

Is Air Pollution Regulation Too Lenient?

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Motivation

- **Optimal corrective taxation: marginal benefits = marginal costs**
 - ▶ Often hard to measure total costs and benefits, let alone marginal
 - ▶ Crime, innovation, smoking, ...
- **Air pollution: important externality**
 - ▶ 5% of premature US mortality from one air pollutant (Dominici et al. 2014)
 - ▶ Ambient levels have fallen dramatically
 - ▶ Increasing marginal costs of abatement: when exceed marginal benefits?

Figure: PM_{2.5}

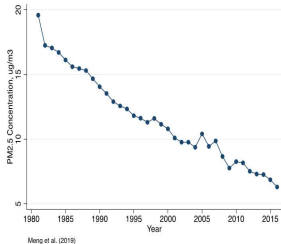
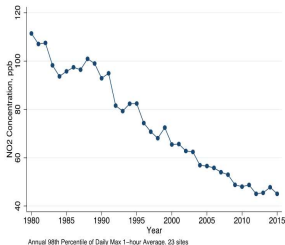


Figure: NO₂



Motivation

- **Air pollution regulation: too lenient?**

“EPA’s ozone standard is insufficiently stringent.” –Livermore and Revesz (2015)

“Existing benefit-cost studies suggest that total benefits for air pollution control have substantially exceeded the total costs in the United States, but this, of course, does not really address the question. It is still possible, and I think likely in view of the evidence, that for several of the criteria air pollutants (such as ground-level ozone), the standards have been pushed well beyond the point where the marginal benefits equal marginal cost.” –Oates (1997)

Our Approach: Background

- **1970 Clean Air Act forbids emission increases from polluted counties**
 - ▶ Entrants: offset pollution with decrease from an incumbent
 - ▶ Entrants pay incumbents, can be tens of millions of \$
 - ▶ Policy applies to “stationary” sources (not cars)
- **Pollution offset markets**
 - ▶ Decentralized, bilateral markets
 - ▶ Separate markets for each nonattainment area \times pollutant
 - ▶ Examples: particulate matter in SF Bay Area; nitrogen oxides in Houston
- **Offsets common**
 - ▶ Data on 16 states, 60 percent of offset market area GDP
 - ▶ More detail in California, Texas
 - ▶ Other offset markets: Australia, Brazil, Canada, EU, many enviro. goods

Our Approach: Intuition

- **Offset prices reflect marginal cost of abatement**
 - ▶ Entrants, incumbents: choose $MC_{\text{abatement}} = \text{offset price}$
 - ▶ Planner chooses $MB_{\text{abatement}} = \text{offset price}$
 - ▶ $MB_{\text{abatement}}$ represents health, other benefits of cleaner air

- **Simple test**
 - ▶ If offset prices $> MB_{\text{abatement}}$, regulation too stringent
 - ▶ If offset prices $< MB_{\text{abatement}}$, regulation too lenient

Results Preview

① Offsets common, have sensible patterns

- ▶ Hundreds of markets, cover 50-60 percent of US population
- ▶ Prices rising rapidly in real terms
- ▶ Prices related to other regulation proxies: abatement expenditures, emissions, polluting industry GDP, nonattainment severity

② Regulation in most markets too lenient, some too stringent

- ▶ NO_x : offset prices are $<$ one fifth of $\text{MB}_{\text{abatement}}$
- ▶ Houston VOCs: offset prices are double $\text{MB}_{\text{abatement}}$

What is New Here

- **Comprehensive analysis of air pollution offset markets**

- ▶ Mostly policy descriptions (Dudek, Palmisano 1988; Abbott and Brady 1990; Foster, Hahn 1995; Swift 2001; Fraas et al. 2017; Leonard 2018)

- **Method to measure marginal costs of pollution abatement**

- ▶ Engineering estimates: miss economic costs (USEPA 2006, 2007; Fowlie 2010)
- ▶ Cost functions: mostly sulfur-coal (Gollop, Roberts 1985; Carlson et al. 2000)
- ▶ Diff-in-diff: total costs (Greenstone 2002; Ryan 2012; Walker 2013)
- ▶ Cap and trade: few markets (Fowlie et al. 2012; Deschenes et al. 2017)

Clarifications

- **We study efficiency within context of U.S. air pollution offset markets**
 - ▶ Discuss external validity to other policies

- **Are estimates robust?**
 - ▶ >6,000 transactions, 9 to 25 years/market, five pollutants, 100 offset markets, seven largest metro areas, four air quality models, five discount rates, six health-pollution elasticities, three values of a statistical life

Overview

- **Design of Pollution Offset Markets**
- Data
- Describing offset markets
- Efficiency
- Extensions
- Conclusions

Offset Market History

- **1970 Clean Air Act**

- ▶ Neighboring counties violating standards: “nonattainment area”
- ▶ All plants need air quality permit
- ▶ Large entrants, retrofits must match cleanest plant in the world
 - ★ ‘May not consider costs’
- ▶ Pollutants: ozone (NO_x, VOCs), particulate matter, others

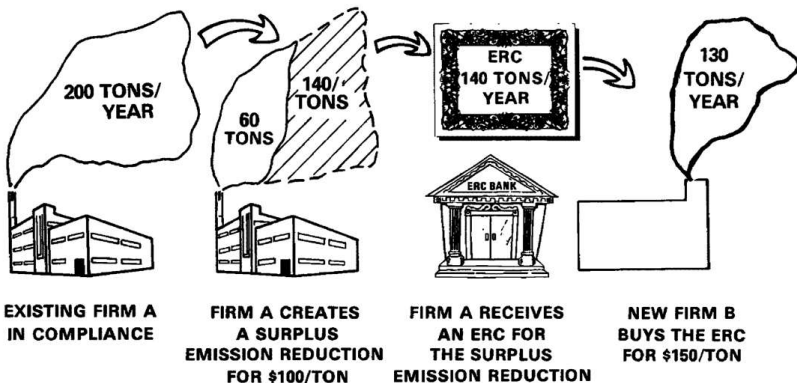
- **Nonattainment prohibits pollution increases**

- ▶ 1970-1975: no entry
- ▶ 1976: large plants can enter if an incumbent decreases
- ▶ 1977-1990: strict offset rules, limited trading

- **1990 Clean Air Act**

- ▶ Encouraged states and air districts to liberalize offset markets
- ▶ Offset banks
- ▶ Formal certification

AVAILABLE ERCs ATTRACT NEW FIRMS



Offset Market Design

The State of Texas

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Certificate Number:

2697



Number of Credits:

21.8 tpy VOC

Emission Reduction Credit Certificate

This certifies that
Scan-Pac Mfg., Inc.
31502 Sugar Bend Drive
Magnolia, Texas 77355

is the owner of 21.8 tons per year of volatile organic compound (VOC) emission reduction credits established under the laws of the State of Texas, transferable only on the books of the Texas Commission on Environmental Quality, by the holder hereof in person or by duly authorized Attorney, upon surrender of this certificate.

The owner of this certificate is entitled to utilize the emission credits evidenced herein for all purpose authorized by the laws and regulations of the State of Texas and is subject to all limitations prescribed by the laws and regulations of the State of Texas. This certificate may be used for credit in the following counties:

Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller

Effective Date of the Emission Reduction: May 15, 2013

Regulated Entity Number: RN100219989

County of Generation: Montgomery

Generator Certificate: Original

- Scan-Pac, a Houston manufacturing plant, built a thermal oxidizer
- Decreased VOC emissions by 21.8 tons per year, received this offset
- Sold this offset to Enterprise Products, an oil company, for \$3.6 million

Offset Market Design

- **Demand (entry, retrofit)**

- ▶ “Major” (large) plants in nonattainment
- ▶ Technically, “Emission Reduction Credits” (ERCs)

- **Supply (incumbents)**

- ▶ Surplus, federally enforceable, quantifiable, permanent

- **Market clearing**

- ▶ State or air district keeps list of offsets
- ▶ Write offsets into air quality permit

Offset Market Design

Appendix Table 5—Offset Versus Cap-and-Trade Markets

Issue	Offset Markets (1)	Cap-and-Trade Markets (2)
What is regulated	Abatement technology	Emissions
When is it regulated	When technology is installed	Year after emissions
What technologies are allowed	Surplus, federally enforceable, quantifiable, permanent	Any
Centralization	Decentralized, bilateral	Centralized
What happens to command-and-control standards	Persist	Removed
Market number, size	Many small markets	Few large markets

Offset Market Design

- **Abatement costs**
 - ▶ Fixed cap, growing region (example: Los Angeles)
- **Example: SpaceY**



Offset Market: Pollutants

- **Nitrogen oxides (NO_x)**

- ▶ From power plants, industrial sources, fossil fuel combustion
- ▶ Ground-level ozone pollution
- ▶ Abatement: selective catalytic reduction, low-NO_x burners, etc.
- ▶ “VOC-constrained” in Los Angeles?

- **Volatile organic compounds (VOCs)**

- ▶ Reactive chemicals (“hydrocarbons”), many sources
- ▶ Ground-level ozone pollution
- ▶ Abatement: air systems, thermal oxidizers

- **Particulate matter (PM_{2.5})**

- ▶ Small particles: fossil fuel combustion, industrial processes
- ▶ Abatement: baghouses, electrostatic precipitators
- ▶ Large health consequences

Overview

- Design of Pollution Offset Markets
- **Data**
 - ▶ **Offset markets**
 - ▶ Marginal benefits of abatement
- Describing offset markets
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Data

- **Pollution offset markets: California and Texas**

- ▶ Transaction-level prices
- ▶ 1993-2018 (TX mostly 2005+)
- ▶ Texas: seller, buyer identity, attributes, list of potential sellers
- ▶ Quantity for other states, seeking prices

- **Pollution offset markets: 14 other states**

- ▶ Average price for each market \times year \times pollutant, some rounding
- ▶ Purchased from leading firm that manages offset transactions
- ▶ Interpret partly as sensitivity analysis of CA and TX
- ▶ Arizona, Connecticut, Delaware, Illinois, Indiana, Maryland, Missouri, New Jersey, New York, Ohio, Pennsylvania, Virginia, Wisconsin, Wyoming, plus Washington, DC

Offset Market Design: Market Locations

Figure: Ozone

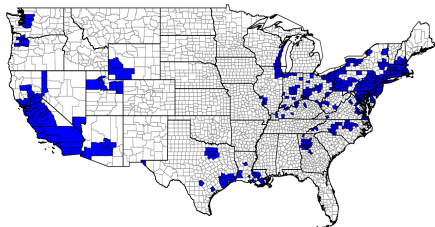


Figure: Particulate matter

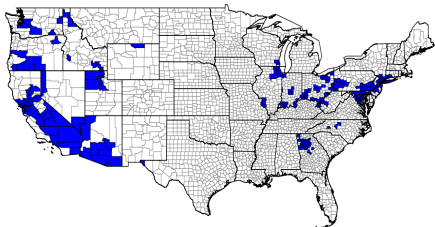
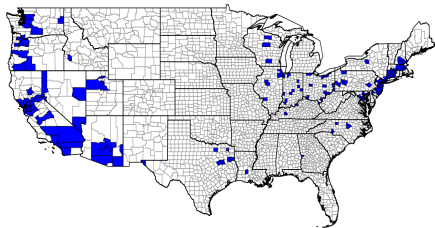


Figure: Other pollutants



Data: Converting Perpetual Permit to Annual Price

Most offsets represent permanent right to emit a ton of pollution.

Most estimates of marginal benefits of abating pollution correspond to one ton of pollution reduction in a single year.

We convert offset price into annual price by taking ratio of one-year, "temporary" offsets to permanent offsets

- Homogenous products, except for duration $\approx 9.3x$ difference in price
- Corresponds to an annual discount rate $\approx 10.6\%$
- Sensitivity analyses using different price ratios / discount rates

Overview

- Design of Pollution Offset Markets
- **Data**
 - ▶ Offset markets
 - ▶ **Marginal benefits of abatement**
- Describing offset markets
- Efficiency
- Conclusions

Data

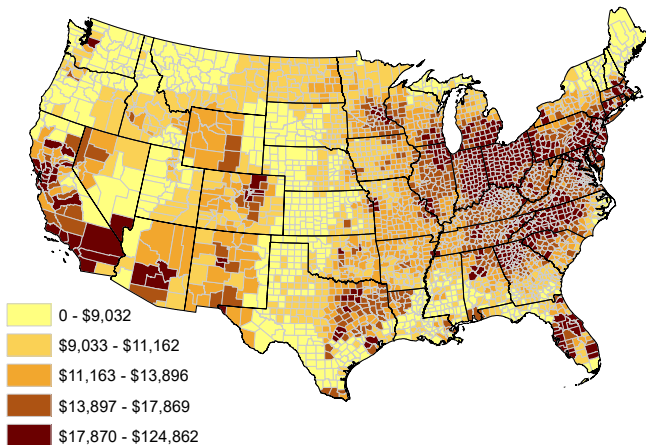
● Marginal benefits of abatement

- ▶ =Marginal damages of emissions
- ▶ AP3 model (Clay et al. 2019, Holland et al. 2020)
- ▶ Precursors: AP2, APEEP (Muller and Mendelsohn 2009, 2012 AER)
 - ★ Used in NRC (2010); Muller et al. (AER 2011); Holland et al. (AER 2016); Gowrisankaran et al. (JPE 2016); Fowlie et al. (QJE 2018)
- ▶ Adult and infant mortality, morbidity, crop and timber yields, recreation visibility, depreciation of materials (e.g., steel in buildings), lost recreation
- ▶ PM_{2.5} versus PM₁₀
- ▶ Sensitivity analyses: EASIUR, InMAP, AP2

Data: Marginal Benefits of Abatement

Appendix Figure 2—Marginal Benefits of Pollution Abatement, by Pollutant and County

(A) Nitrogen oxides (NO_x)



Overview

- Design of Pollution Offset Markets
- Data
- **Describing Offset Markets**
 - ▶ Market coverage
 - ▶ Offset price trends
 - ▶ Offset prices versus environmental aggregates
- Efficiency
- Conclusions

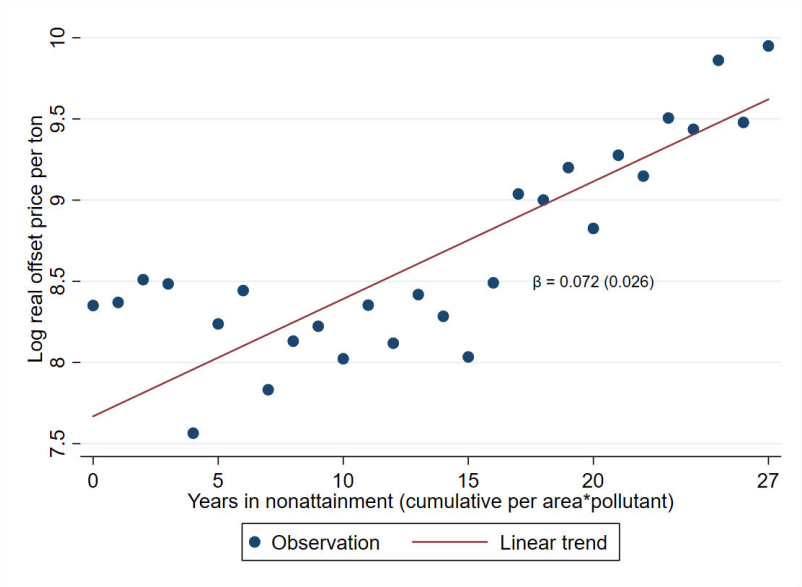
Data: Offset Market Coverage

Table 1: Prevalence of Offset Markets

	Number of markets (1)	Population (mn)		GDP (trn)		Manufacturing employment (mn)	
		People (2)	% (3)	\$ (4)	% (5)	Workers (6)	% (7)
<i>Panel A. National</i>							
Any pollutant	491	182.1	59	11.08	66	6.44	56
Ozone	282	173.2	56	10.65	63	6.09	53
Particulate matter	83	121.2	39	7.58	45	3.97	34
<i>Panel B. National—analysis period</i>							
Any pollutant	226	158.1	51	9.74	58	5.38	47
Ozone	118	145.0	47	9.08	54	4.83	42
Particulate matter	63	114.3	37	7.11	42	3.74	32
<i>Panel C. Full sample (16 states plus Washington, DC) as proportion of all national markets</i>							
Any pollutant	42	94.5	60	6.14	63	3.00	56
Ozone	37	94.5	65	6.14	68	3.00	62
Particulate matter	5	30.3	27	1.83	26	1.05	28

Results: Offset Price Trends

Appendix Figure 4—Offset Prices, by Years in Nonattainment



Results: Offset Price Trends

	Offset prices		
	(1)	(2)	(3)
<i>Panel A. All pollutants</i>			
Year	0.05*** (0.02)	0.08 (0.06)	0.06*** (0.02)
<i>N</i>	208	208	208
<i>Panel B. Nitrogen oxides (NO_x)</i>			
Year	0.05** (0.02)	0.08*** (0.02)	0.06*** (0.02)
<i>N</i>	98	98	98
<i>Panel C. Volatile organic compounds (VOCs)</i>			
Year	0.05 (0.03)	0.08 (0.09)	0.05 (0.03)
<i>N</i>	110	110	110
Weight		Tons	Population

Comparing Offset Prices to Environmental Aggregates

Appendix Table 1: Relationship Between Offset Prices and Abatement Expenditures

	(1) Offset Price NO _x	(2) Offset Price VOC	(3) Offset Price Combined
<u>Operating Costs</u> Output	1.791* (0.753)	1.015*** (0.314)	1.424*** (0.337)
<u>Operating Costs</u> Value Added	3.475*** (0.821)	1.222** (0.445)	1.851*** (0.409)
<u>Total Costs</u> Output	1.298* (0.531)	0.611*** (0.167)	0.890*** (0.199)
<u>Total Costs</u> Value Added	2.189*** (0.529)	0.720*** (0.180)	1.109*** (0.214)
<u>Capital Stock</u> Output	1.303* (0.575)	0.502** (0.202)	0.789*** (0.210)
<u>Capital Stock</u> Value Added	2.223** (0.685)	0.541* (0.256)	0.927*** (0.255)
<u>Operating+Capital Stock</u> Output	1.303* (0.540)	0.606*** (0.172)	0.888*** (0.201)
<u>Operating+Capital Stock</u> Value Added	2.213*** (0.550)	0.712*** (0.191)	1.105*** (0.217)
N	129	339	603

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Comparing Offset Prices to Environmental Aggregates

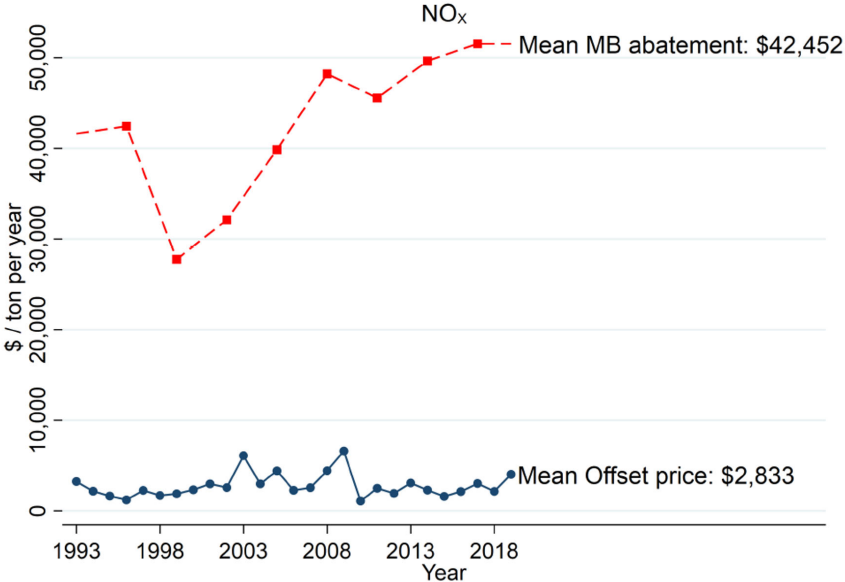
Appendix Table 2: Relationship Between Offset Prices and Plant-level Emissions Intensity

	(1)	(2)	(3)
	NO _x	VOC	Combined
Panel A: Emissions Per Unit of Output			
$\frac{\text{Emissions}}{\text{Output}}$	-0.169*	-0.143	-0.137***
	(0.083)	(0.093)	(0.045)
N	1599	2266	4497
Panel B: Emissions Per Unit of Value Added			
$\frac{\text{Emissions}}{\text{Value Added}}$	-0.149*	-0.139	-0.130***
	(0.085)	(0.085)	(0.043)
N	1599	2266	4497

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- Design of Pollution Offset Markets
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- **Efficiency**
- Conclusions

Results: MB Abatement v. Offset Prices, by Year



Results: Marginal Benefits of Abatement / Offset Prices, National

Table 3: Ratio of Marginal Benefits of Abatement to Mean Offset Prices, 2010-2019

	NO _x		VOCs	
	(1)	(2)	(3)	(4)
<i>Panel A. Full sample (16 states plus Washington, DC)</i>				
1. Marginal benefits of abatement / Offset price	38.21	11.89	29.19	8.99
2. p-val: MBabatement / Offset price = 1	[0.00]	[0.00]	[0.00]	[0.00]
3. Mean marginal benefits of abatement	\$43,044	\$51,540	\$24,934	\$20,657
4. Mean offset prices	\$1,126	\$4,334	\$854	\$2,297
Weight:				
Tons	X		X	
Population		X		X

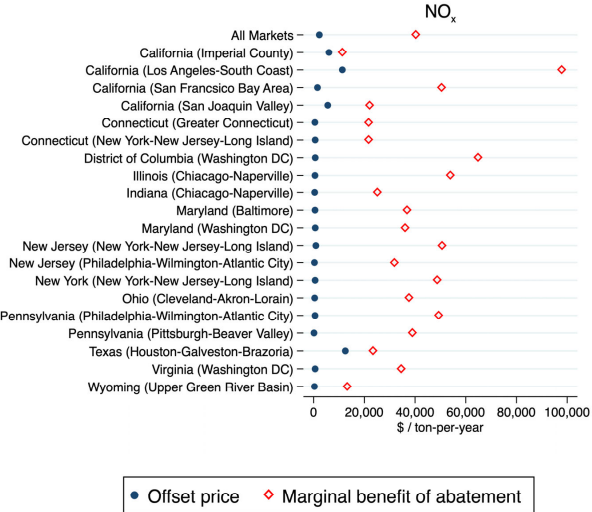
Results: Marginal Benefits of Abatement / Offset Prices

Table 3: Ratio of Marginal Benefits of Abatement to Mean Offset Prices, 2010-2019

	NO _x		VOCs	
	(1)	(2)	(3)	(4)
<i>Panel B. Northeast</i>				
1. Marginal benefits of abatement / Offset price	79.03	70.45	46.92	52.28
2. p-val: MBabatement / Offset price = 1	[0.00]	[0.00]	[0.00]	[0.00]
3. Mean marginal benefits of abatement	\$44,777	\$44,015	\$29,169	\$32,274
4. Mean offset prices	\$567	\$625	\$622	\$617
<i>Panel C. South</i>				
1. Marginal benefits of abatement / Offset price	20.84	5.97	11.67	2.30
2. p-val: MBabatement / Offset price = 1	[0.00]	[0.01]	[0.02]	[0.23]
3. Mean marginal benefits of abatement	\$38,093	\$29,155	\$19,934	\$13,464
4. Mean offset prices	\$1,828	\$4,884	\$1,708	\$5,852
<i>Panel D. West</i>				
1. Marginal benefits of abatement / Offset price	8.59	8.33	4.62	6.58
2. p-val: MBabatement / Offset price = 1	[0.00]	[0.00]	[0.00]	[0.00]
3. Mean marginal benefits of abatement	\$36,940	\$71,745	\$7,389	\$15,501
4. Mean offset prices	\$4,302	\$8,609	\$1,601	\$2,356
<i>Panel E. Midwest</i>				
1. Marginal benefits of abatement / Offset price	85.15	89.99	46.01	49.10
2. p-val: MBabatement / Offset price = 1	[0.04]	[0.02]	[0.02]	[0.01]
3. Mean marginal benefits of abatement	\$44,504	\$48,578	\$19,856	\$22,351
4. Mean offset prices	\$523	\$540	\$432	\$455
Weight:				
Tons	X		X	
Population		X		X

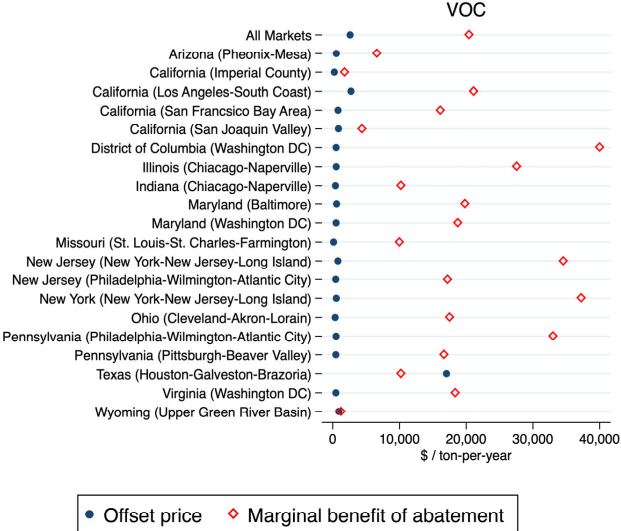
Results: Marginal Benefits of Abatement / Offset Prices

Figure 3—Offset Prices and Marginal Benefits of Abatement, Large Individual Markets

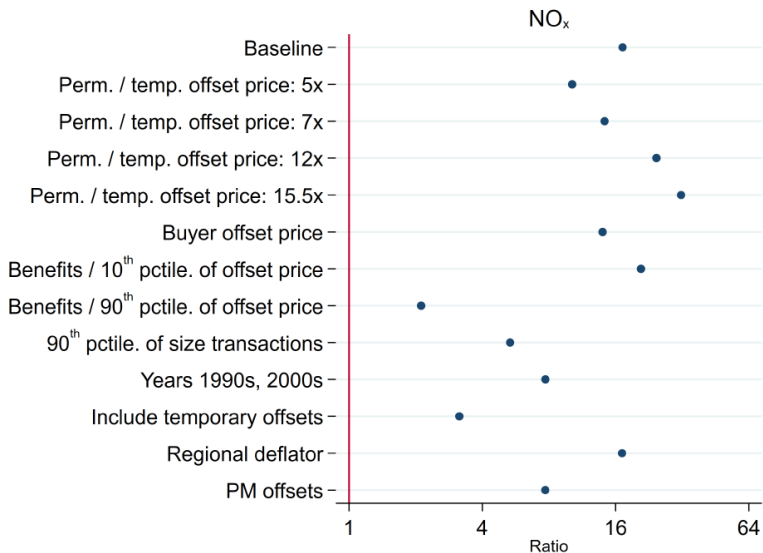


Results: Marginal Benefits of Abatement / Offset Prices

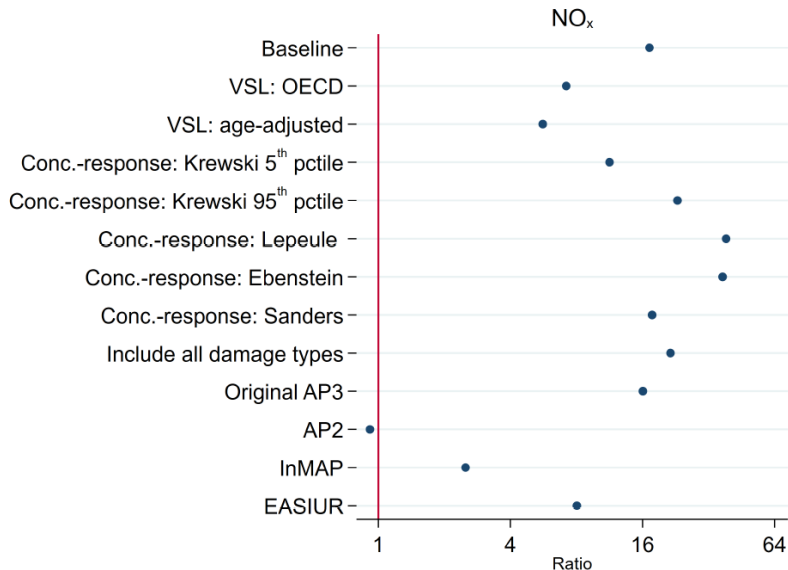
Figure 3—Offset Prices and Marginal Benefits of Abatement, Large Individual Markets



Results: Marginal Benefits of Abatement / Offset Prices, Sensitivity



Results: Marginal Benefits of Abatement / Offset Prices, Sensitivity



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- **Conclusions**

Conclusions

- Designing efficient corrective policy requires measuring marginal costs and benefits
 - ▶ Usually hard
 - ▶ Pollution: historic advances in measuring MB, less for measuring MC
 - ▶ Offsets: a new approach to measure marginal costs of abatement
- Results:
 - ▶ Offset markets common, prices rapidly rising, related to regulation proxies
 - ▶ Policy in most markets too lenient
 - ★ Despite big fall in pollution, additional reductions seem valuable