# Valuing the environment: Measurement and Empirics I

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# Plan for today

So far: externalities, market failures, and ways to solve them!

Today: first empirical lecture.

# Need for empirical approach

Our previous work shows that $D(\cdot)$ and $\pi(\cdot)$ determine

- inefficiency of market outcomes
- net benefits $+$ distributional outcomes of policy designed to correct the externality

How would we measure $D(\cdot)$ and $\pi(\cdot)$ in practice?

- much of our course will concern some specific applications
- today, we will focus on the benefits of urban trees and cleaner air as two examples to illustrate some useful principles

## Benefits of environmental regulation

- Indirect methods
- Han et al. (2024)
- Chay and Greenstone (2005)

# Estimating environmental damages

Key challenge: recovering individuals' willingness to pay for goods and services for which there are **not** explicit markets.

Some solutions:

1. survey methods (problematic; see Diamond and Hausman 1994)
2. direct, outcome-based methods (e.g., effect of pollution on health)
3. indirect, market-based methods

# Survey methods

In environmental economics, sometimes called “contingent valuation”

- ask people directly how much they are willing to pay

Used in damage assessments in litigation and government decision-making

# Survey methods

https://www.youtube.com/watch?v=G0ZZJXw4MTA&t=22s

# Indirect methods

- **Implicit price theory** (Rosen 1974) offers the promise of valuing certain aspects of environmental quality
- Idea: in the world, we often observe "bundles" of goods that are assigned **one** price

↪ For example, we observe the price of a house, but houses consist of a number of characteristics,
  - such as the number of rooms, neighborhood quality, air quality, et cetera

- With a model of supply and demand, we can learn about the value of different characteristics from how the price changes with characteristics…

  … even though the characteristics themselves are **not** priced!

**Remark**. Sometimes called "hedonic" price theory. "Hedonic" just means "relating to pleasure"; we are using prices to learn about the pleasure people obtain from the environment.

# Indirect methods

Implicit price theory:

- The goal is to observe houses that are identical in every characteristic but one, and then use the differences in house prices to infer the value of that characteristic

Two main questions:

- How is the price of the house set in the market?
- How can we infer consumer willingness to pay for changes in the characteristic—i.e., estimate the demand curve for environmental quality?

# Indirect methods

- Consider the price of a house, $p$. Suppose it depends on a vector of characteristics,

  $\mathbf{v} = (t, x_1, x_2, \dots) =$ (environmental quality, nbd quality, local labor market, ...

- If the price depends on $\mathbf{v}$, we can write it as

$$p(\mathbf{v}).$$

- Our goal is to estimate the implicit price

$$\frac{\partial p(\mathbf{v})}{\partial t}$$

  for $t$, in order to trace out the demand curve for environmental quality.

# Housing prices and trees

Let's apply this method to data:

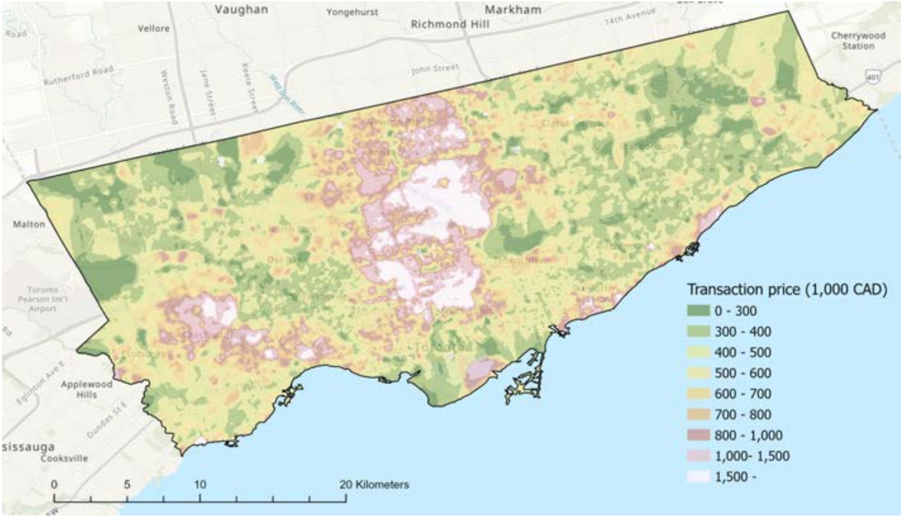
Lu Han, Stephan Heblich, Chris Timmins, and Yanos Zylberberg (2024). "Cool Cities: The Value of Urban Trees," National Bureau of Economic Research (NBER) Working Paper **32063**, http://www.nber.org/papers/w32063.

Han et al. (2024) take data from Toronto on

- property transactions
- transaction and neighborhood characteristics
- tree density
- urban tree management

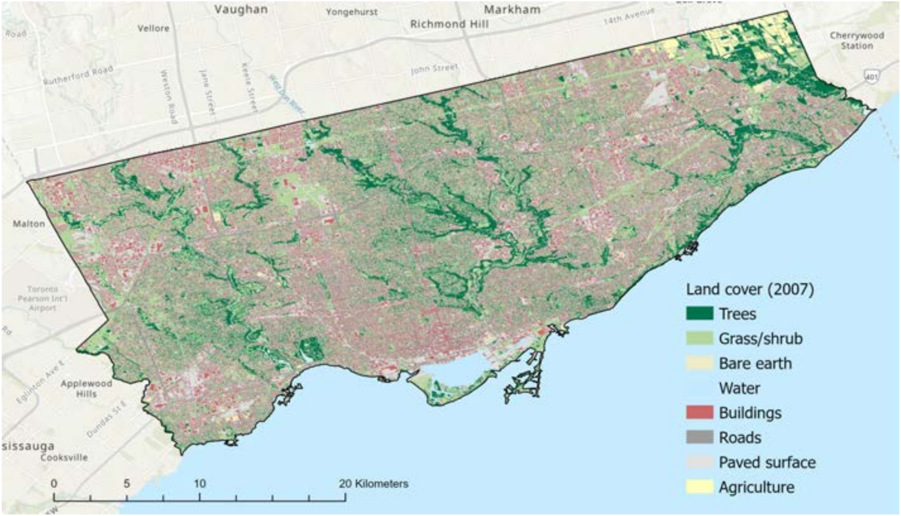
to relate changes in housing prices to changes in trees.

# 1. Housing prices in Toronto



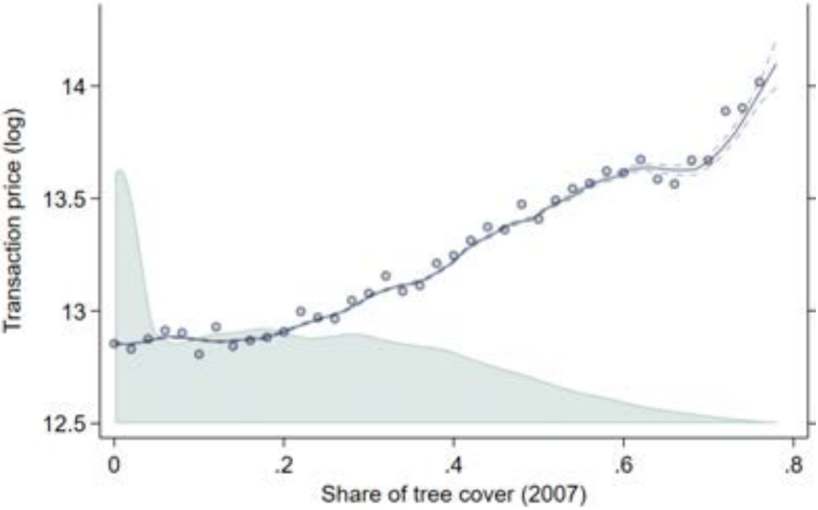

457,035 transactions, 2007–2018 (Han et al. 2024, Figure 6B)

# 2. Trees and neighborhood characteristics in Toronto




≈ 600,000 trees, 2007 (Han et al. 2024, Figure 6B)

# 3. Statistical relationship: home prices and trees




**Unconditional** empirical relationship between trees and prices (Figure 7(a))
**Green blob**: density of tree cover observations.

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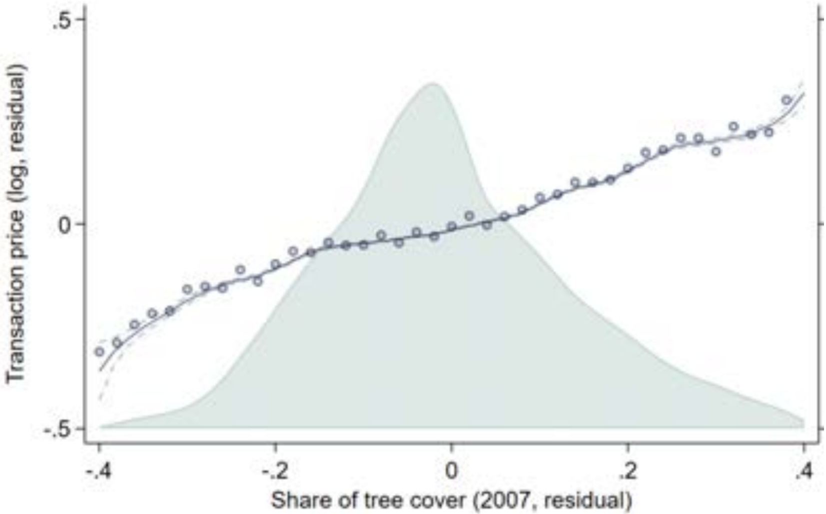
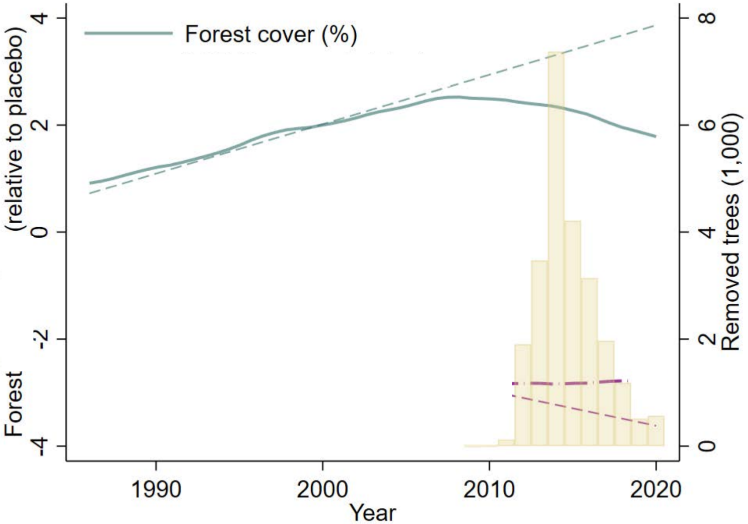



**With controls** for neighborhood, year, number of rooms. (Fig. 7(b))
**Green blob**: density of tree cover residuals.

# 4. An even better comparison: Ash tree removal project

**Figure 1**. Tree canopy, and the Emerald Ash Borer infestation in Toronto.



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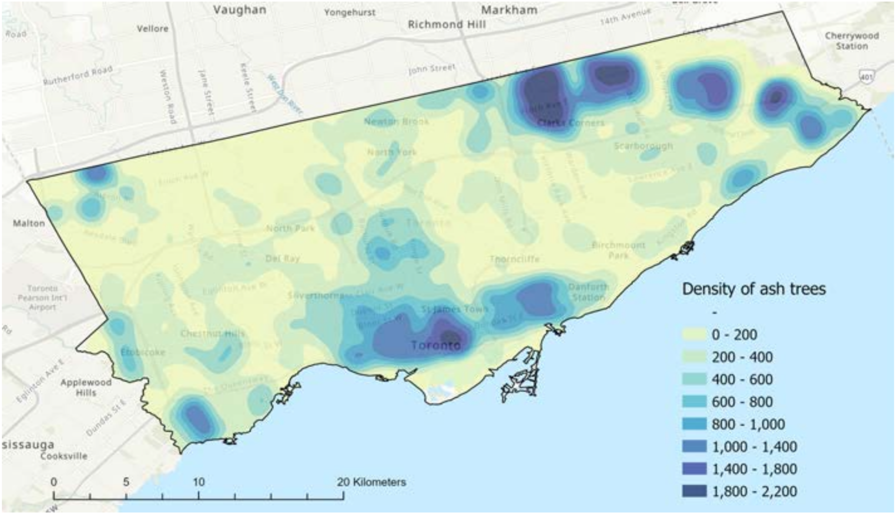


(b) City-managed ash trees

# 4. Pulling it all together

**Table 3**. The amenity value of trees—baseline specification.

| Transaction price (log) | (1) | (2) | (3) |
|---|---|---|---|
| Tree cover | -0.056 | 0.971 | 1.024 |
| | (0.014) | (0.259) | (0.242) |
| Transaction controls | No | No | Yes |
| Observations | 457,047 | 457,047 | 457,035 |

Column (1). **All trees** included in comparison.

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Column (1). **All trees** included in comparison.
Column (2)–(3). **Only ash trees** compared.

The latter comparison implies 1% increase in tree density leads to a 0.97–1.02% increase in property values.

$\hookrightarrow$ one tree $\approx 35\text{m}^2/8000\text{m}^2 \approx 0.45\%$ increase in property prices

- or about C$300/year (from C$2500/mo average rent)

# Housing prices and air pollution

Second, more ambitious application.

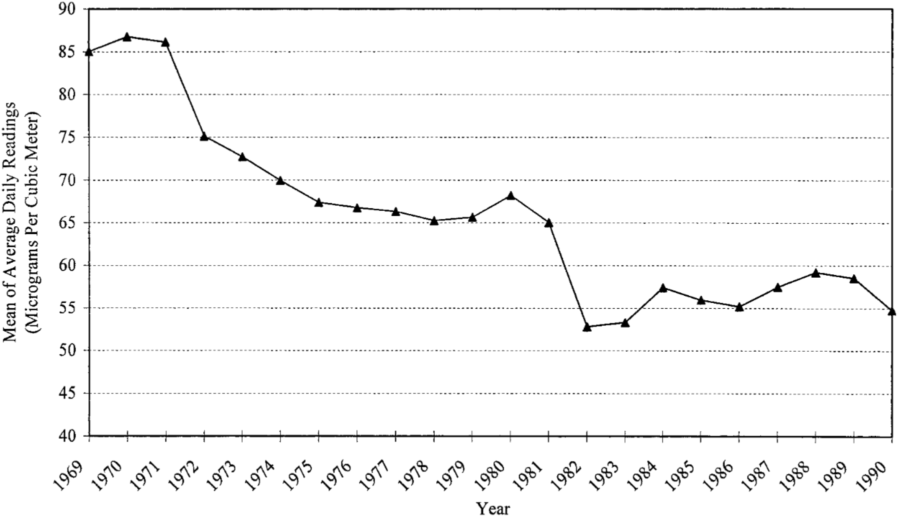
Chay and Greenstone (2005)

- infer value of cleaner air (fewer "total suspended particulates," or TSP) from housing values

Two challenges:

1. have to assemble a lot of data
    - track pollution, housing values across time and space
2. pollution is **not** randomly assigned
    - could be a third factor driving both pollution and housing values

# Total suspended particulates (TSP), 1969–1990



# Data on house prices and pollution

TABLE 1
SUMMARY STATISTICS, 1970 AND 1980

| | 1970 | 1980 |
|---|---|---|
| Mean housing value | 40,290 | 53,166 |
| Mean TSPs | 64.1 | 56.3 |
| Economic condition variables: | | |
| Income per capita (1982–84 dollars) | 7,122 | 8,186 |
| Total population | 161,889,646 | 177,192,574 |
| Unemployment rate | .046 | .068 |
| % employment in manufacturing | .249 | .226 |
| Demographic and socioeconomic variables: | | |
| Population density | 608 | 585 |
| % ≥ high school graduate | .504 | .646 |
| % ≥ college graduate | .097 | .147 |
| % urban | .576 | .593 |
| % poverty | .124 | .097 |

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# Estimating equation

Denote, for each county $c$,

- total suspended particulates by $t_c$
- other controls by $x_c$
- home values by $p_c$

A simple model could be

$$p_c = \theta t_c + \beta' x_c + \varepsilon_c,$$

where $\varepsilon_c$ is whatever explains the housing price that our data does not (the "unobservable").

We could estimate this model with ordinary least squares (OLS) if $t_c$ is uncorrelated with $\varepsilon_c$ (conditional on $x_c$).

# Leads to problems with a simple comparison

TABLE 3
CROSS-SECTIONAL AND FIRST-DIFFERENCE ESTIMATES OF THE EFFECT OF TSPS POLLUTION ON LOG HOUSING VALUES

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | A. 1970 Cross Section | | | |
| Mean TSPs (1/100) | .032 | −.062 | −.040 | −.024 |
| | (.038) | (.018) | (.017) | (.017) |
| $R^2$ | .00 | .79 | .84 | .85 |
| Sample size | 988 | 987 | 987 | 987 |
| | B. 1980 Cross Section | | | |
| Mean TSPs (1/100) | .093 | .096 | .076 | .027 |
| | (.066) | (.031) | (.030) | (.028) |
| $R^2$ | .00 | .82 | .89 | .89 |
| Sample size | 988 | 984 | 984 | 984 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |

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# Discussion

Despite data on almost 1,000 counties,

- correlation between pollution and property values is weak
- not robust to adding controls

Either:

1. individuals place a small (or negative!) value on air quality
    - e.g., if Pittsburgh lowered 1970 pollution by 50% (65$\mu$g/m$^2$, housing prices would increase by only 4% ($3200) under the most optimistic estimate!

   or

2. **substantial omitted variable bias**
    - i.e., some part of $\varepsilon_c$ is correlated with some part of $t_c$

# Pollution is not randomly assigned!

TABLE 2
DIFFERENCES IN SAMPLE MEANS BETWEEN GROUPS OF COUNTIES, DEFINED BY TSPs LEVELS, CHANGES, OR NONATTAINMENT

| | | | TSPs NONATTAINMENT | | |
|---|---|---|---|---|---|
| | CROSS SECTION 1970 (1) | FIRST DIFFERENCE 1980−1970 (2) | In 1970, 1971, or 1972 (3) | In 1975 or 1976 (4) | In 1975 Regression Discontinuity Sample (5) |
| Total counties (nonattainment) | 988 | 988 | 988 | 988 | 475 |
| | | | (380) | (280) | (123) |
| Housing value | 1,092 | −3,237** | −517 | 2,609** | 2,007 |
| | (918) | (713) | (726) | (806) | (1,193) |
| Mean TSPs | 39.2** | −30.9** | −19.6** | −10.0** | −12.3** |
| | (1.2) | (1.0) | (1.4) | (1.8) | (2.4) |
| Economic condition variables: | | | | | |
| Income per capita (1982–84 dollars) | 377.7** | −159.9** | −81.6* | 48.6 | 47.2 |
| | (94.7) | (40.7) | (41.2) | (46.4) | (65.1) |
| Total population (% change) | 142,016** | −.058** | −.046** | −.001 | .005 |
| | (24,279) | (.013) | (.013) | (.017) | (.028) |
| Unemployment rate (×100) | −.144 | .519** | .200 | .043 | .305 |
| | (.120) | (.129) | (.132) | (.152) | (.215) |
| % employment in manufacturing (×10) | .098 | −.119** | −.081** | −.005 | −.057 |
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# Housing prices and air pollution

Let's apply this method to data.

Chay and Greenstone (2005):

- study the relationship between air pollution ("total suspended particulates," or TSP, concentration) and housing values

Two challenges:

1. have to assemble a lot of data ✓
2. pollution is **not** randomly assigned
   - use variation in the introduction of the **Clean Air Act** over time and space
   - knowledge of the exact rule that determined that variation
   - lets them compare otherwise **very similar** counties

# Background on the U.S. Clean Air Act

- Landmark piece of federal environmental legislation, from 1970
  - major amendments in 1977 and 1990
  - (also, basis of federal obligation to act on climate change; see Massachusetts v. EPA 2007)
- Imposed air quality standards for five pollutants
- Law established that EPA would assign "attainment/nonattainment" status to each county annually.
- Nonattainment defined as exceeding the "maximum allowable concentration" (i.e., regulates **quantities**) $\hookrightarrow$

# Design of the Clean Air Act

TABLE A1
SELECTED NATIONAL AMBIENT AIR QUALITY STANDARDS

| | Maximum Allowable Concentration (Primary Standard) |
|---|---|
| Carbon monoxide: | |
| Maximum 8-hour concentration | 9 parts per million |
| Maximum 1-hour concentration | 35 parts per million |
| Nitrogen dioxide: | |
| Annual arithmetic mean | .053 parts per million |
| Ozone: | |
| Maximum 1-hour concentration | .12 parts per million (after 1979)<br>.08 parts per million (through 1979) |
| Sulfur dioxide: | |
| Annual arithmetic mean | .03 parts per million |
| Maximum 24-hour concentration | .14 parts per million |
| Total suspended particulates: | |
| Annual geometric mean | 75 micrograms per cubic meter |
| Maximum 24-hour concentration | 260 micrograms per cubic meter |

NOTE.—A county is in violation of one of the hourly based standards (i.e., one-hour, eight-hour, or 24-hour) if it exceeds the standard more than once in a year. In 1987 the EPA switched its focus from the regulation of all particulates (i.e., TSPs) to small particulates (i.e., PM10s). In 1997 the ozone standard was revised, and the particulates standard was further modified to regulate even smaller particulates (i.e., PM2.5s).

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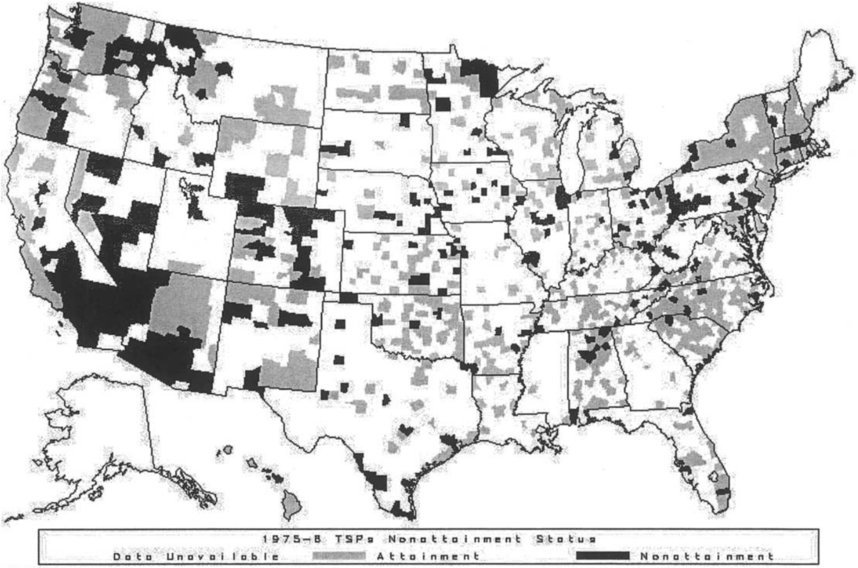
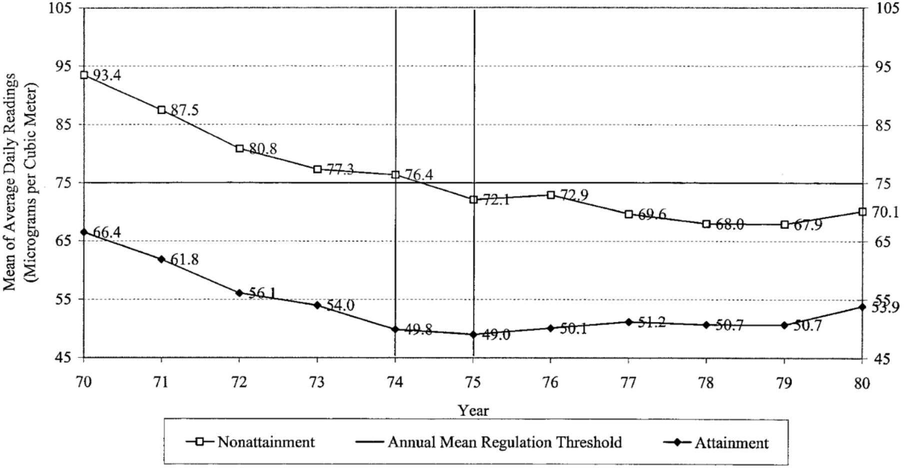
# Attainment status across space



# Nonattainment counties forced to lower pollution



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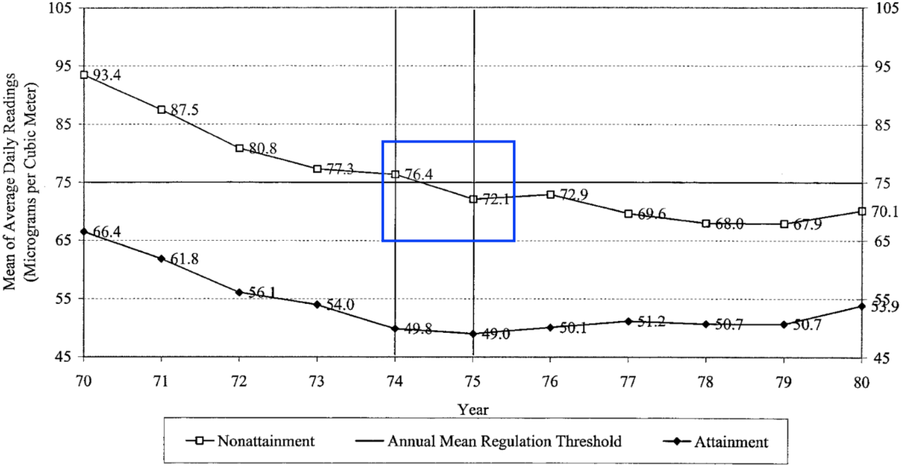

# Research design

**Idea**: compare counties with and without attainment status

Two statistical relationships:

1. legal status under the Clean Air Act $\mapsto$ air pollution
2. Clean Air Act $\mapsto$ housing prices

Then, combine to get the causal effect of air pollution on housing prices.

# Research design

Suppose that pollution is determined by

$$t_c = \alpha_1 z_c + \gamma_1' x_c + \nu_c \tag{1}$$

where

- $z_c$ is the source of quasi-experimental variation (attainment status)
- $x_c$ are the same controls as before
- $\nu_c$ is the unobserved component of pollution

Then we can estimate (1) and $p_c = \alpha_2 z_c + \gamma_2' x_c + \upsilon_c$ to obtain $\hat{\theta} = \frac{\alpha_2}{\alpha_1}$ !

Chay and Greenstone set $z_c = \mathbf{1}(t_{c,1975} > \bar{t})$.

**Different assumptions**: need the variation in attainment status to be relevant (i.e., $\alpha_1 \neq 0$) and random (i.e., $\varepsilon_c$ is uncorrelated with $z_c$, conditional on $x_c$).

# Nonattainment counties seem otherwise similar to attainment counties

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# A better comparison: the "experiment" of nonattainment

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| | (1) | (2) | (3) | (4) |
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| | A. Mean TSPs Changes | | | |
| TSPs nonattainment in 1975 or 1976 | −9.96 | −10.41 | −9.57 | −9.40 |
| | (1.78) | (1.90) | (1.94) | (2.02) |
| *F*-statistic TSPs nonattainment* | 31.3 | 29.9 | 24.4 | 21.5 |
| | (1) | (1) | (1) | (1) |
| $R^2$ | .04 | .10 | .19 | .20 |
| | B. Log Housing Changes | | | |
| TSPs nonattainment in 1975 or 1976 | .036 | .022 | .026 | .019 |
| | (.012) | (.009) | (.008) | (.008) |
| *F*-statistic TSPs nonattainment* | 8.5 | 6.2 | 9.3 | 6.4 |
| | (1) | (1) | (1) | (1) |
| $R^2$ | .01 | .56 | .66 | .73 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |
| Sample size | 988 | 983 | 983 | 983 |

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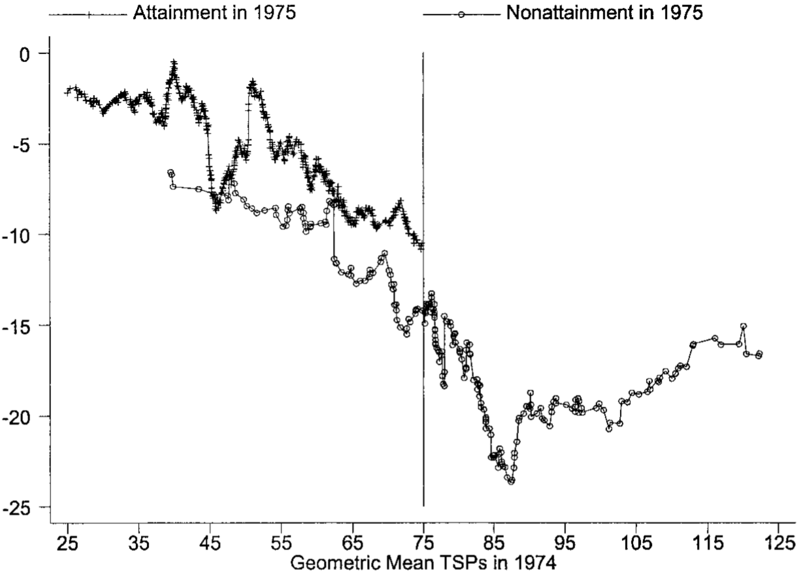
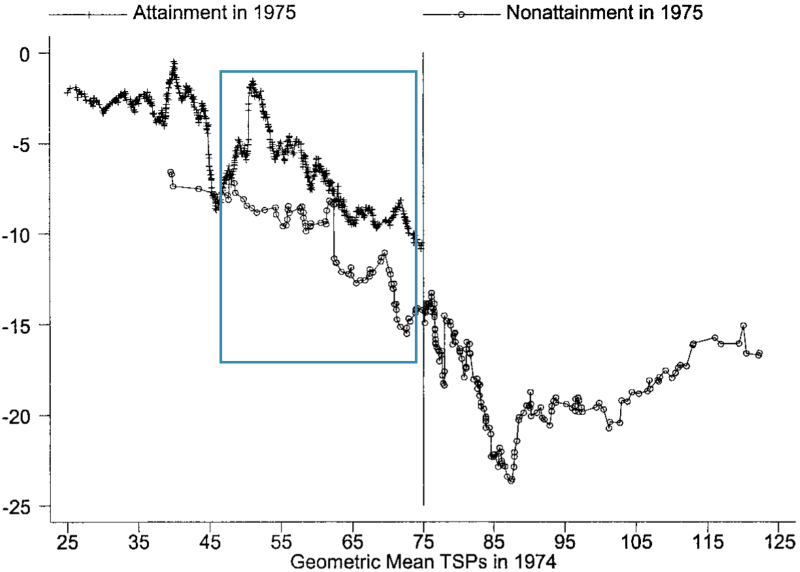
| | B. Log Housing Changes | | | |
| TSPs nonattainment in 1975 or 1976 | .036<br>(.012) | .022<br>(.009) | .026<br>(.008) | .019<br>(.008) |
| $F$-statistic TSPs nonattainment* | 8.5<br>(1) | 6.2<br>(1) | 9.3<br>(1) | 6.4<br>(1) |
| $R^2$ | .01 | .56 | .66 | .73 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |
| Sample size | 988 | 983 | 983 | 983 |

# County-level changes in pollution from 1970–80



# County-level changes in pollution from 1970–80

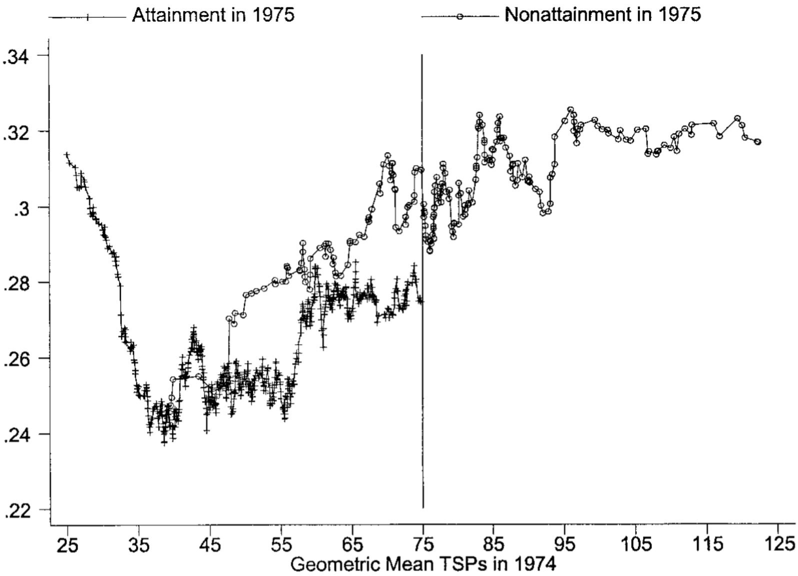


# A better comparison: the "experiment" of nonattainment

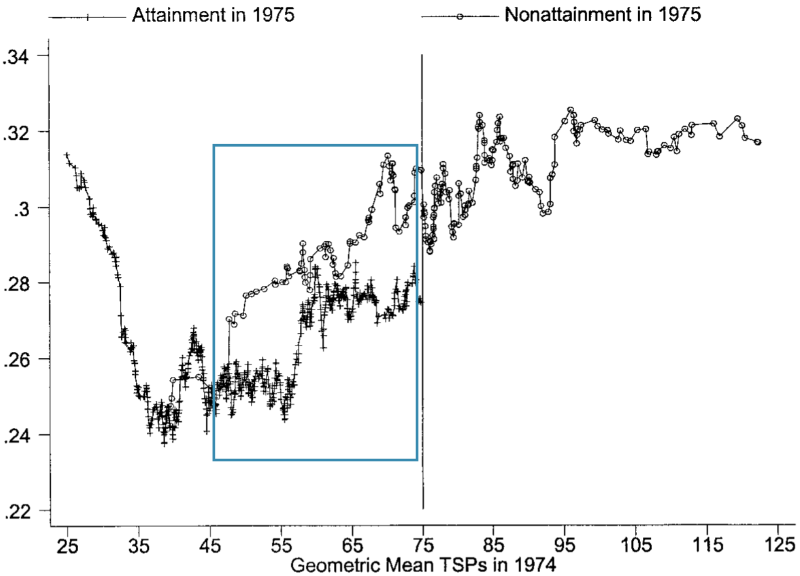
TABLE 4
ESTIMATES OF THE IMPACT OF MID-DECADE TSPS NONATTAINMENT ON 1970–80 CHANGES IN TSPS POLLUTION AND LOG HOUSING VALUES

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | A. Mean TSPs Changes | | | |
| TSPs nonattainment in 1975 or 1976 | −9.96 | −10.41 | −9.57 | −9.40 |
| | (1.78) | (1.90) | (1.94) | (2.02) |
| *F*-statistic TSPs nonattainment* | 31.3 | 29.9 | 24.4 | 21.5 |
| | (1) | (1) | (1) | (1) |
| $R^2$ | .04 | .10 | .19 | .20 |
| | B. Log Housing Changes | | | |
| TSPs nonattainment in 1975 or 1976 | .036 | .022 | .026 | .019 |
| | (.012) | (.009) | (.008) | (.008) |
| *F*-statistic TSPs nonattainment* | 8.5 | 6.2 | 9.3 | 6.4 |
| | (1) | (1) | (1) | (1) |
| $R^2$ | .01 | .56 | .66 | .73 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |
| Sample size | 988 | 983 | 983 | 983 |

# County-level changes in housing prices from 1970–80



# County-level changes in housing prices from 1970–80



# The "experiment" of nonattainment: Results

TABLE 5
INSTRUMENTAL VARIABLES ESTIMATES OF THE EFFECT OF 1970–80 CHANGES IN TSPS POLLUTION ON CHANGES IN LOG HOUSING VALUES

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | A. TSPs Nonattainment in 1975 or 1976 | | | |
| Mean TSPs (1/100) | −.362 | −.213 | −.266 | −.202 |
| | (.152) | (.096) | (.104) | (.090) |
| Sample size | 988 | 983 | 983 | 983 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |

# The "experiment" of nonattainment: Results

TABLE 5
INSTRUMENTAL VARIABLES ESTIMATES OF THE EFFECT OF 1970–80 CHANGES IN TSPS POLLUTION ON CHANGES IN LOG HOUSING VALUES

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| Sample size | 988 | 983 | 983 | 983 |
| County Data Book covariates | no | yes | yes | yes |
| Flexible form of county covariates | no | no | yes | yes |
| Region fixed effects | no | no | no | yes |

# Summing it all up

The estimates suggest

- a 1 $\mu$g/m$^3$ reduction in mean TSPs results in a 0.2–0.4 percent increase in property values

Supposing constant marginal willingness to pay, then

- 1975–76 nonattainment counties reduced TSPs by 10 units ($\mu$g/m$^3$)
- capitalized into property values at 0.28%/unit
- average value of house was \$152,075 (in 2024 dollars)
- 19 million houses
- $\implies$ willingness to pay for these reductions is about $\boxed{\$80 \text{ billion}}$

# Next time

We'll look at estimating some of the costs of environmental regulation.

Problem set 1 due next Monday before lecture.

Some optional readings posted on the website:

- Greenstone (2017), on hedonics
- Diamond and Hausman (1994), on survey methods