SRE Economics Lecture 4

From Green Buildings to Green Cities

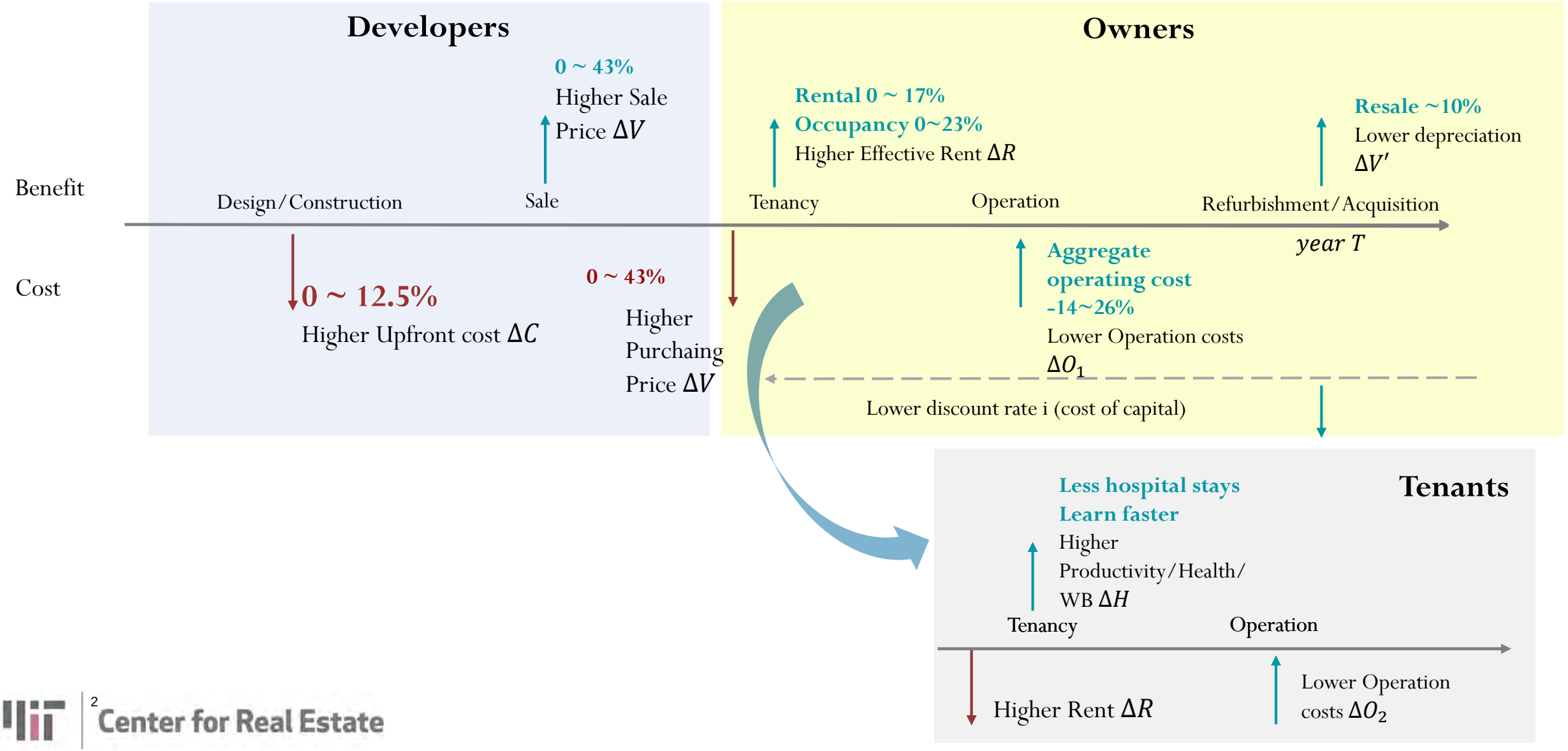
Pricing Environmental Features & Supporting Decision Making

Siqi Zheng

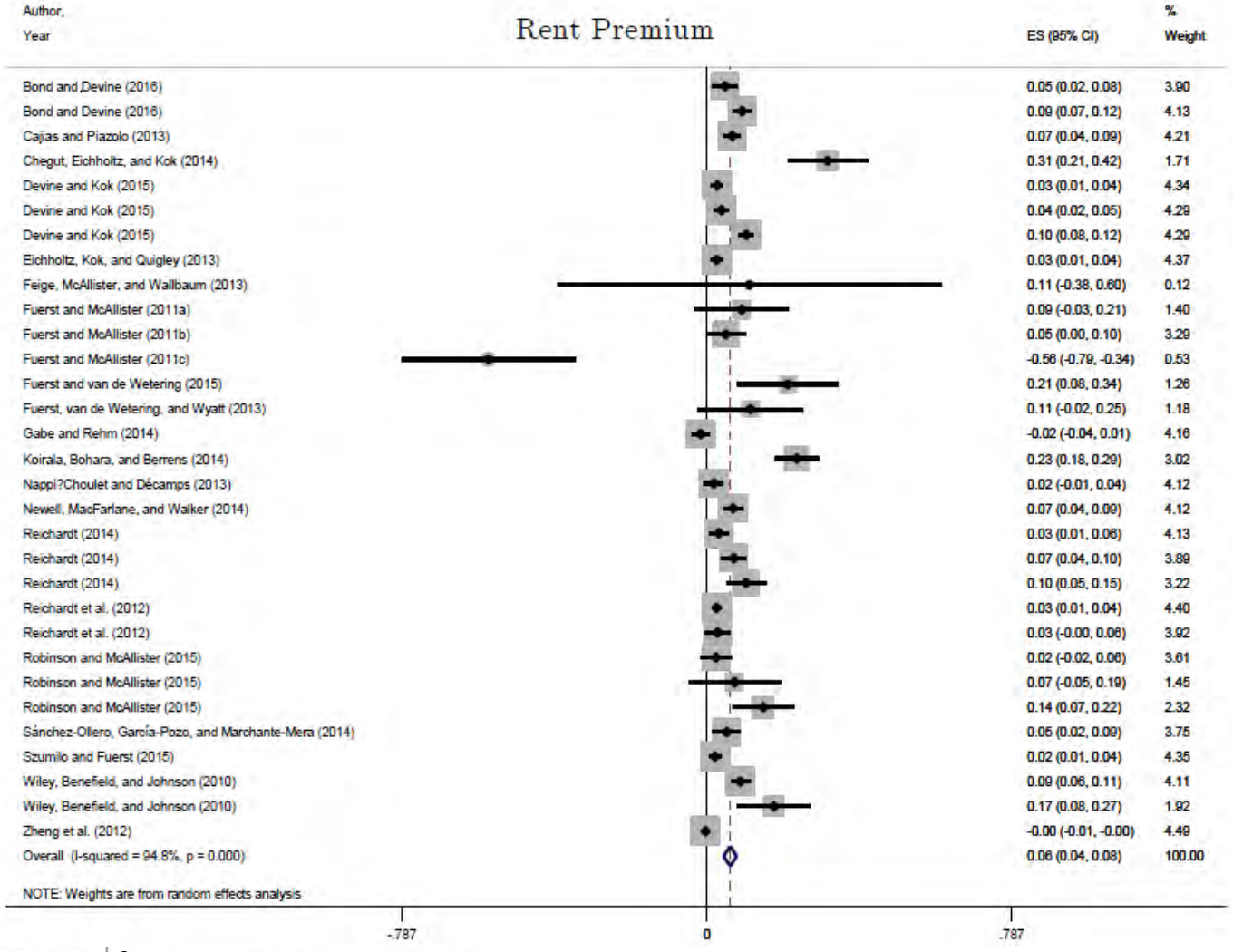
March 2023

(MIT Center for Real Estate)

Is There a Business Case for Green/Healthy Buildings?



Rental Premium of Green Building



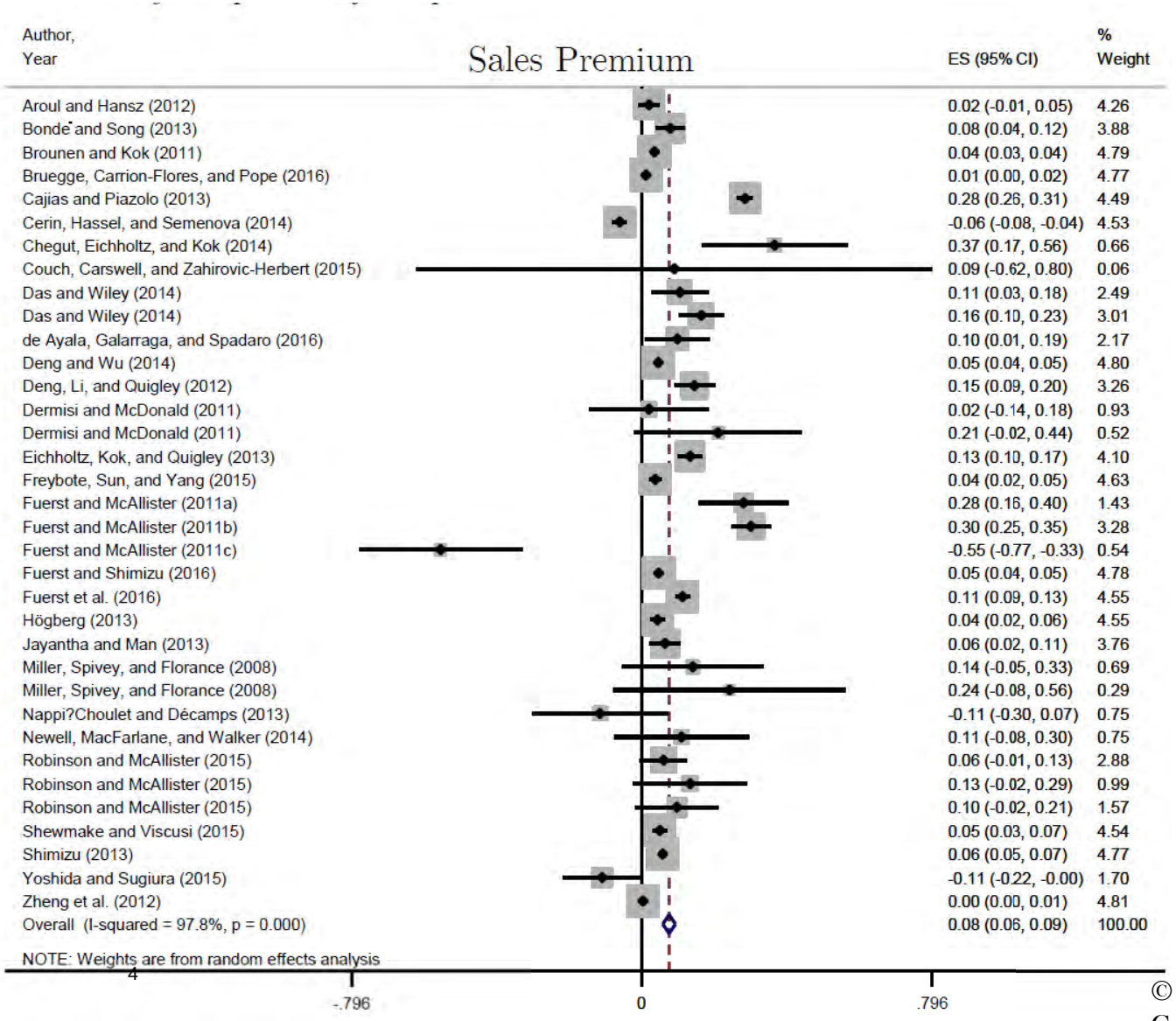
Dalton and Fuerst (2018): meta analysis of green real estate rents

Overall significant rent premium of 6%

- 5.4% commercial
- 8.2% residential

Studies also find 5% - 9% higher occupancy rates for commercial real estate.

Price Premiums of Green Building



Dalton and Fuerst (2018) also look at evidence sales prices

Overall price premium of 7.6%

- For commercial 11.5%
- For residential 5.5%

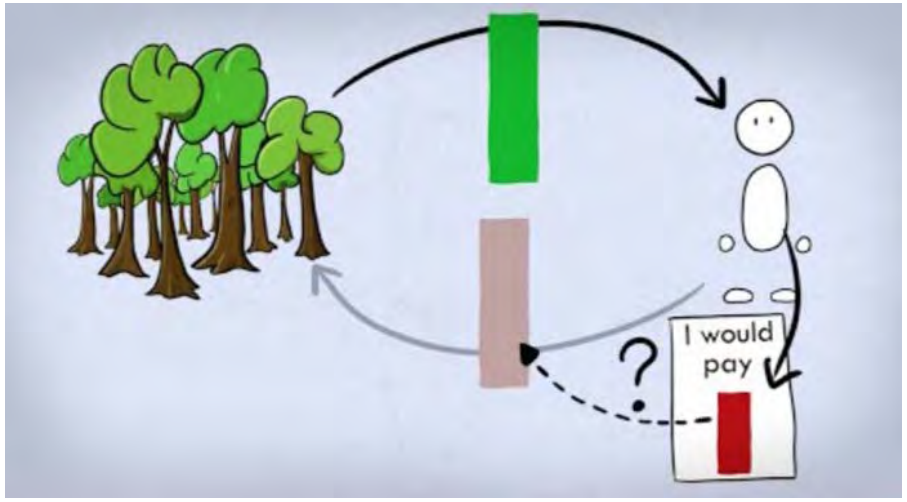
Outline

- Estimating **Green Building** Premium: Hedonic Pricing Techniques
- Pricing **Green Amenities in Cities**
  - Within-city
  - Across-city
- Decision Making: Business & Policy

Hedonic Pricing Technique

- Stated preference and revealed preference
  - **Stated preference:** using survey techniques to elicit willingness to pay for a marginal improvement or for avoiding a marginal loss.
  - **Revealed Preference:** linking with observed purchase behaviors with the attributes of a product.

- Hedonic pricing model is a **revealed preference** method of estimating demand or value of market and non-market attributes.



Stated preference:
https://www.youtube.com/watch?v=___xzmlG4L8s

Hedonic Model - "Decomposition"

- The price of a housing unit as the sum of the implicit values of its various "attributes".

P = 3 Rooms + 2 Subway Stops + LEED + A Nice Park + Residual

$1M = $0.6M + $0.1M + $0.1M + $0.1M + $0.1M

$1M = $0.2M × 3 + $0.05M × 2 + $0.1M × 1 + $0.1M × 1 + $0.1M

$$P = \alpha_1 \times X_1 + \alpha_2 \times X_2 + \alpha_3 \times X_3 + \alpha_4 \times X_4 + \varepsilon$$

Input

Output

(R^2= 83%)

Hedonic Model - "Decomposition"

$$\text{Log}(Price_{ijt}) = \boldsymbol{X_{1i}\beta_1} + \boldsymbol{X_{2j}\beta_2} + U_{ijt}$$

Quantity of an attribute

Implicit price of an attribute (%)

$Price_{ijt}$ is the house price per square meter of housing i in location j at time t;
$\boldsymbol{X_{1i}}$ represents the physical attributes of the house i;
$\boldsymbol{X_{2j}}$ represents location j's locational attributes.

Example

Log(Price) = 0.05 living rooms
(the number of living rooms)
+ 0.03 bathrooms
(the number of bathrooms)
+ 0.08 subway
(dummy: within 1-mile subway buffer)
+ 0.05 green park
(dummy: within 1-mile park buffer)
+ …

Estimate Green Building Premium

Example: Green label in office building (by Fuerst and McAllister 2009)

	Log(rent/sf)
Other variables	YES
LEED	0.06**
Energy Star	0.06***
Obs.	10,970

Ordinary Least Square (OLS)

$$Log(Price_{ijt}) = \boldsymbol{X_{1i}\beta_1} + \boldsymbol{X_{2j}\beta_2} + U_{ijt}$$

$$\boldsymbol{X'_{1i}\beta'_1} + \boldsymbol{\beta_g Green}$$

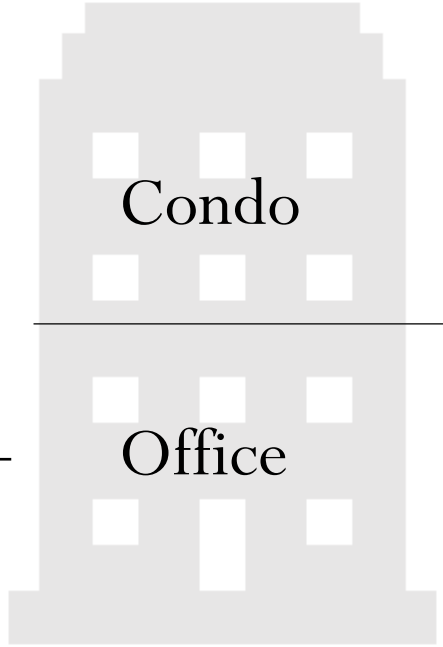
Green Premium

Dummy (green = 1, otherwise = 0)

Or categorical variables, such as LEED {Silver, Gold, Platinum}

Hedonic Model

Winthrop Center team can collect the data of nearby property transactions and estimate a hedonic model.



Sell ← Condo

LEED GOLD

Lease ← Office

Passive House
+ WELL
+ LEED Platinum

Challenges?

Log(Price) = 0.3 View
(view from the window)
+ 0.05 Green
(energy efficiency and other green attributes)
+ 0.1 Health
(air quality, indoor comfort, etc.)
+ …

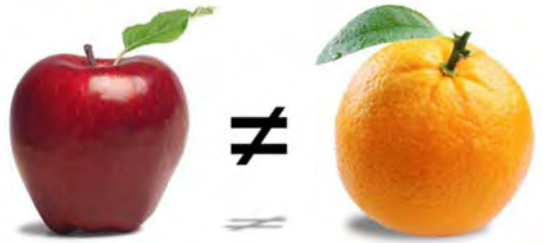
Log(Price) = 0.01 View
(view from the window)
+ 0.2 Green
(energy efficiency and other green attributes)
+ 0.15 Health
(air quality, indoor comfort, etc.)
+ …

How to make an "Apple-to-Apple" Comparison

TABLE 2.—COMPARISON OF GREEN-RATED BUILDINGS AND NEARBY CONTROL BUILDINGS IN 2009
PROPENSITY-SCORE WEIGHTED OBSERVATIONS (STANDARD DEVIATIONS IN PARENTHESES)

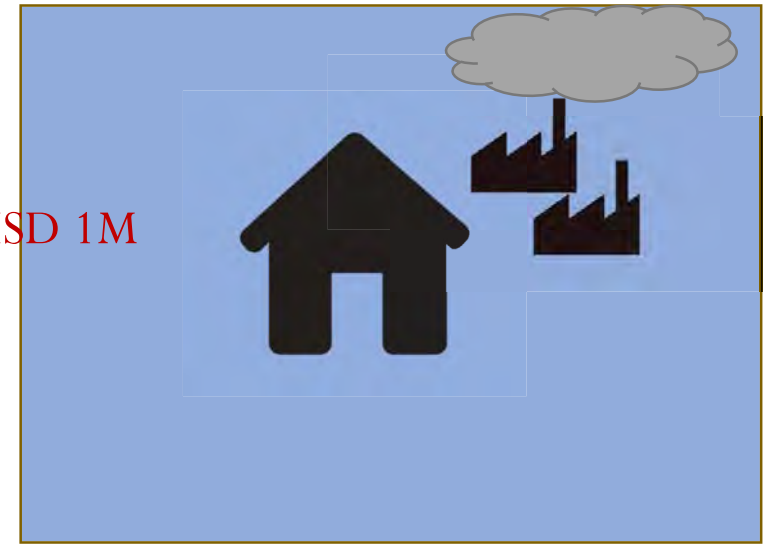
	Rental Sample			Sales Sample		
	Rated Buildings	Control Buildings	PSM Controls	Rated Buildings	Control Buildings	PSM Controls
Sample size	1,943	18,858	18,858	744	5,249	5,249
Contract rent (dollars/sq. ft.)	25.83	26.75	29.28			
	(9.67)	(12.48)	(12.12)			
Effective rent[a] (dollars/sq. ft.)	22.28	22.70	25.24			
	(9.61)	(12.39)	(10.89)			
Sales price (dollars/sq. ft.)				244.60	252.80	267.80
				(137.15)	(200.45)	(157.58)
Size (thousands sq. ft.)	299.83	155.65	282.88	326.39	139.92	311.86
	(292.40)	(245.73)	(176.74)	(336.85)	(275.21)	(270.99)
Occupancy rate (%)	85.80	83.45	85.32			
	(13.11)	(16.39)	(31.54)			
Building class (%)						
Class A (1 = yes)	75.75	26.9	71.94	75.66	21.50	69.53
	(42.87)	(44.34)	(37.53)	(42.95)	(41.09)	(44.23)
Class B (1 = yes)	23.21	52.73	26.90	23.47	51.16	29.24
	(42.23)	(49.93)	(12.57)	(42.41)	(49.99)	(15.16)
Class C (1 = yes)	1.04	20.37	1.16	0.87	27.34	1.23
	(10.15)	(40.27)	(1.31)	(9.32)	(44.58)	(1.01)
Age (years)	24.65	53.22	25.93	26.31	60.48	28.37
	(17.36)	(34.33)	(7.56)	(19.47)	(37.29)	(9.84)
Renovated building (%)	24.25	40.31	26.20	27.26	43.26	30.07
	(42.87)	(49.05)	(18.39)	(44.56)	(49.55)	(23.28)
Stories (number)	13.71	10.24	13.67	14.01	9.24	13.94
	(12.64)	(10.05)	(6.95)	(12.61)	(10.28)	(8.67)
On-site amenities (%)[b]	53.53	28.8	51.88	60.50	28.42	57.41
	(49.89)	(45.28)	(31.82)	(48.92)	(45.11)	(38.32)
Public transport (%)[c]	12.75	11.55	12.46	14.14	10.93	14.19
	(33.37)	(31.96)	(15.84)	(34.87)	(31.20)	(19.94)
Employment growth, 2006–2008 (%)	1.18	−0.07	−1.47	4.53	3.53	4.63
	(4.56)	(5.86)	(3.33)	(12.20)	(10.07)	(7.65)
Rental contract (%)						
Triple net (1 = yes)	22.11	14.74	22.94			
	(41.51)	(35.45)	(42.05)			
Modified gross (1 = yes)	1.31	7.94	2.58			
	(11.39)	(27.04)	(15.85)			
Plus all utilities (1 = yes)	8.81	9.51	9.86			
	(28.36)	(29.33)	(29.81)			
Gross (1 = yes)	69.07	75.76	67.20			
	(46.23)	(42.86)	(46.95)			

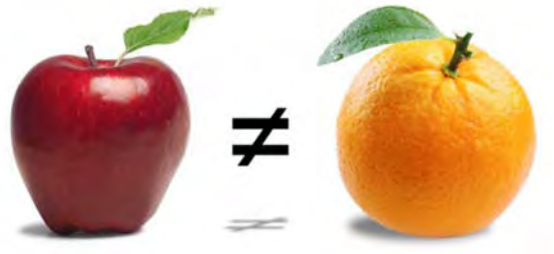
[a]Effective rent equals the contract rent multiplied by the occupancy rate.
[b]One or more of the following amenities are available on-site: banking, convenience store, dry cleaner, exercise facilities, food court, food service, mailroom, restaurant, retail shops, vending areas, fitness center.



Eichholtz, P., Kok, N., & Quigley, J. M. (2013). The Economics of Green Building. *The Review of Economics and Statistics, 95*(1), 50-63.

Price difference USD 1M

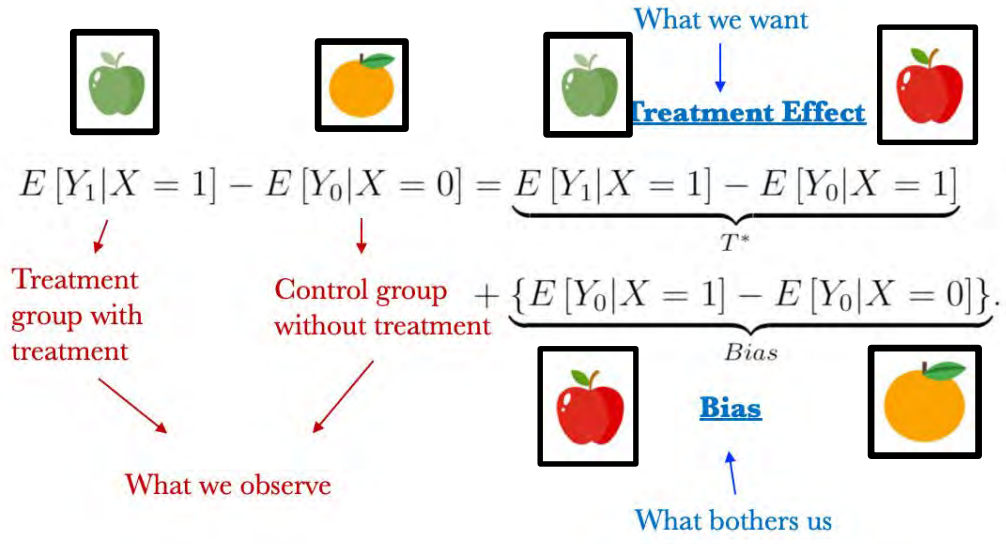


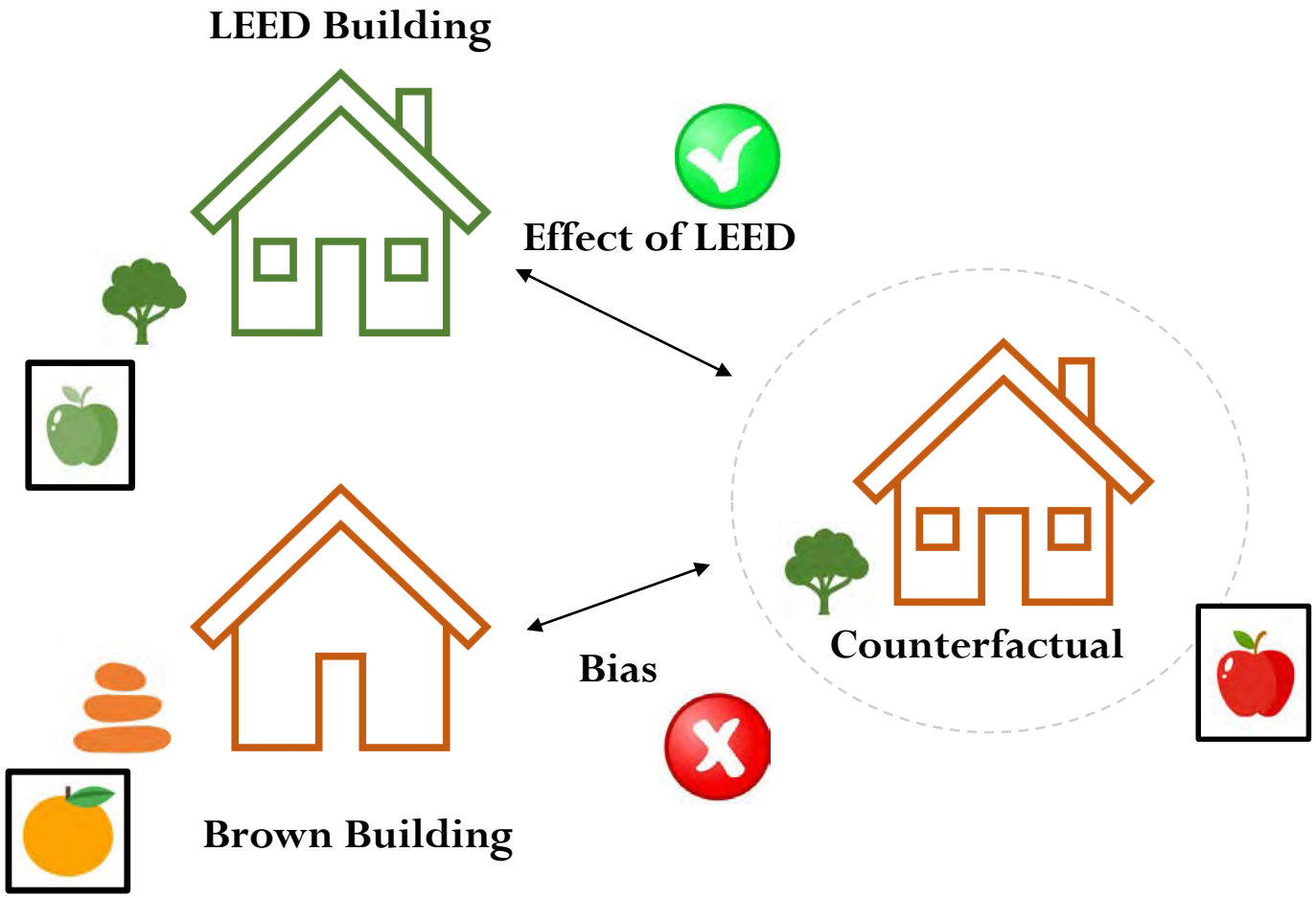


A Big Picture of Causal Inference

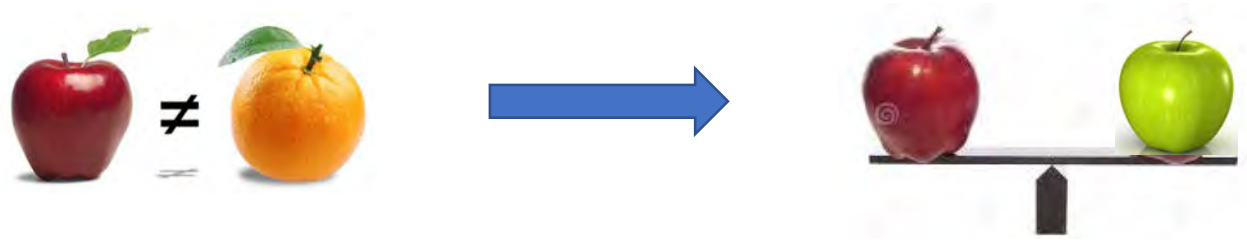
- Fundamental problem of causal inference:

  we cannot observe the "counter-factual"





Key Challenge to Causal Inference: Endogeneity



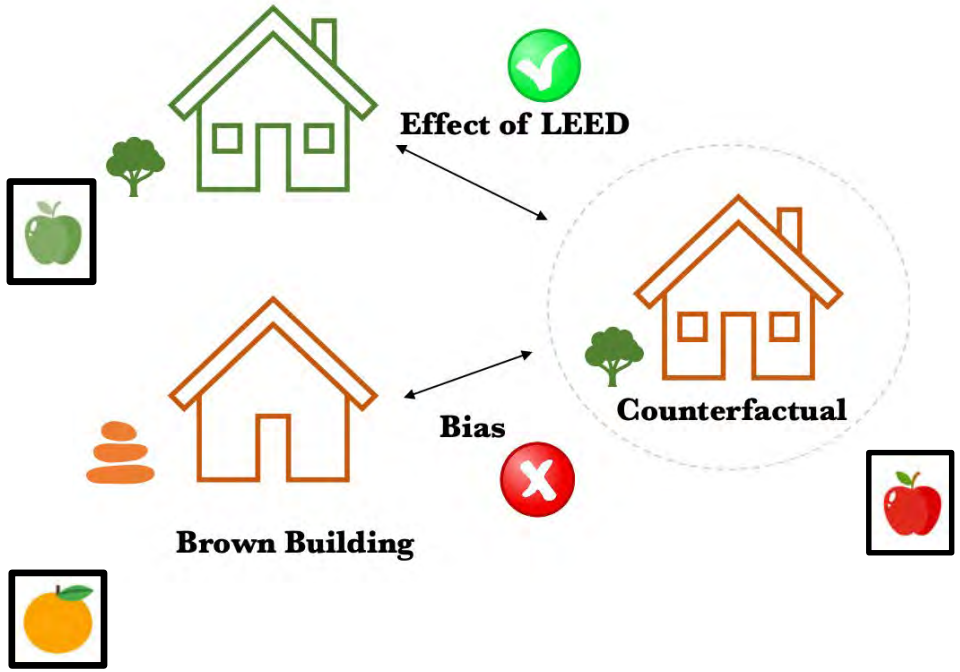
- In econometrics:

$$Y = \alpha + \beta_1 D + \beta_2 X + \varepsilon$$

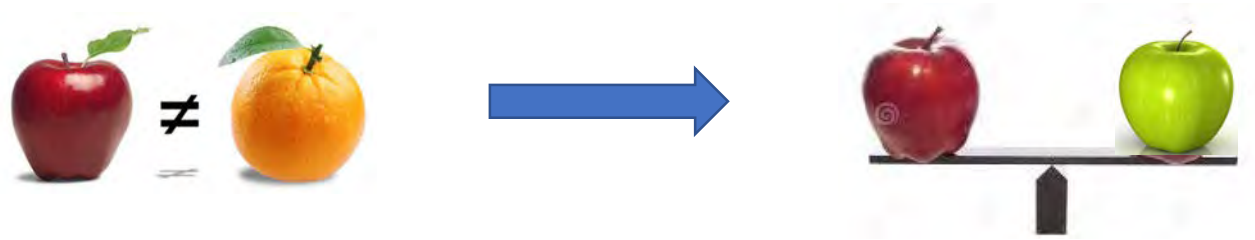
where $D = 1$ if treated; Otherwise $D = 0$.

Endogeneity $\rightarrow \mathrm{COV}(\varepsilon, D) = 0$ is violated.

- Three major types of endogeneity
  - I *Omitted variables* (correlated with D)
  - II *Reverse causality* (or called "simultaneity")
  - III *Selection bias*



Seeking Apple-to-Apple Comparison



- Experimental design
  - Field Exp. — Random controlled Trial (RCT)
  - Field Exp. / Natural Exp. — Quasi-experiment (*mimic randomization*)
    - **Matching**
    - Difference-in-Differences (DID)
    - Regression Discontinuity Design (RDD)
    - Instrumental Variable (IV)
- Non-experimental design
  - **OLS**
  - Fixed Effects Regression

More advanced methods seeking for exogeneous variation

RCT on Healthy-Building's Impacts

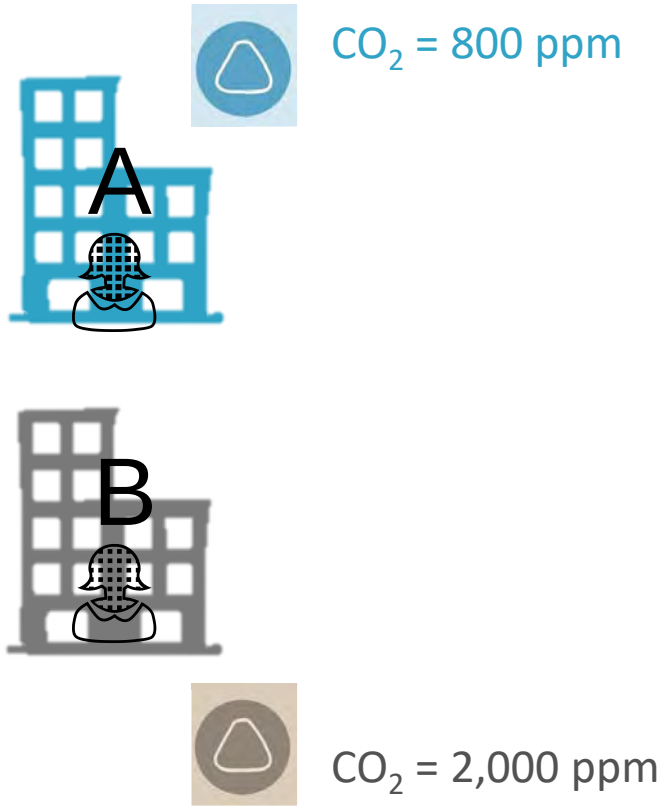
A

CO_2 = 800 ppm

B

CO_2 = 2,000 ppm

RCT on Healthy-Building's Impacts



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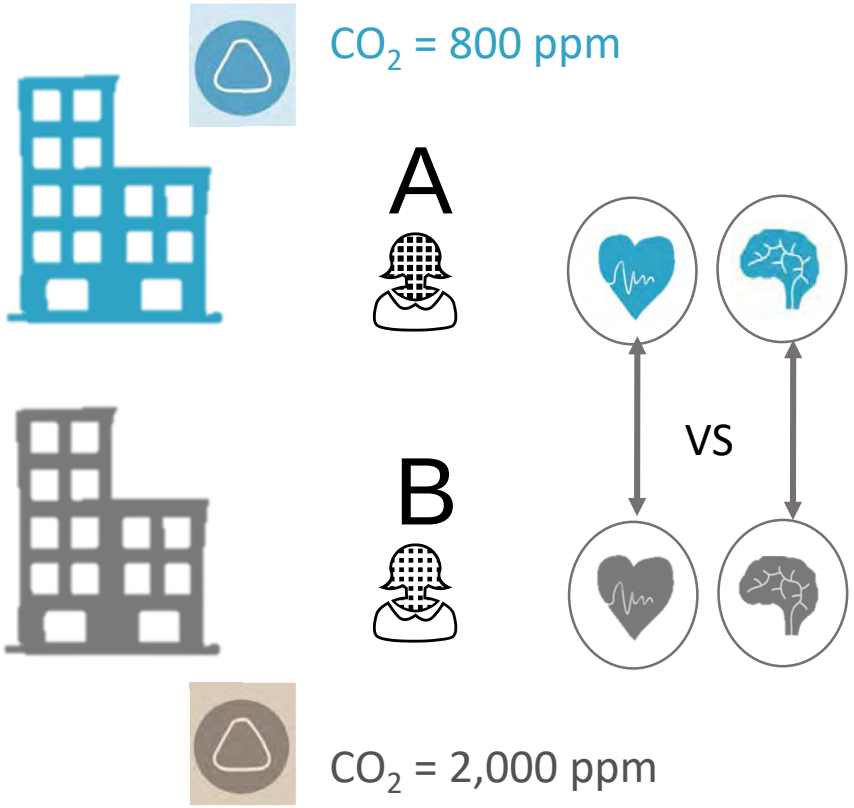
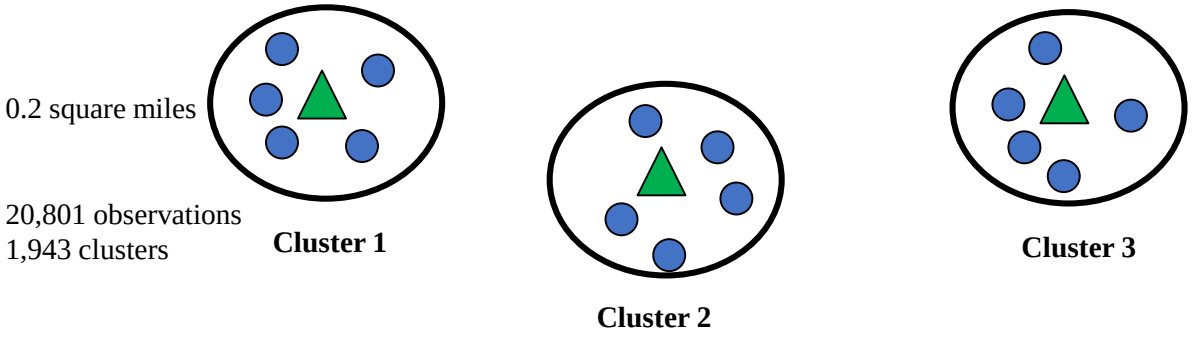


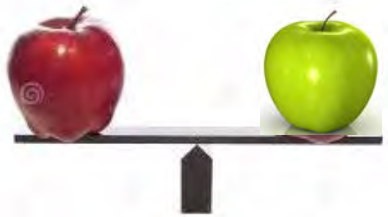
Matching: Seeking Apple-to-Apple Comparison

- Twins
- Geographic matching



- Propensity score matching (PSM)

How to make an "Apple-to-Apple" comparison?



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Class C (1 = yes)	1.04	20.37	1.16	0.87	27.34	1.23
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[a]Effective rent equals the contract rent multiplied by the occupancy rate.
[b]One or more of the following amenities are available on site: banking, convenience store, dry cleaner, exercise facilities, food court, food service, mailroom, restaurant, retail shops, vending areas, fitness center.

TABLE 3.—GREEN RATINGS, RENTS, AND SALES PRICES
PROPENSITY-SCORE WEIGHTED OBSERVATIONS, 2009 SAMPLE FRAME

	Rent (per square foot)		Effective Rent# (per square foot)		Sales Price (per square foot)	
	(1)	(2)	(3)	(4)	(5)	(6)
Green rating (1 = yes)	0.026***		0.076***		0.133***	
	[0.007]		[0.010]		[0.017]	
Green rating × gross (1 = yes)	−0.011		−0.037***			
	[0.008]		[0.012]			
Green rating × modified gross (1 = yes)	−0.024		0.016			
	[0.035]		[0.053]			
Green rating × plus utilities (1 = yes)	−0.001		−0.049**			
	[0.013]		[0.019]			
Energy Star (1 = yes)		0.021***		0.065***		0.129***
		[0.005]		[0.007]		[0.0191]
Label vintage (years)		−0.004**		−0.010***		−0.017*
		[0.002]		[0.002]		[0.011]
LEED (1 = yes)		0.058***		0.060***		0.111***
		[0.010]		[0.015]		[0.0419]
Building size (millions of square feet)	0.034***	0.034***	0.076***	0.076***	−0.049***	−0.049***
	[0.003]	[0.003]	[0.004]	[0.004]	[0.010]	[0.010]
Fraction occupied	−0.000	−0.000				
	[0.000]	[0.000]				

Consider the Bias in Hedonic Model

P = 3 Rooms + 2 Subway Stops + LEED + A Nice Park + Residual

$ 1M = $0.6M + $0.1M + $0.1M + $0.1M + $0.1M

$ 1M = $0.2M × 3 + $0.05M × 2 + $0.1M × 1 + $0.1M × 1 + $0.1M

$$P = \alpha_1 \times X_1 + \alpha_2 \times X_2 + \alpha_3 \times X_3 + \alpha_4 \times X_4 + \varepsilon$$

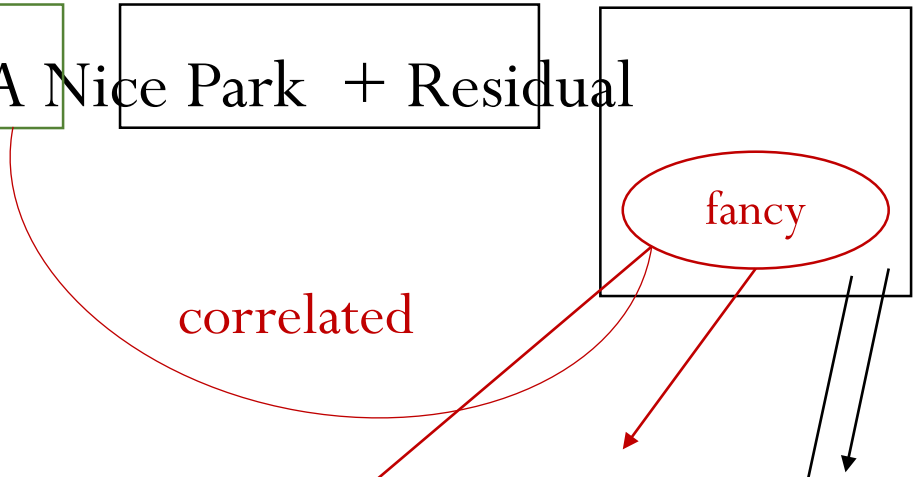
Input

Output

(R^2= 83%)

Consider the Bias in Hedonic Model

P = 3 Rooms + 2 Subway Stops + LEED + A Nice Park + Residual



If we can observe and measure "fancy":

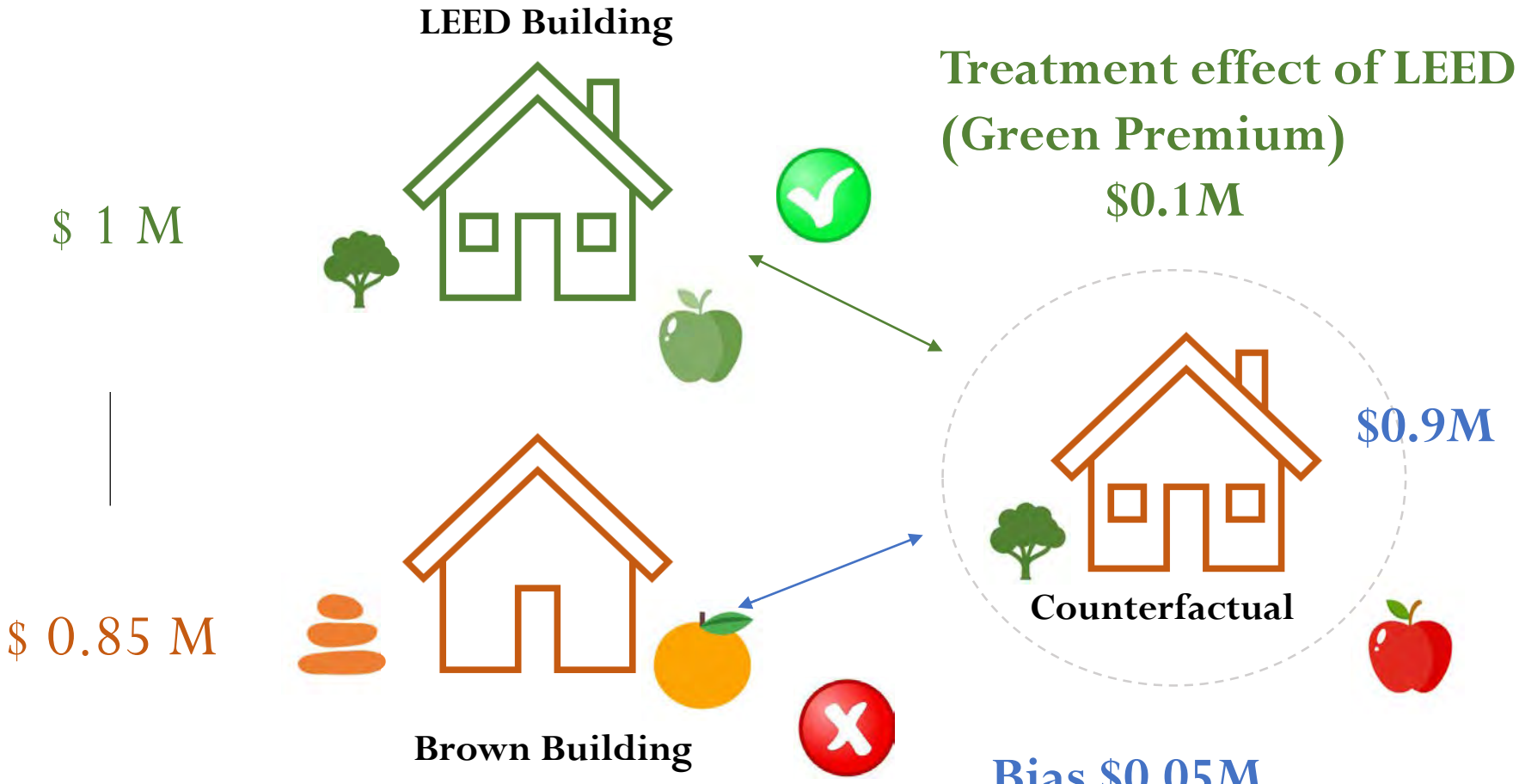
$ 1M = $0.6M + $0.1M + $0.1M + $0.1M + $0.05M + $0.05M

If we cannot observe and measure "fancy", and "LEED = fancy" (extreme case):

$ 1M = $0.6M + $0.1M + $0.1M + $0.05M + $0.1M + $0.05M

Overestimate → $0.15M

“Apple-to-Apple” Comparison



$ 0.15 M ← Green Premium?

Pricing Green Amenities: Within-City

- Again, Hedonic Model

$$Log(Price_{ijt}) = \boldsymbol{X_{1i}\beta_1} + \boldsymbol{X_{2j}\beta_2} + U_{ijt}$$

Example

Log(Price) = .08 school
(dummy: good school zone)
+ .05 subway
(dummy: within 1-mile subway station buffer)
+ .03 green park
(dummy: within 1-mile park buffer)
- 0.005 air pollution
(continuous: $\mu g/m^3$)
+ …

$\boldsymbol{X'_2\beta'_2}$ + $\boldsymbol{X_2^G\beta_2^G}$ → WTP for 1 extra unit of an amenity

Other locational attributes:
- School
- Transit
- Restaurants
- ……

Green Amenities:
- **Green Space**
- **Clean Air**
- **Walkability**
- **Health Facilities**
- **……**

Siqi's Research

- Zheng , S., & Kahn, M. E. (2008). Land and residential property markets in a booming economy: New evidence from Beijing. *Journal of Urban Economics*, 63(2), 743-757.
  - Research Question: To present new evidence on real estate price gradient (and land price gradient) with respect to various location attributes and local public goods in Beijing's nascent free housing market.
  - Data: Pooled cross-sectional housing transactions and land sales.

Dependent variable 1: housing prices

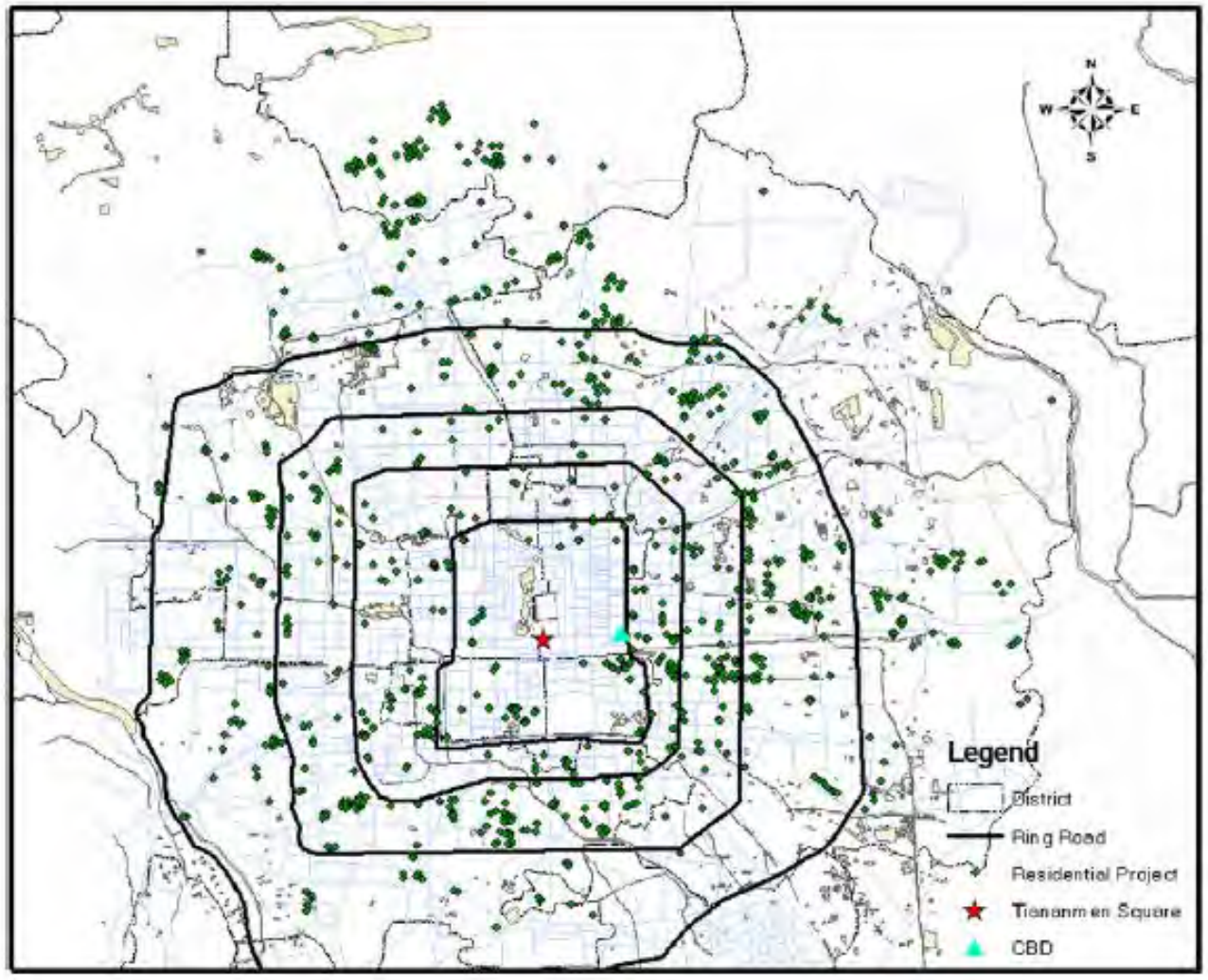


Fig. 1. The location of 920 new housing projects in Beijing.

Dependent variable 2: land prices

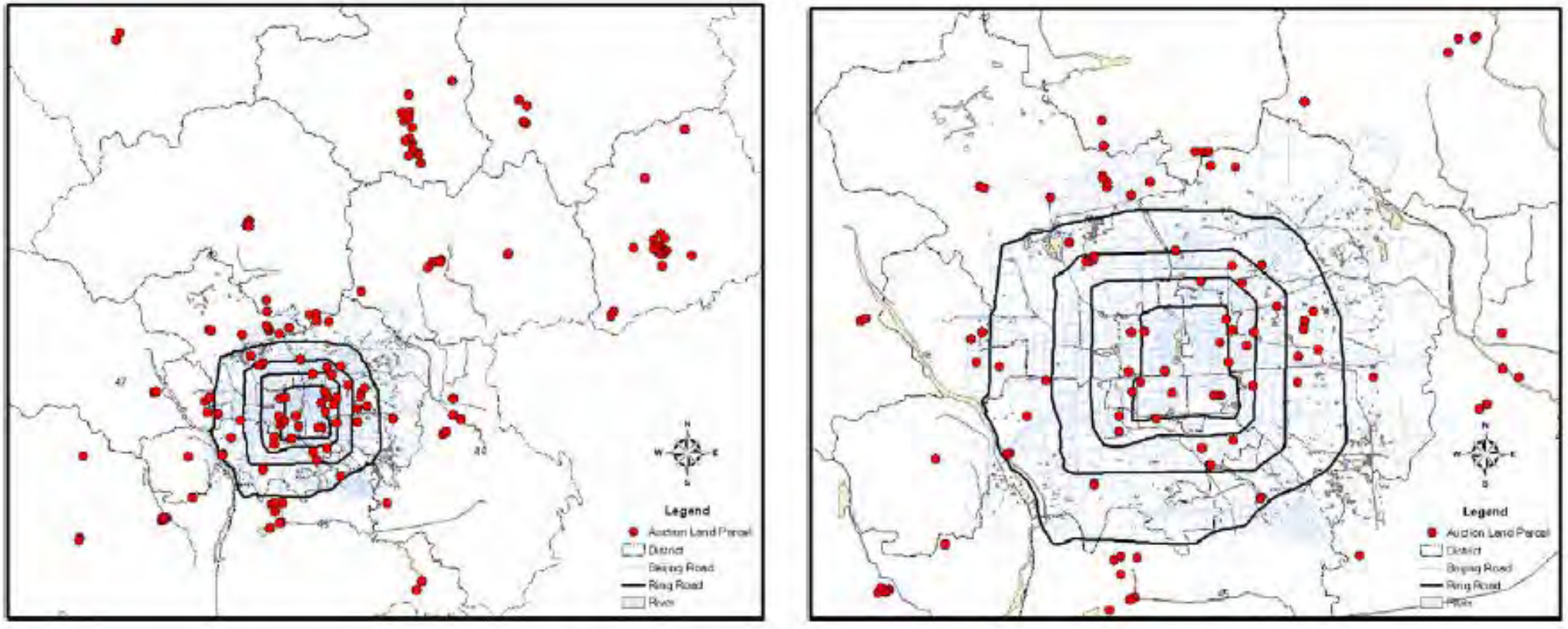


Fig. 2. Spatial distribution of land parcels in Beijing.

Local public goods: subway and bus stops

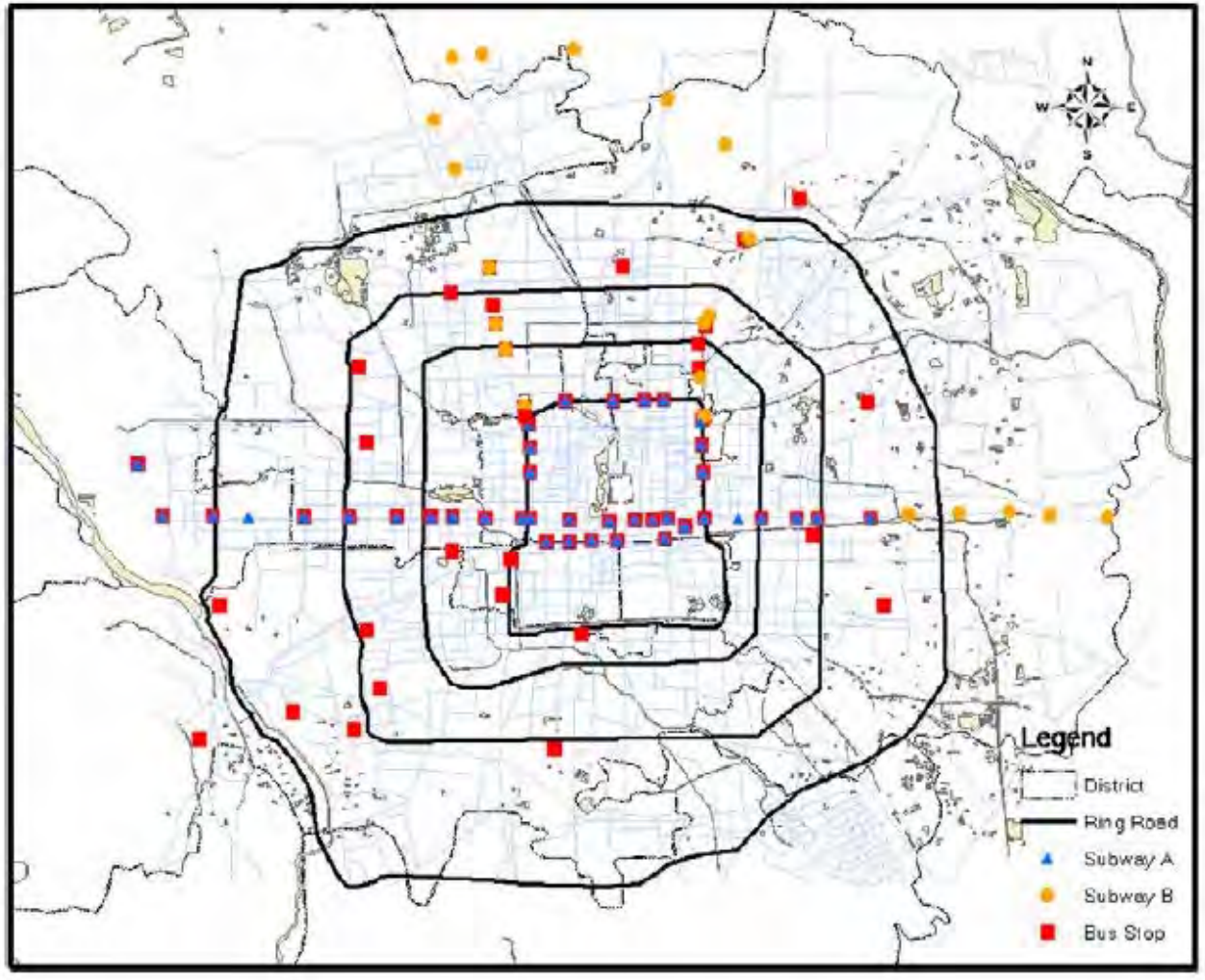


Fig. 3. Major transportation infrastructure in Beijing.

Local public goods: crime, school, university

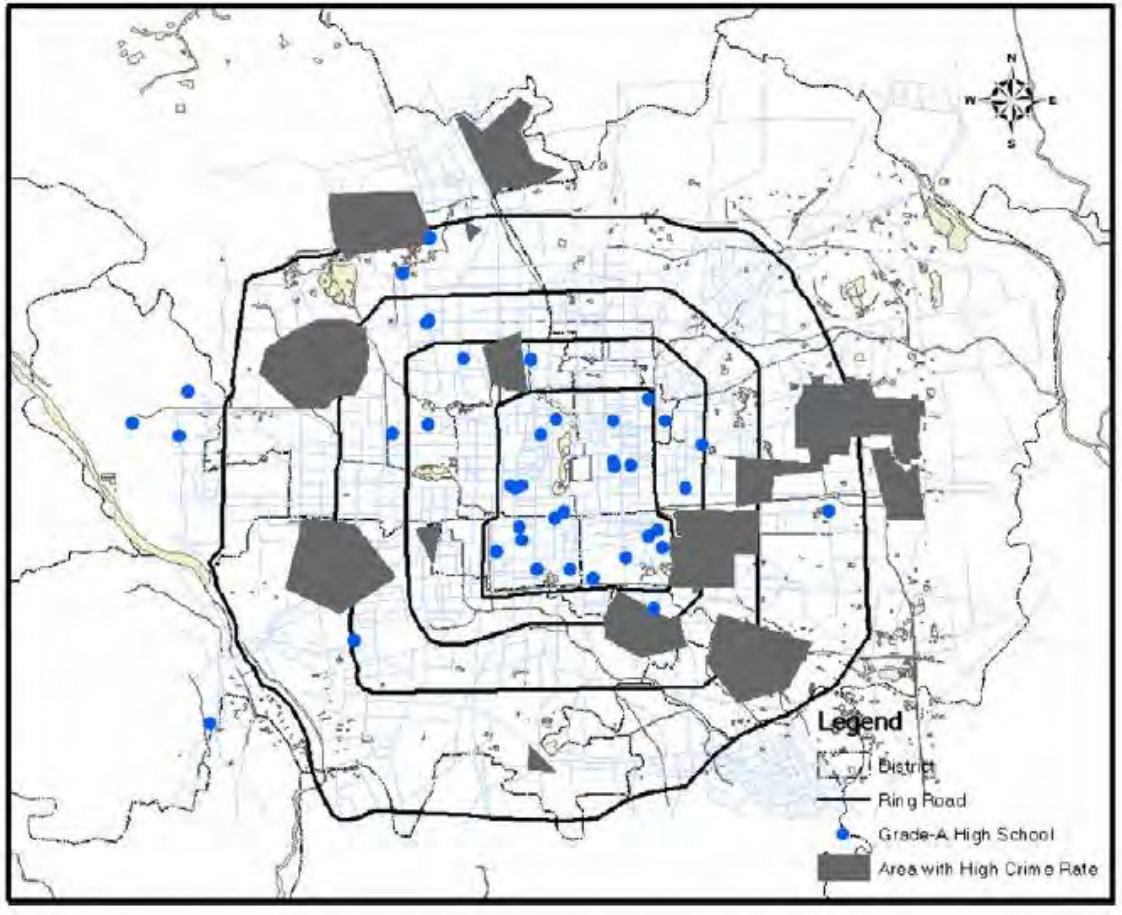


Fig. 4. Crime and school quality in Beijing.

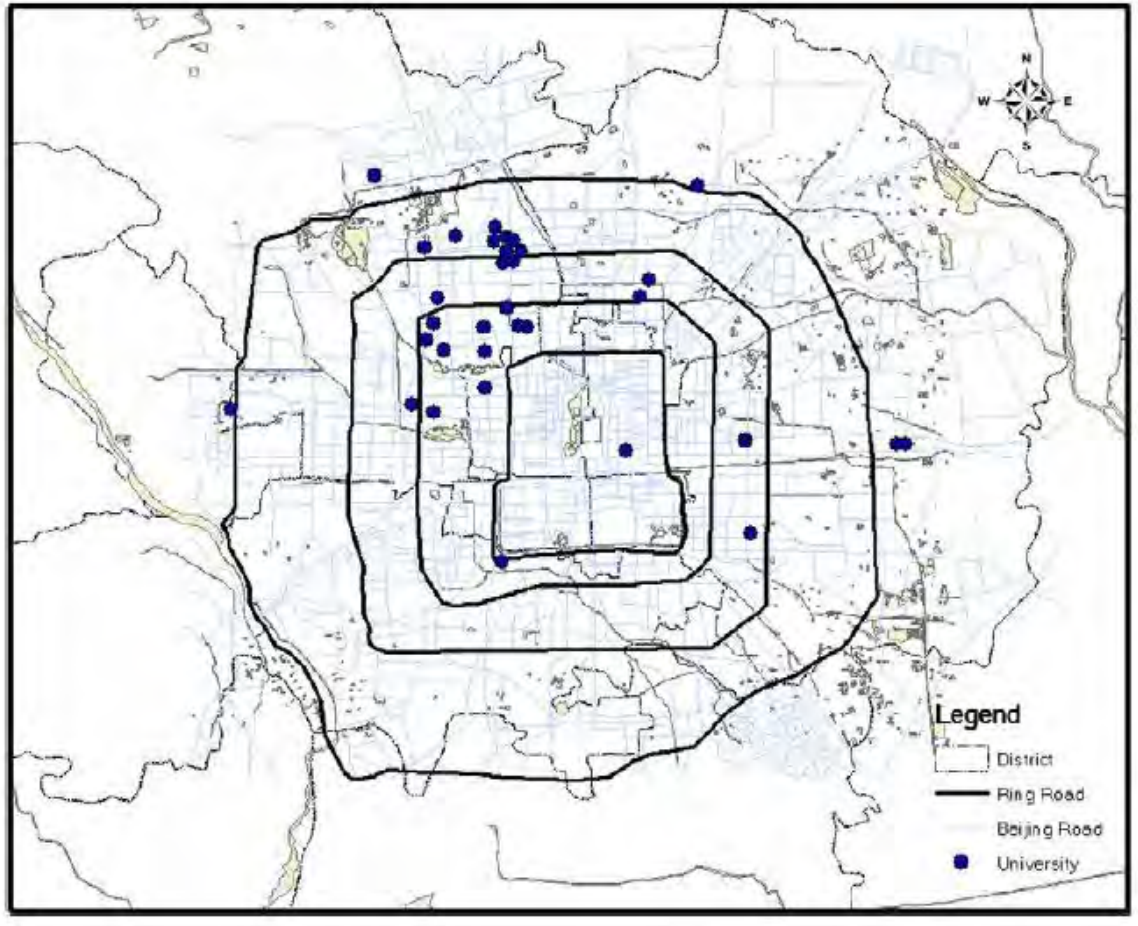


Fig. 6. Major universities in Beijing.

Local public goods: environmental amenities

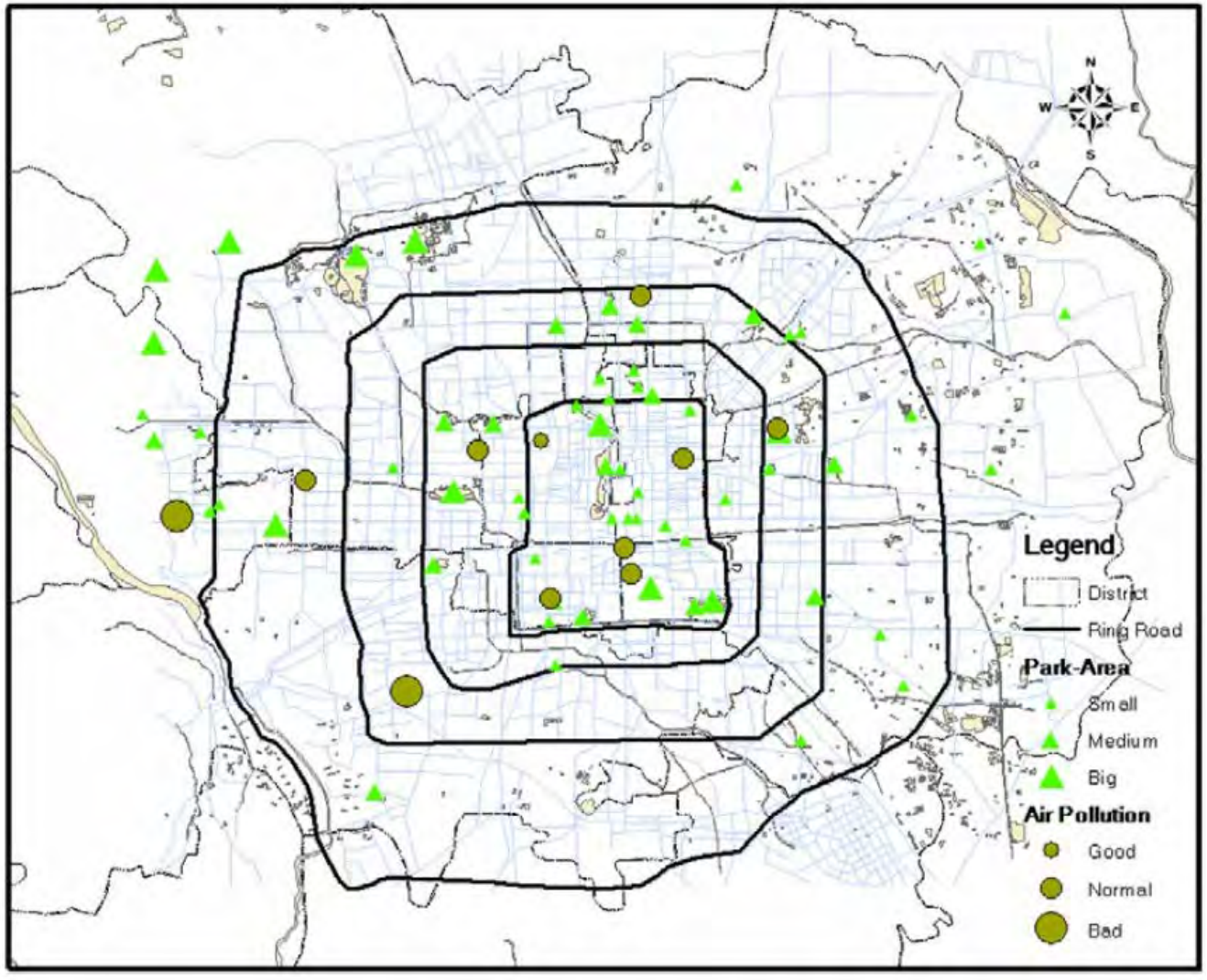


Fig. 5. Environmental amenities in Beijing.

Pricing Green Amenities: Within-City

$$\widehat{Log(Price_{jqt})} = B1 * X_{1j} + B2 * X_{2q} - 0.005 * Bad\ air - 0.057 * Park$$

$$(-5.85) \qquad (-2.06)$$

Table 5
Hedonic capitalization estimates of local public goods. Dependent variable: Log(P_PRICE)

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	8.491***	8.805***	9.843***	10.046***	10.252***	8.945***
	(110.15)	(127.39)	(19.95)	(30.13)	(43.60)	(19.12)
D_CENTER	−0.019***	−0.011***	−0.008***	−0.007***	−0.007***	−0.007***
(in kilometers)	(−7.67)	(−4.81)	(−4.01)	(−3.55)	(−3.82)	(−3.98)
UNIT_SIZE	0.003***	0.003***	0.002***	0.002***	0.002**	0.002**
(in square meters)	(4.46)	(4.78)	(3.74)	(2.67)	(2.65)	(2.52)
UNIT_SIZE^2	−2.09E − 6***	−1.24E−6***	2.53E−7	4.40E−7***	1.60E−7	8.93E−7
	(−1.03)	(−0.72)	(0.10)	(0.18)	(0.06)	(0.38)
PRO_SIZE	−0.164***	−0.132***	−0.131***	−0.110***	−0.115***	−0.100***
(in 000 units)	(−4.32)	(−4.07)	(−3.36)	(−3.64)	(−3.56)	(−3.63)
PRO_SIZE^2	0.025**	0.022**	0.022***	0.018***	0.020***	0.017***
	(2.15)	(2.27)	(4.40)	(4.16)	(4.76)	(3.75)
SOE	−0.091**	−0.077**	−0.100***	−0.098***	−0.100**	−0.087**
	(−3.64)	(−3.64)	(−3.46)	(−3.21)	(−2.87)	(−2.88)
Log(D_SUBA)		−0.161***	−0.113**	−0.089**	−0.082**	−0.108***
(in kilometers)		(−14.25)	(−3.25)	(−2.70)	(−2.54)	(−3.80)
Log(D_SUBB)		−0.038***	−0.014	−0.014	0.021	0.023
(in kilometers)		(−3.43)	(−0.90)	(−0.67)	(0.84)	(1.11)
Log(D_BUS)		−0.079***	−0.074**	−0.074*	−0.051*	−0.035
(in kilometers)		(−5.21)	(−2.43)	(−2.13)	(−1.94)	(−1.01)
Log(D_PARK)			−0.104***	−0.086**	−0.041	−0.057*
(in kilometers)			(−3.46)	(−2.51)	(−1.57)	(−2.06)
AIRBAD			−0.0041**	−0.0049***	−0.006***	−0.005***
(μg/m^3)			(−2.44)	(−4.40)	(−6.93)	(−5.85)
Log(D_SCHOOL)				−0.065**	−0.066**	−0.054**
(in kilometers)				(−2.56)	(−2.87)	(−2.45)
CRIME				−0.024	−0.055	−0.051
				(−0.64)	(−1.19)	(−1.55)
Log (D_UNIV)					−0.104***	
					(−3.68)	
UNIV_3KM						0.106***
						(3.60)
UNIV_SCORE						0.002***
						(3.28)
Quarter dummies	yes	yes	yes	yes	yes	yes
R^2	0.356	0.533	0.569	0.578	0.597	0.601
No. of obs.	900	900	900	900	900	900

This table reports six OLS estimates of Eq. (3) in the text. In columns (3), (4), (5), and (6), the standard errors are clustered by the eleven air quality monitors (see Fig. 5). See Table 1 for variable definitions.

- Environmental amenities are important set of local public goods.
- proximity to fast public transit, clean air, high-quality schools, major universities, and environmental amenities are capitalized into real estate prices.
- A 10 microgram per cubic meter increase in PM10 reduces home prices by 5%

Hedonic Method in Business Decision

- Bryant Park and W. R. Grace Building, 1980s – 2000s, NYC

This image is in the public domain.

1983

2019

Photos: https://livingnewdeal.org/projects/bryant-park-new-york-ny/
https://bryantpark.org/blog/life-of-bryant-bryant-parks-transformation-into-the-center-of-midtown

Hedonic Method in Business Decision

$$Log(\widehat{Price_i}) = Controls + \hat{\beta} X_i$$

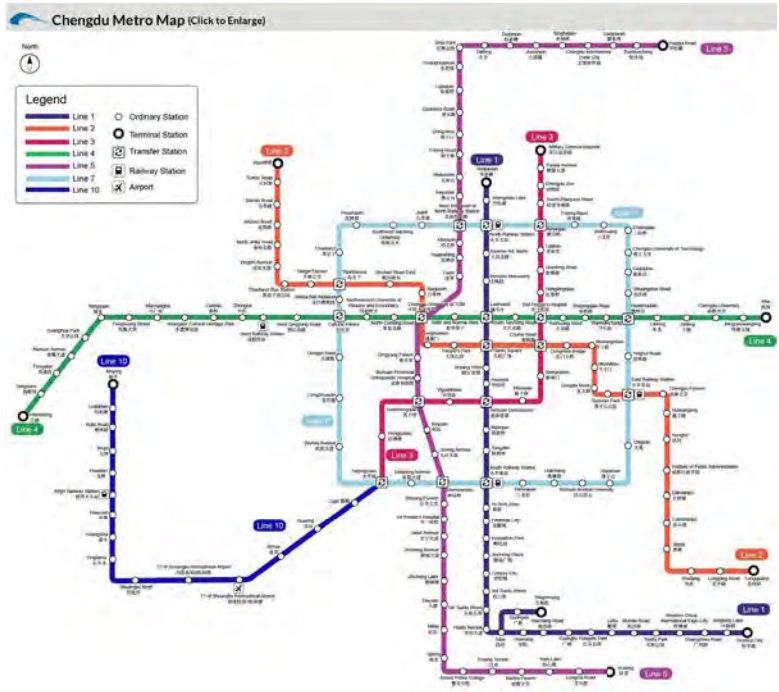
- Benefit and Cost Analysis
  - Cost of producing x additional units of amenity < Consumer's willingness to pay for x additional units amenity
  - E.g. Choosing quantity of green space in a community, Plan A (QA) vs. Plan B (QB)
    - ΔCOST (Q_{A-B}) (upfront cost + maintenance cost + opportunity cost) < $\hat{\beta}$ (Q_A - Q_B)*Housing Units
      - Note: If QA or QB are very different from what was observed in data, sorting of residents might dominant the WTP mechanism. For example, rich households would not consider a community with zero green space.

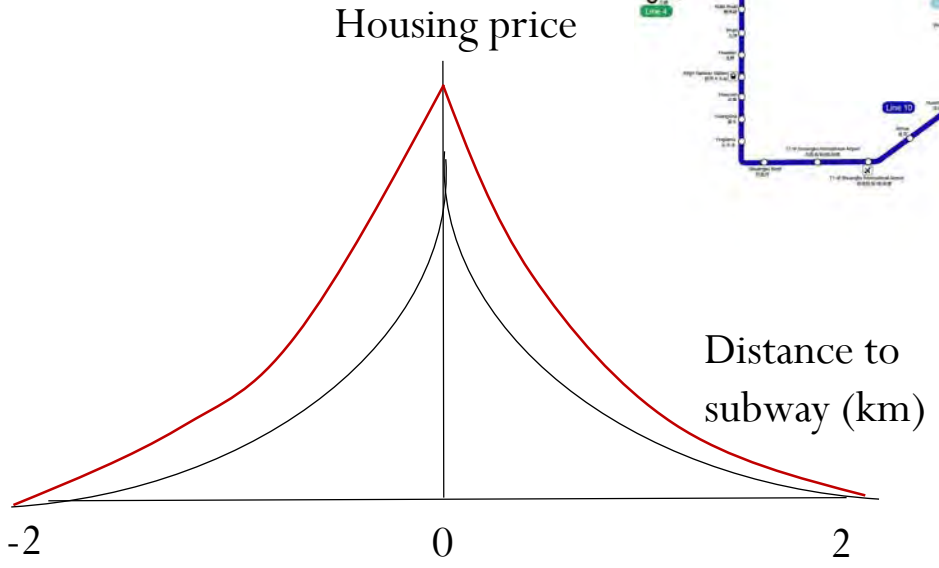
The 1st Subway Line in Chengdu, China

$$Log(\widehat{Price_i}) = Controls + \hat{\beta}\boldsymbol{X_i}$$

	Log(Housing Price)
Log(distance to subway)	-0.030 *** (-10.87)
Log(distance to subway) × Post	-0.165*** (-35.21)
Constant	8.598*** (879.63)
N	22,080
R2	0.731

Note: ***p<0.01, ** p<0.05, * p<0.1, t value in brackets.





Hedonic Method in Infrastructure Decision

Distance (km)	Price premium	Base value (RMB/m2)	House areas (hectare)	Total value (billion RMB)
0-0.5	14%	7304.29	553.21	5.7
0.5-1	7.4%	7304.29	583.17	3.2
1-1.5	7.5%	7304.29	392.29	2.1
Total				10.96

- The results indicate building the new subway line in Chengdu can generate **$11B RMB** benefit, measured by people's increased willingness to pay for the houses close to stations.

- Government can thus think about a tailored "value capture" mechanism to recover the infrastructure cost from nearby real estate developers.

Hedonic Method to Support Policy Making: Clean Air Act

50 years in, the Clean Air Act's societal benefits still outweigh costs 10 to 1, research finds

DECEMBER 13, 2020 | BY MORGAN FOY AND LAURA COUNTS

Read Caption >

Example

Log(Price) =

- 0.0028 air pollution

(continuous: mg/m^3)

+ Controls

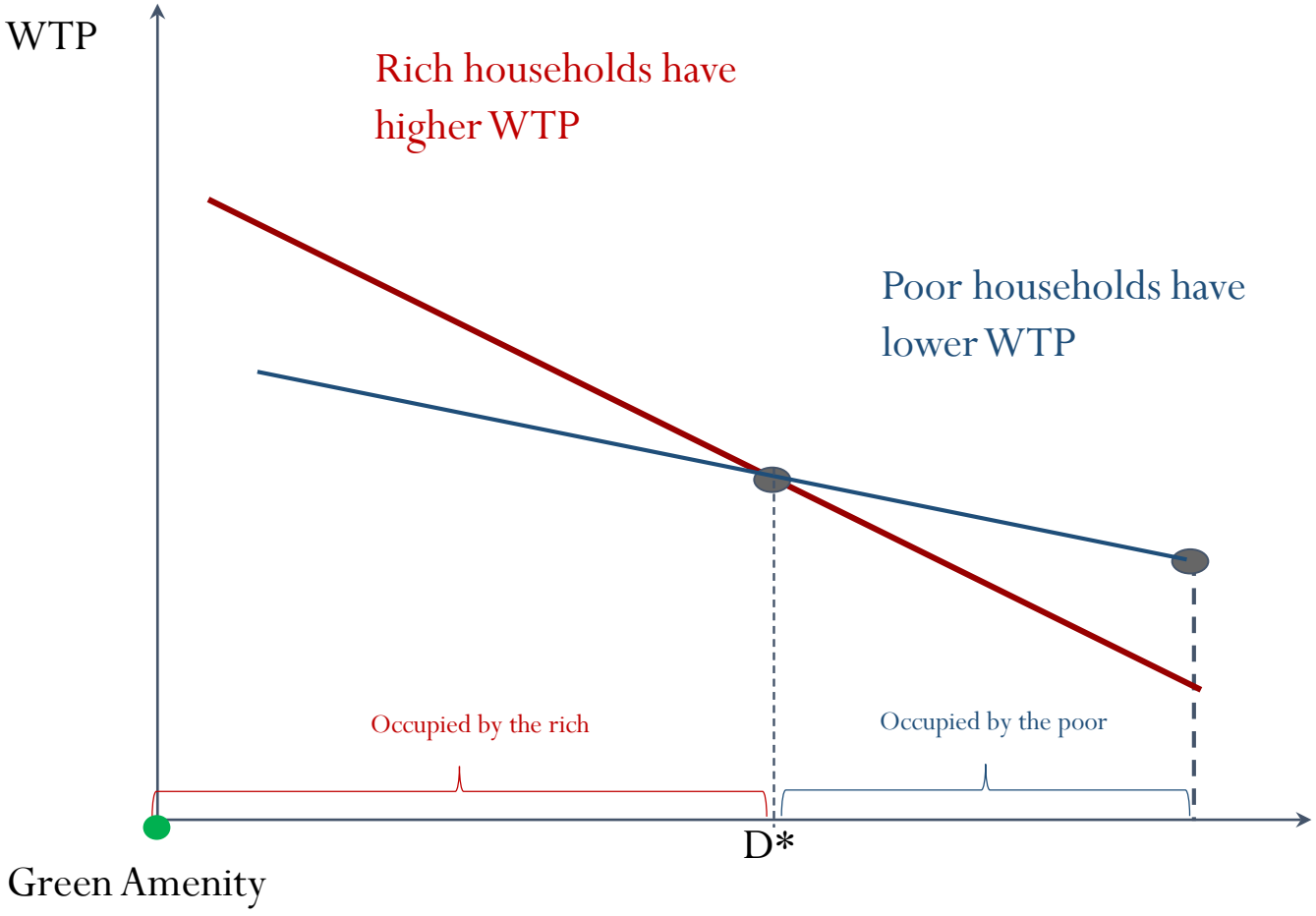
19 million homes in non-attainment counties,
Average home value = $86,900 (1970, in 2001 $)

10 units reduction in TSP -> $2,400 value increase per home

Total WTP = $45 billion

Larger tax base → higher property tax

Environmental Gentrification



The High Line Park
(West Chelsea, Manhattan)