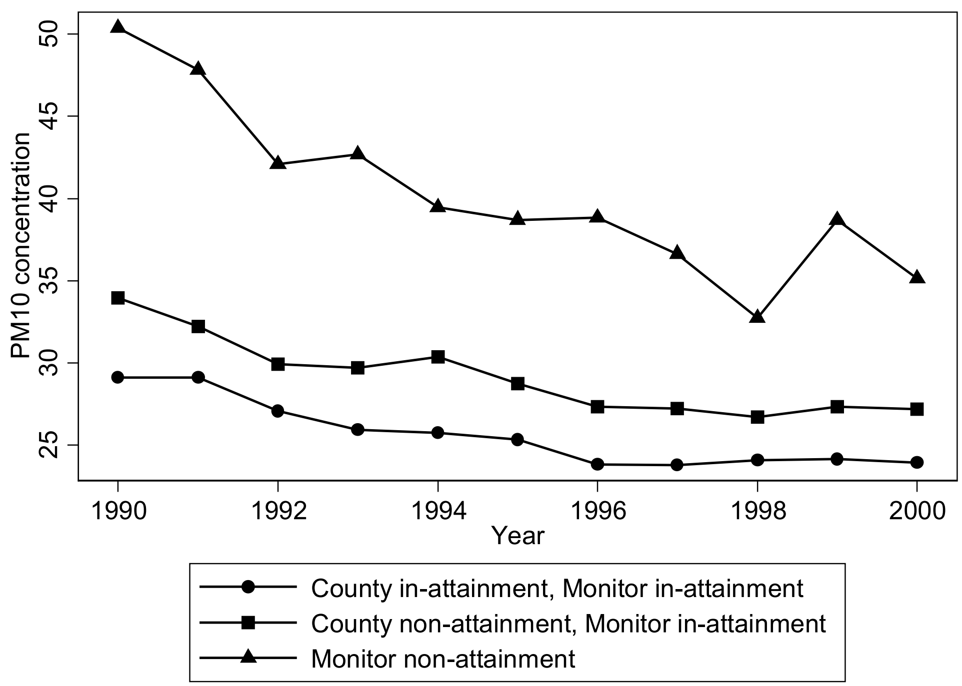
Figures

Figure 1.—The relationship between select socioeconomic characteristics and distance from monitors



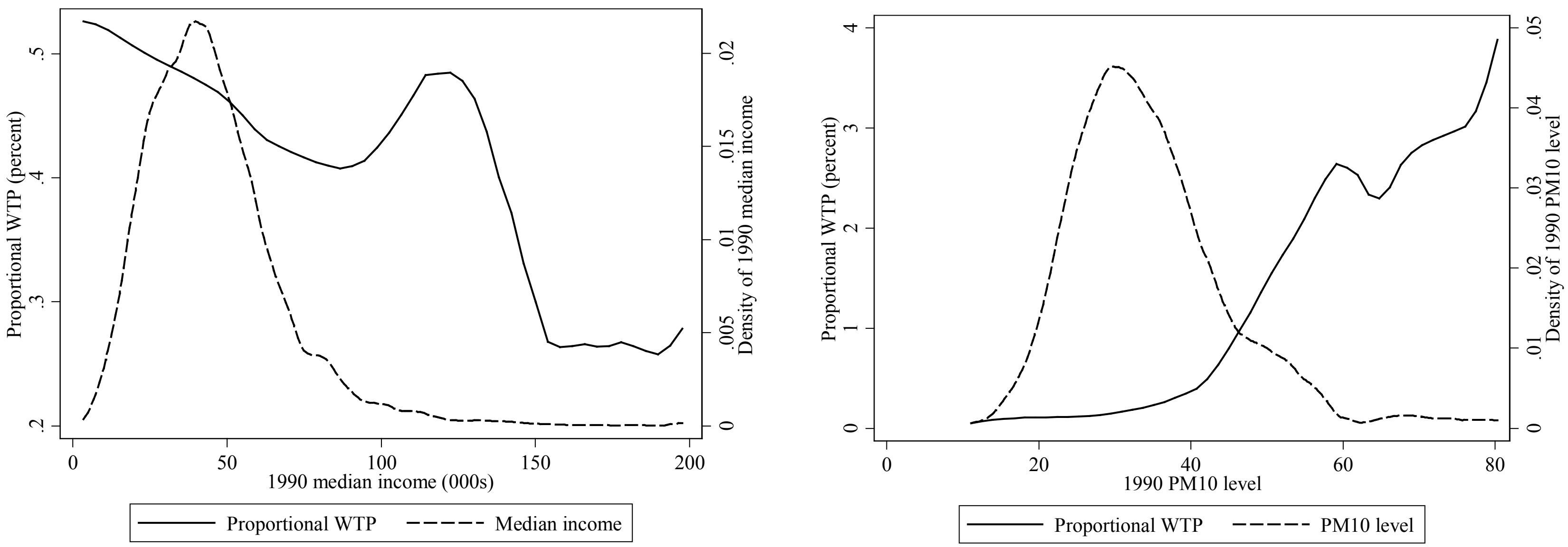
Notes: The sample of 22,941 census tracts consists of tracts within included counties whose centroid is less than 20 miles from a sample monitor. All values are from the 1990 Decennial Census. The graphed line is the mean estimated by local polynomial.

Figure 2.—PM_{10} concentration trends by attainment status



Notes: The monitor sample includes all 375 monitors that are included in the analysis. A monitor is classified as 'monitor non-attainment' if it exceeds either of the EPA standards at somepoint during 1992-1997. A monitor is classified as 'county non-attainment' if it is located in a county that is non-attainment at somepoint during 1992-1997, but is not non-attainment itself. All but one monitor designated 'monitor non-attainment' are located in non-attainment counties.

Figure 3.—The relationships between proportional WTP and income and proportional WTP and 1990 PM_{10} levels



Notes: The sample of 10,706 census tracts consists of tracts within included counties whose centroid is less than 5 miles from a sample monitor. Proportional WTP is calculated for each tract from the first and second stage IV coefficient estimates in Table 3 and the 1990 median house price and median income of the tract. Coefficient estimates from the ring models are assigned according to the distance from each tract's centroid to the monitor. Mean proportional WTP is estimated by local polynomial. The income and PM10 densities are estimated by epanechnikov kernel.

Tables

Table 1.—Summary statistics for 0-1 mile ring split by attainment status

		Monitor in attainment, county in attainment	Monitor in attainment, county out of attainment	Monitor out of attainment	p-value of means test		
		(1)	(2)	(3)	(1) v (2)	(1) v (3)	(2) v (3)
Sample size		255	93	27			
PM_{10} concentration	1990	29.3	34.3	50.7	0.00	0.00	0.00
	2000-1990	-5.5	-7.2	-14.9	0.02	0.00	0.00
Median house value	1990	101,210	112,171	102,383	0.34	0.93	0.53
	2000-1990	11,056	16,499	3,938	0.40	0.39	0.20
Median rent	1990	514	572	548	0.01	0.30	0.51
	2000-1990	27	7	-8	0.05	0.02	0.37
Median family income	1990	37,230	42,242	35,576	0.01	0.43	0.01
	2000-1990	3,602	2,069	625	0.04	0.00	0.18
Share owner-occupied housing units	1990	52.0%	55.7%	52.8%	0.08	0.85	0.50
	2000-1990	0.2%	0.6%	0.2%	0.34	0.96	0.69
Share same house as 5 years ago	1990	49.9%	50.0%	45.9%	0.92	0.11	0.13
	2000-1990	-0.3%	1.1%	2.6%	0.02	0.03	0.28
Share white	1990	70.1%	73.3%	63.1%	0.31	0.28	0.13
	2000-1990	-6.2%	-9.0%	-9.5%	0.01	0.05	0.77
Share unemployed	1990	8.9%	9.1%	10.0%	0.74	0.22	0.38
	2000-1990	-0.5%	-1.0%	1.4%	0.19	0.08	0.03
Population density (per sq. mile)	1990	3,406	4,773	3,174	0.22	0.70	0.19
	2000-1990	-3	217	220	0.02	0.05	0.98
Total housing units	1990	4,353	5,232	3,664	0.26	0.32	0.11
	2000-1990	9	116	202	0.10	0.02	0.36
Share housing units built last 10 years	1990	9.8%	11.8%	15.4%	0.20	0.05	0.24
	2000-1990	-1.2%	-3.0%	-3.1%	0.11	0.25	0.95
Share housing units with 3 or more bedrooms	1990	64.4%	66.6%	59.9%	0.20	0.14	0.05
	2000-1990	0.0%	-1.2%	-1.9%	0.04	0.05	0.45

Notes: Housing and demographic data come from Neighborhood Change Database. Housing prices and income are adjusted to 2000 levels using the CPI. PM10 data are from Air Quality Standards Database.

Table 2.—First Stage Instrumental Variables Results

	(1)	(2)
Monitor Non-attainment	-11.85	-9.71
	(2.71)***	(2.67)***
County Non-attainment		-2.79
		(0.81)***
F-stat	19.17	15.37
R-Squared	0.29	0.29
Sample size	375	375

Notes: The dependent variable is the change in PM10 concentration. Both regressions include the full set of controls listed in Appendix Table 2 and use the ratio instruments constructed from years 1992-97. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the county level. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 3.—Reduced form and second stage instrumental variables regression results for homeowners

	0-1 mile		1-3 mile		3-5 mile	
Reduced Form	(1)	(2)	(3)	(4)	(5)	(6)
Monitor Non-attainment	0.11	0.07	0.10	0.06	0.09	0.05
	(0.06)*	(0.06)	(0.05)**	(0.05)	(0.04)**	(0.05)
County Non-attainment		0.06		0.05		0.06
		(0.03)*		(0.02)**		(0.03)**
R-Squared	0.68	0.69	0.77	0.78	0.77	0.78
Second Stage						
ΔPM_{10} (1/100)	-0.92	-1.33	-0.82	-1.24	-0.67	-1.08
	(0.5)*	(0.5)***	(0.36)**	(0.4)***	(0.31)**	(0.37)***
R-Squared	0.68	0.66	0.77	0.74	0.76	0.74
Sample Size	375	375	375	375	373	373

	5-10 mile		10-20 mile	
Reduced Form	(7)	(8)	(9)	(10)
Monitor Non-attainment	0.03	0.00	-0.04	-0.06
	(0.04)	(0.04)	(0.05)	(0.05)
County Non-attainment		0.03		0.02
		(0.02)		(0.02)
R-Squared	0.80	0.81	0.79	0.79
Second Stage				
ΔPM_{10} (1/100)	-0.18	-0.44	0.26	0.07
	(0.24)	(0.25)*	(0.26)	(0.28)
R-Squared	0.80	0.80	0.79	0.79
Sample Size	370	370	334	334

Notes: The dependent variable is the change in the natural log of median house price. All regressions include the full set of controls listed in Appendix Table 2 and use the ratio instruments constructed from years 1992-97. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the county level. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 4.— Reduced form and second stage instrumental variables regression results for renters

	0-1 mile		1-3 mile		3-5 mile	
Reduced Form	(1)	(2)	(3)	(4)	(5)	(6)
Monitor Non-attainment	-0.04	-0.03	0.04	0.03	0.02	0.01
	(0.04)	(0.04)	(0.02)*	(0.02)	(0.03)	(0.04)
County Non-attainment		-0.01		0.01		0.01
		(0.01)		(0.01)		(0.01)
R-Squared	0.59	0.59	0.63	0.63	0.62	0.63
Second Stage						
ΔPM_{10} (1/100)	0.37	0.43	-0.32	-0.38	-0.14	-0.22
	(0.31)	(0.27)	(0.17)*	(0.2)*	(0.24)	(0.2)
R-Squared	0.57	0.56	0.62	0.61	0.62	0.62
Sample Size	375	375	375	375	373	373

	5-10 mile		10-20 mile	
Reduced Form	(7)	(8)	(9)	(10)
Monitor Non-attainment	0.01	0.00	-0.02	-0.05
	(0.03)	(0.04)	(0.04)	(0.05)
County Non-attainment		0.02		0.02
		(0.01)		(0.02)
R-Squared	0.63	0.63	0.57	0.58
Second Stage				
ΔPM_{10} (1/100)	-0.08	-0.23	0.14	-0.06
	(0.19)	(0.17)	(0.24)	(0.25)
R-Squared	0.63	0.63	0.57	0.57
Sample Size	370	370	334	334

Notes: The dependent variable is the change in the natural log of median rent. All regressions include the full set of controls listed in Appendix Table 2 and use the ratio instruments constructed from years 1992-97. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the county level. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 5.—Correlated coefficient model for homeowners

	0-1 mile	1-3 mile	3-5 mile	5-10 mile	10-20 mile
PM_{10} change (1/100)	-1.23	-1.22	-1.04	-0.38	0.04
	(0.52)**	(0.43)***	(0.41)**	(0.25)	(0.32)
Residual (1/100)	1.22	1.09	1.01	0.59	0.12
	(0.61)**	(0.48)**	(0.44)**	(0.31)*	(0.4)
PM_{10} change x residual	4.87	2.05	2.30	2.56	0.98
(1/10,000)	(2.59)*	(1.91)	(1.7)	(1.75)	(2.05)

Notes: Coefficients and standard errors (shown in parentheses) are calculated using 1,000 bootstrap replications of the two-stage estimator. All estimates come from models using both county and monitor level instrument, similar to those in Table 3. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 6.—Non-price responses to changes in air quality

Dependent variable	0-1 mile	1-3 mile	3-5 mile	5-10 mile	10-20 mile
Change in share living in the same house as	0.13	-0.19	-0.79	1.21	-1.48
5 years ago (1/1000)	(1.2)	(0.91)	(0.79)	(0.71)*	(1.27)
Change in population density	5.13	-0.54	-0.91	-0.91	-5.51
	(9.27)	(5.09)	(4.42)	(4.09)	(2.69)**
Change in total housing units	-3.40	-22.85	-39.82	-36.82	116.85
	(7.21)	(33.76)	(41.42)	(146.04)	(213.64)
Change in share owner occupied units (1/1000)	-0.77	-1.48	-0.40	0.65	0.11
	(0.75)	(0.61)**	(0.54)	(0.43)	(0.48)

Notes: Each coefficient comes from a separate regression, which uses the same two-stage IV first difference model that produced the overidentified results in Table 3 and uses the same covariates except that the variable of interest is removed. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the county level. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 7.—Additional second stage results for homeowners

	0-1 mile	1-3 mile	3-5 mile	5-10 mile	10-20 mile
Panel A: Include demographic and housing trends 1980-1990 as covariates					
ΔPM_{10} (1/100)	-1.64	-1.45	-1.32	-0.43	0.01
	(0.56)***	(0.37)***	(0.33)***	(0.26)	(0.35)
Sample Size	312	312	310	308	272
Panel B: Relax reliability requirements for monitors					
ΔPM_{10} (1/100)	-0.89	-1.20	-0.79	-0.53	-0.06
	(0.39)**	(0.46)**	(0.32)**	(0.27)**	(0.29)
Sample Size	591	591	587	581	522
Panel C: First stage instrument based on difference between 1991 annual PM_{10} concentration and standard					
ΔPM_{10} (1/100)	-0.21	-1.06	-0.97	-0.48	-0.03
	(0.47)	(0.33)***	(0.39)**	(0.37)	(0.28)
Sample Size	308	308	306	303	273

Notes: Each coefficient comes from a separate regression, which uses a similar two-stage IV first difference model to that which produced the results in Table 3. Panel A is identical to the overidentified model in Table 3 except that changes between 1980 and 1990 in ln(average family income), population density, share black, and total housing units are added as covariates. Panel B includes monitors that do not meet the reliability requirements discussed in Section 3, but the model and covariates are the same as the overidentified model in Table 3. Panel C is a just identified model where the monitor level instrument equals max(0, annual pm concentration in 1991 - 50). First stage results for Panel C are given in the Appendix Table 10. Standard errors are shown in parentheses and are estimated using the Eicker-White formula to correct for heteroskedasticity and are clustered at the county level. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 8.—Distribution of benefits for homeowners by ring

	0-1 mile	1-3 mile	3-5 mile
1990 median income	40,742	44,147	47,688
1990 median house value	109,968	115,721	125,924
Total number of owner occupied units (thousands)	245	1,315	1,606
Total value of owner occupied units (billions)	37	188	260
MWTP	129	126	120
Proportional WTP	1.13%	0.99%	0.85%
Appreciation per house	5,206	5,040	4,634
Total appreciation (billions)	1.5	7.9	10.3

Notes: All amounts are in 2000$. Only areas matched to non-attainment monitors or monitors in non-attainment counties are included in the calculation of the statistics presented in the table. Coefficient estimates used to calculate MWTP, proportional WTP, appreciation per house, and total appreciation come from the overidentified model for each ring.

Table 9.—Actual and counterfactual benefits to PM_{10} reductions

Policy description	Total Benefits ($ billions)	Percent decline in PM10 for monitor non-attainment areas	Percent decline in PM10 for monitor in-attainment areas
Panel A: CAAA standards (status quo)			
owners only	20.5	12.7	2.3
with renters paying rental increase but not receiving benefits	19.1		
with renters receiving benefits akin to owners	30.1		
Panel B: National reallocation of PM reductions			
Reduce PM10 levels in line with Portland, OR in order of highest capitalization potential	86.2	5.5	3.3
Panel C: County reallocation of PM reductions			
El Paso County, Texas			
CAAA standards (status quo)	0.26	8.6	8.4
Reduce pm to lowest level in county in order of highest capitalization potential	0.38	0.0	11.1
Los Angeles County, California			
CAAA standards (status quo)	6.0	9.7	6.5
Reduce pm to lowest level in county in order of highest capitalization potential	7.8	8.2	8.4

Notes: All amounts are in 2000$. In Panel A, owner only benefits are derived from the estimates in Tables 2 and 3, and the number of housing units in our treated sample. For the scenario with renters paying for rent increases but not receiving benefits, we used the results in Tables 2 and 4 and the number of rental units in our treated sample to estimate the total increase in rent possible from the CAAA and then subtract that number from the owner only benefits. For the scenario with renters receiving benefits akin to owners, we applied the owner coefficient estimates from Table 3 to our renter population and calculated total benefits for all renters in our treated sample, and then added this number to the benefits calculated under the scenario where renters pay rent increases but do not receive benefits. In Panel B, counterfactual benefits (for owner-occupiers only) were constructed by first estimating the total reductions in PM10 in our sample of monitors due to the CAAA using the Table 2 results. We then created a measure of 'capitalization potential', equal to the total housing value times the corresponding capitalization coefficient from Table 3 summed over the rings within five miles. Then monitors were ordered from largest to smallest capitalization potential, and in that order, PM10 levels in 2000 were lowered to equal Portland, Oregon's 2000 PM10 level, which was 16.6, up to the point that total PM10 reductions were equal with the actual policy. In Panel C, we have constrained the counterfactual policy to work within a single county, but similarly PM reductions are re-distributed favoring areas with high capitalization potential.