The Abatement Cost of Methane Emissions from Natural Gas Production

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Natural gas for electricity generation:

- Produces roughly half the carbon dioxide emissions as coal
- Is abundant and cost-competitive with other fuels
- Has large-scale infrastructure already in place
- Complementary to intermittent renewables

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However, methane (CH_4):

- Is itself a greenhouse gas about 30x more potent than CO_2 on a 100-year time horizon
- 3.2% leakage rate implies no climate advantage over coal (Alvarez et al., 2012)
- 2-6% leakage rates estimated by scientific studies (Sanchez & Mays, 2015)

This Paper

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- Simulate effects of increasing price

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Intuition:

- Firms choose an optimal level of methane emissions such that Marginal Abatement Cost = Marginal Private Benefit = Gas Price

Background

Sources of Emissions from Production:

- Unintentional leaks from extraction, processing, transportation, and storage equipment
- Intentional venting during completion and maintenance

Data

EPA Greenhouse Gas Reporting Program (GHGRP):

- Annual estimated methane emissions for over 500 onshore gas production facilities
- "Facility" is delineated at firm-basin level
- Six-year panel from 2011-2016
- Quality issues because methane leakage is hard to measure

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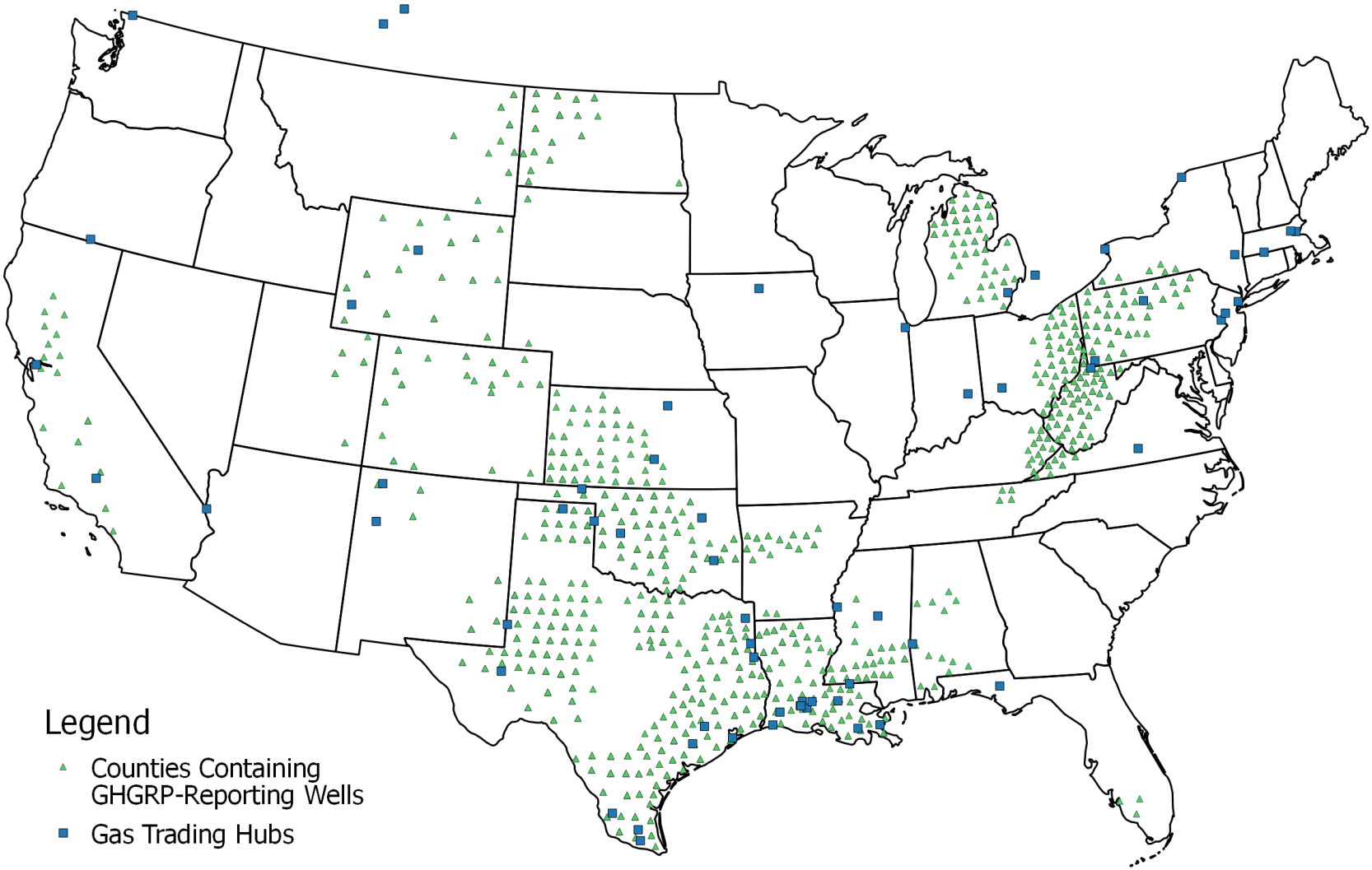
SNL:

- Spot gas prices for 96 geographically-dispersed trading hubs

Data: GHGRP Facilities



Empirical Framework

Fractional Polynomial Model: Separately estimates all possible combination of A and B and selects the best fit for the data

$$R_{it} = \beta_0 + \beta_1 P_{it}^A + \beta_2 P_{it}^B + \mathbf{X}_{it}\psi + \gamma_i + \lambda_{rt} + \varepsilon_{it}$$

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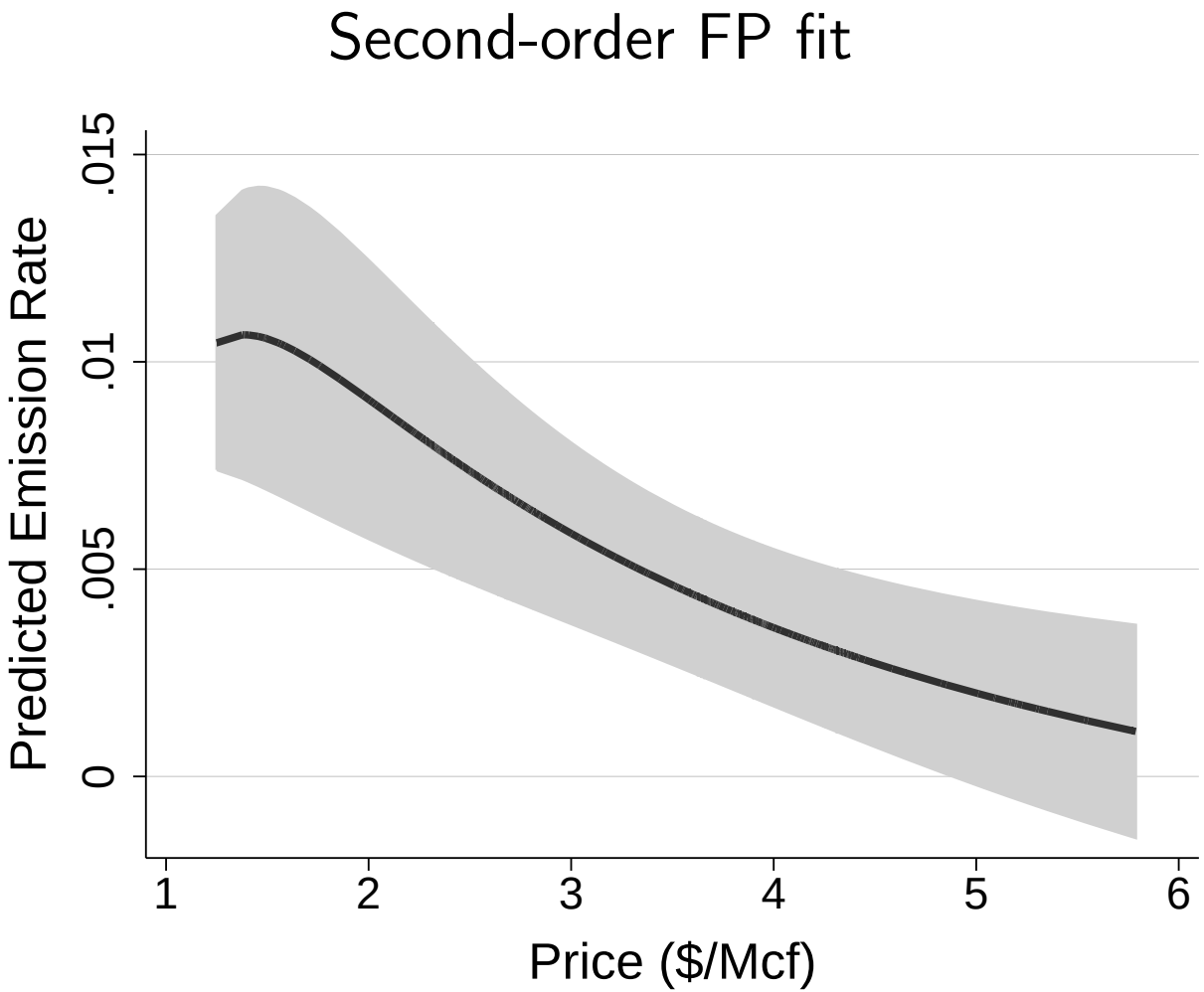
$X_{it} \equiv$ Controls (wells, completions, oil production, Colorado post-2014 FE)

$\gamma_i \equiv$ Facility FE

$\lambda_{rt} \equiv$ Region-Year FE (South Central, East, Mountain, Pacific)

Results: Relationship between Prices and Emission Rates



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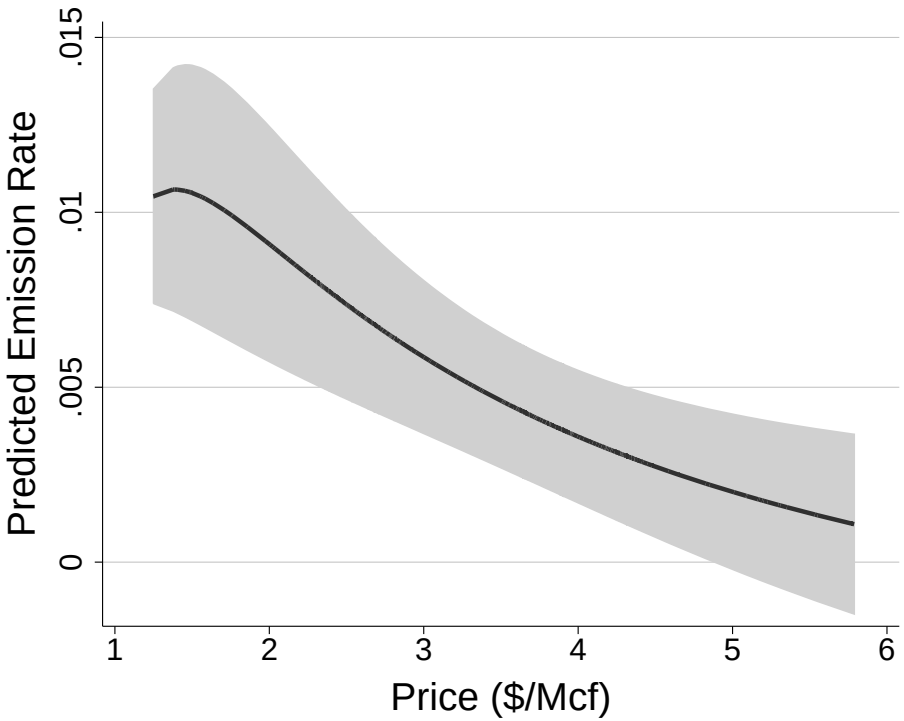
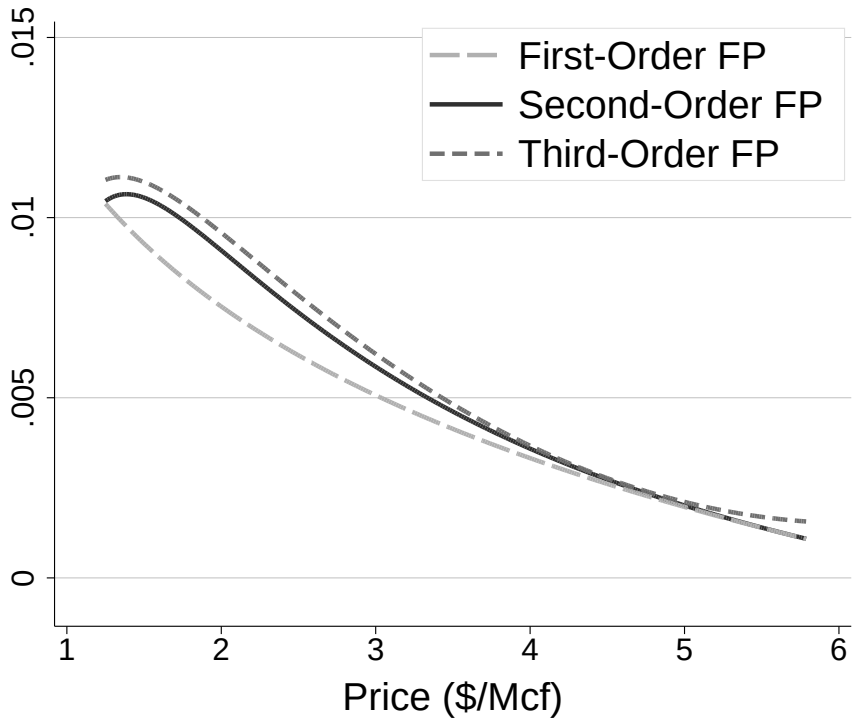
Comparison of second-order FP with higher- and lower-order models





Results: Relationship between Prices and Emission Rates

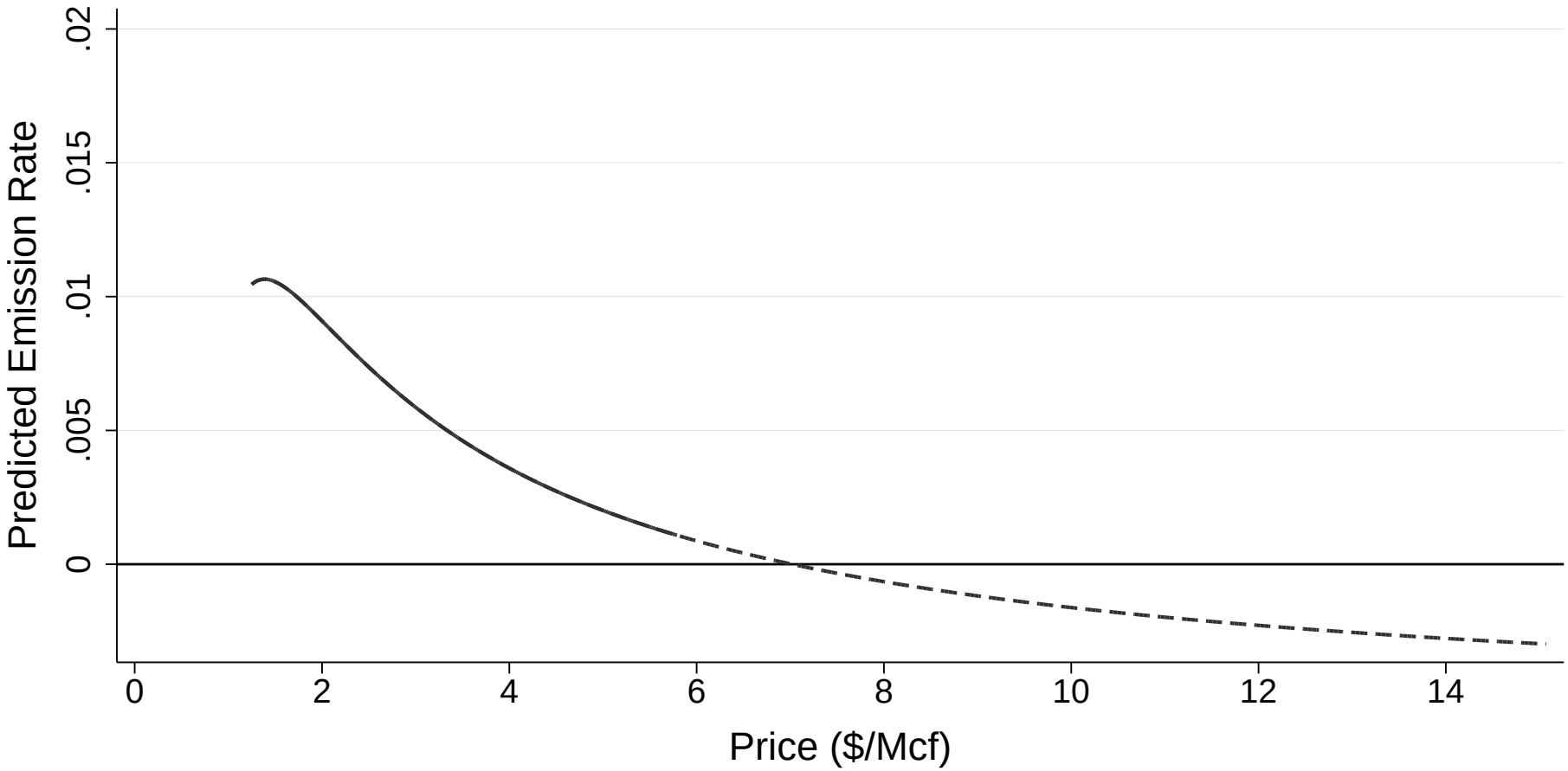
	Linear	1st-Order FP	**2nd-Order FP**	3rd-Order FP
P_{it}	-0.0018***			
	(0.0006)			
log(P_{it})		-0.0061***		
		(0.0017)		
$P_{it}^{-0.5}$				0.0493***
				(0.0168)
P_{it}^{-1}			**0.0460*** **	
			(0.0154)	
P_{it}^{-2}			**-0.0319*** **	-0.0202**
			(0.0123)	(0.0085)
P_{it}^{3}				0.00001
				(0.00001)
Constant	0.0127***	0.0117***	**-0.0059***	0.0216***
	(0.0025)	(0.0023)	**(0.0033)**	(0.0058)
N	1,150	1,150	**1,150**	1,150

Standard errors in parentheses (clustered at the parent firm level) $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

All models include facility FE, region-year FE, and controls

Observations weighted by facilities' mean gas production

Simulation Framework: Effect of a Methane Tax



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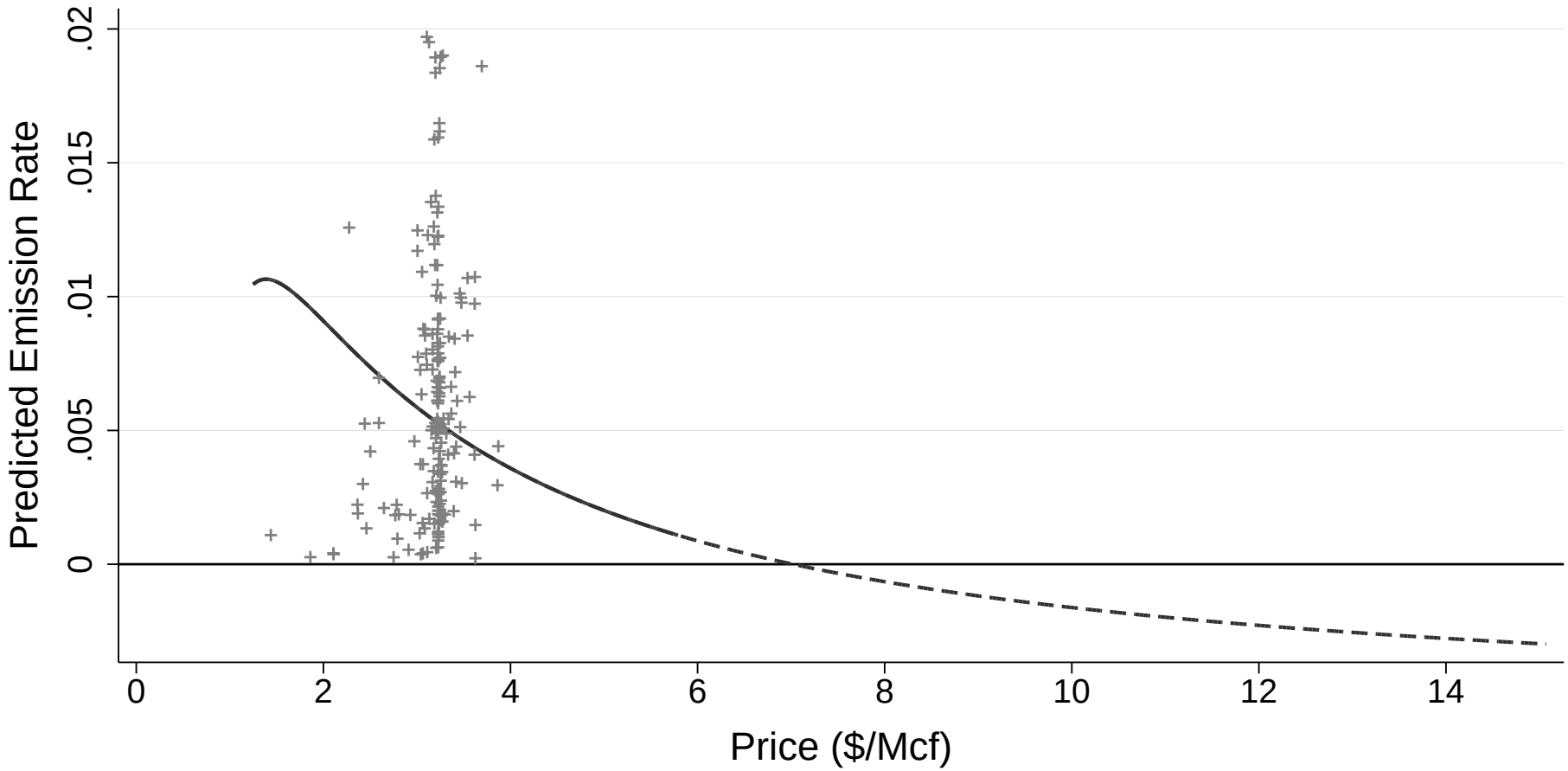
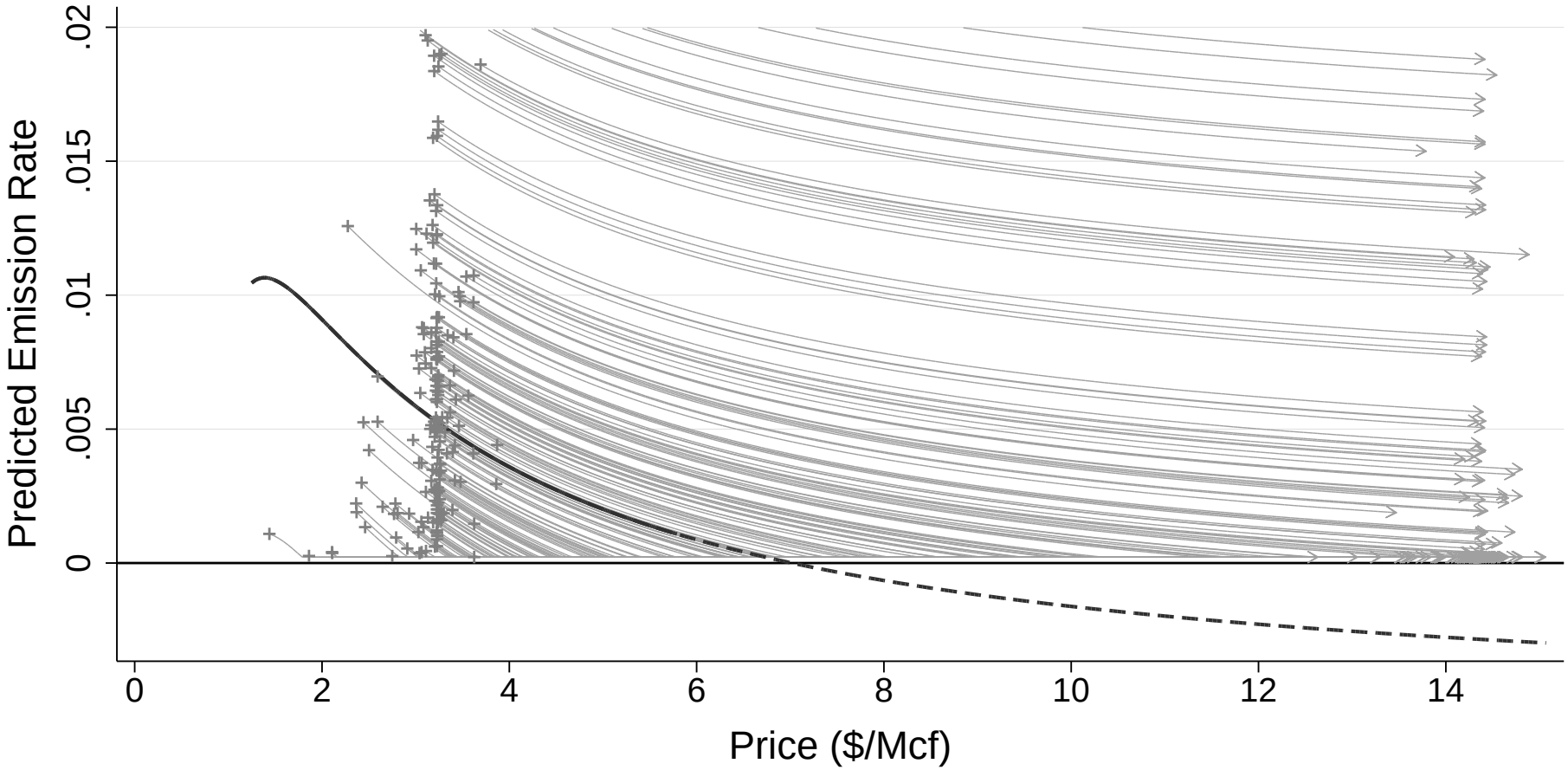
- Start facilities at average emission rates and prices



Simulation Framework: Effect of a Methane Tax

- ▷ Start facilities at average emission rates and prices
- ▷ Increase prices & decrease emission rates following slope of estimated curve



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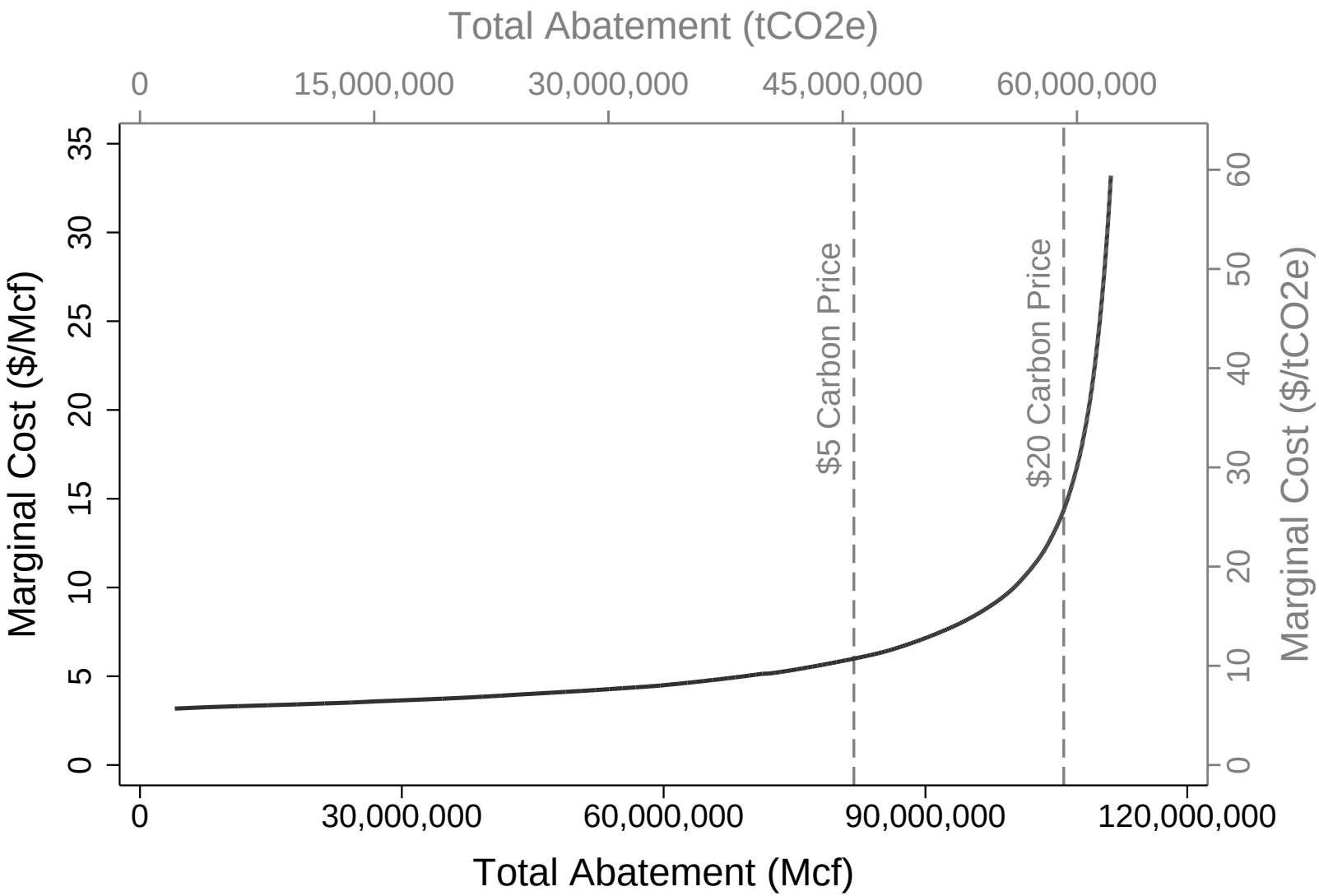

Results: Effect of a Methane Tax

Predicted Effects at Selected Methane Prices

Methane Tax ($/Mcf)	**Equiv. CO_2 Price** ($/t$CO_2$e)	**Total Abatement** (tCO_2e)	**Total Abatement** (Percent)	**Total Cost** ($ Millions)	**Value of Recvrd Gas** ($ Millions)	**Net Cost** ($/Mcf)
2.79	5.00	45,904,000 (15,542,000)	55.7% (23.8)	336.7 (143.7)	265.3 (111.6)	0.0026 (0.0011)
11.18	20.00	58,437,000 (20,184,000)	72.0% (33.4)	528.3 (272.3)	336.5 (155.7)	0.0067 (0.0042)
27.37	48.97	61,301,000 (22,130,000)	75.5% (36.8)	632.6 (383.0)	353.9 (171.5)	0.0098 (0.0077)
N		1,150	1,150	1,150	1,150	1,150

Bootstrapped standard errors in parentheses

Results: Adjusting Simulation Parameters

Predicted Effects of Fully Internalizing Social Cost ($27.37/Mcf)

Model	Total Abatement (tCO_2e)	Total Abatement (Percent)	Total Cost ($ Millions)	Value of Recvrd Gas ($ Millions)	Net Cost ($/Mcf)
Base Model	61,301,000 (22,130,000)	75.5% (36.8)	632.6 (383.0)	353.9 (171.5)	0.0098 (0.0077)
Lower-Bounding Rates at 0.1%	50,342,000 24,819,000	61.6% (30.4)	530.3 (321.0)	290.3 (142.6)	0.0084 (0.0064)
Starting Facilities at 2016 Prices & Rates	43,179,000 (21,989,000)	67.7% (34.5)	341.3 (239.7)	178.7 (90.7)	0.0057 (0.0054)
Using First-Order Fractional Polynomial	66,838,000 (27,637,000)	81.8% (33.8)	827.5 (455.4)	384.7 (157.7)	0.0155 (0.0108)
N	1,150	1,150	1,150	1,150	1,150

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Comparison with Other Abatement Cost Estimates

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- \$1.55/tCO_2e under \$5 carbon tax (average abatement cost)
- \$4.56/tCO_2e under \$50 carbon tax

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Johnson (2014):

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Fowlie, Greenstone, and Wolfram (2018):

- \$201/tCO_2 for federal Weatherization Assistance Program

Conclusion

Summary:

- Estimated MACC for methane emissions from gas production
- Predicted 56% abatement under $5 carbon price
- Abatement costs relatively low compared to other sectors
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Discussion:

- Efficient area to prioritize for short-term GHG mitigation
- Implementing methane tax with imperfect/costly monitoring presents significant challenge
- More economics research on methane leakage needed

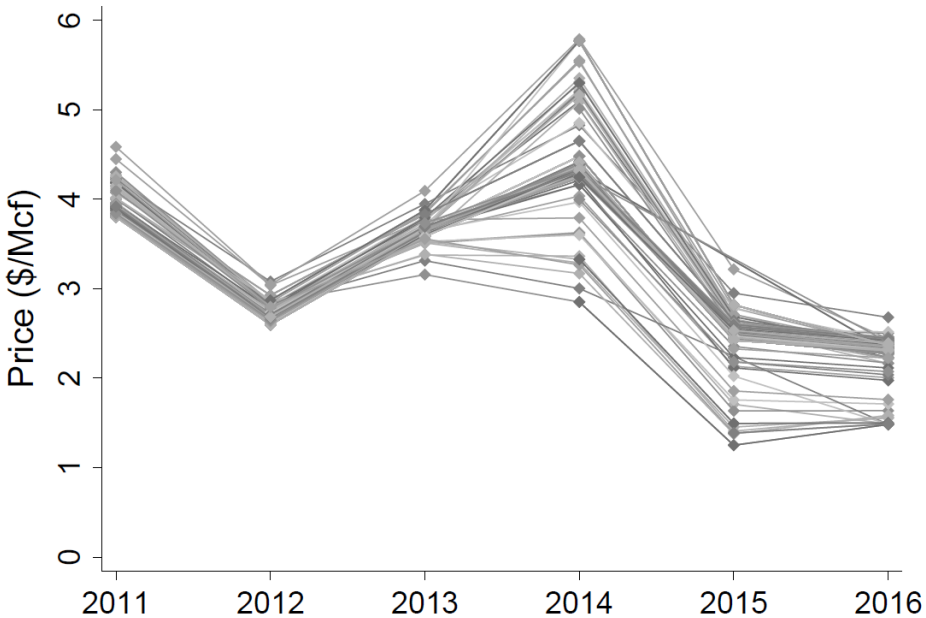
Thank You

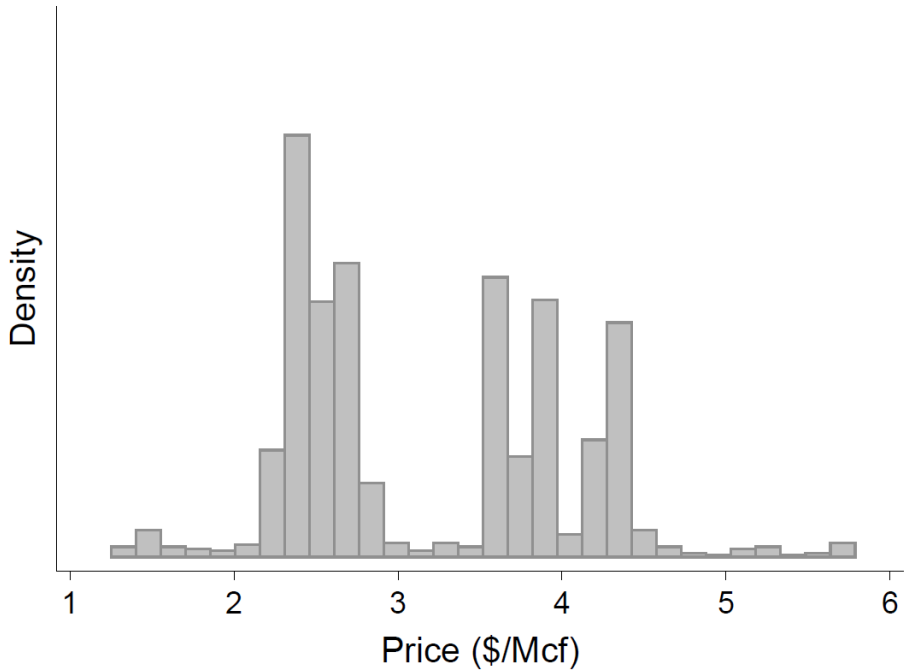
Data: Summary Statistics

		Full Sample		Trimmed Sample	
	Source	**Mean**	**SD**	**Mean**	**SD**
CH_4 Emissions Rate	GHGRP & DI	0.3894	4.0953	0.0108	0.0152
CH_4 Emitted (MMcf)	GHGRP	217	518	266	389
From Completions	GHGRP	29	169	34	134
From Equipment	GHGRP	117	276	143	222
From Maintenance	GHGRP	49	110	58	116
Gas Production (MMcf)	DrillingInfo	57,729	164,731	63,436	98,459
Oil Production (Mbbl)	DrillingInfo	4,199	10,854	4,523	10,992
Wells Per Facility	DrillingInfo	797	1,409	879	1,489
Completions	DrillingInfo	35	73	47	90
Wholesale Gas Price ($/Mcf)	SNL	3.23	0.83	3.20	0.85
Number of Facilities		683		222	
Total Observations		2,980		1,150	

Mcf ≡ Thousand cubic feet; MMcf ≡ Million cubic feet; Mbbl ≡ Thousand barrels

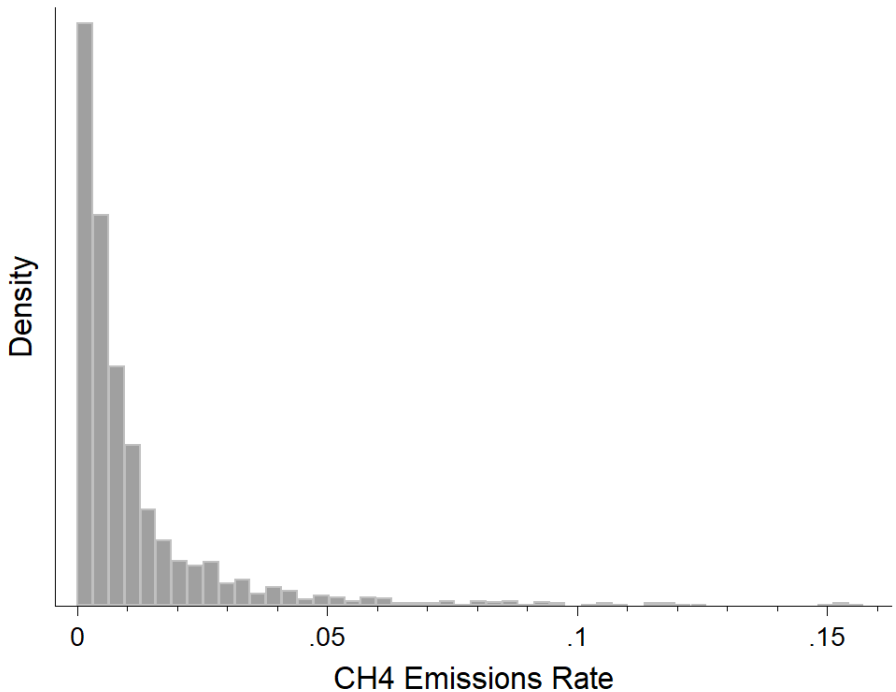
Data: Variation in Prices

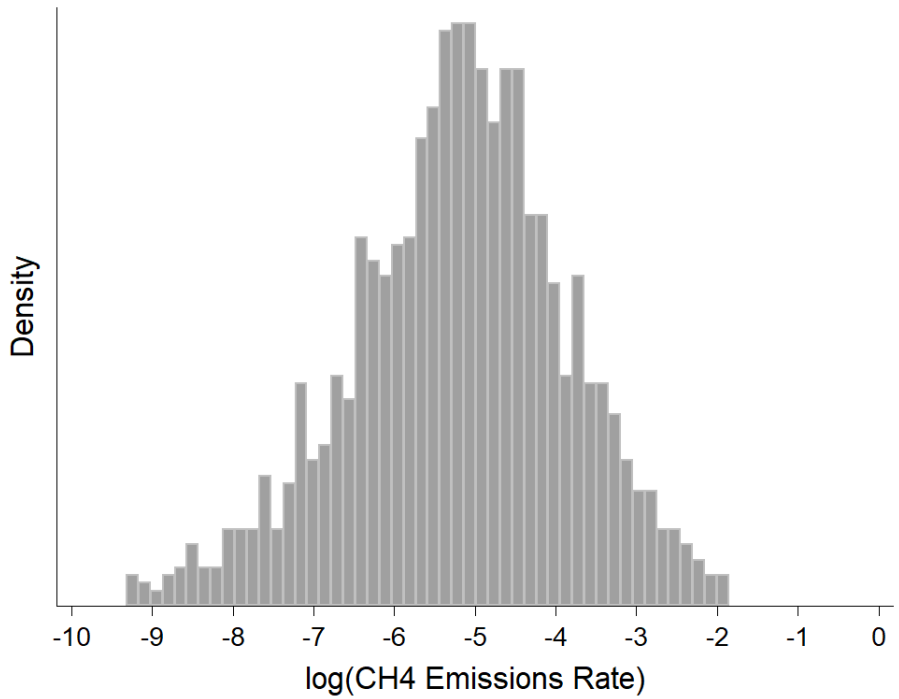




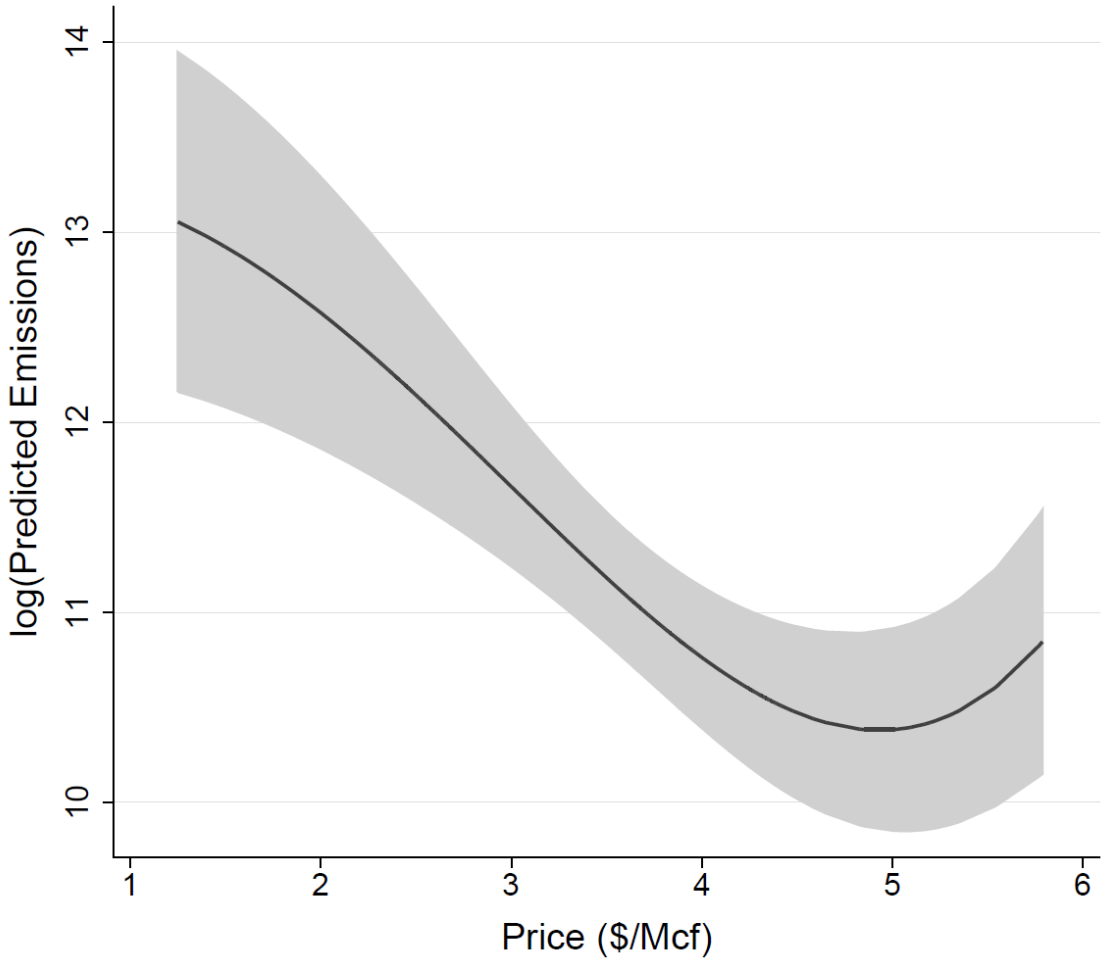
Data: Emissions Rates

Density of emissions rates vs. log emissions rates

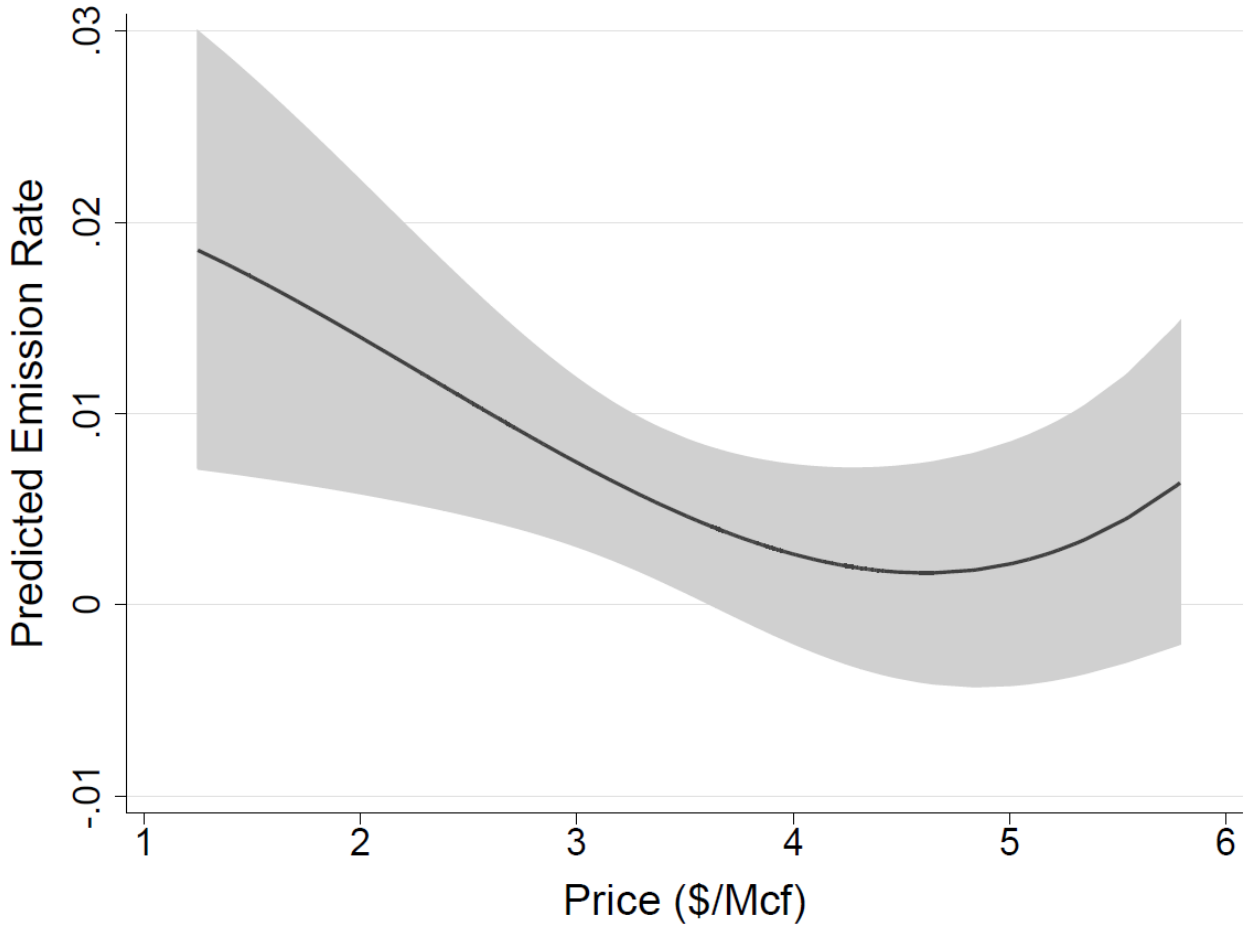




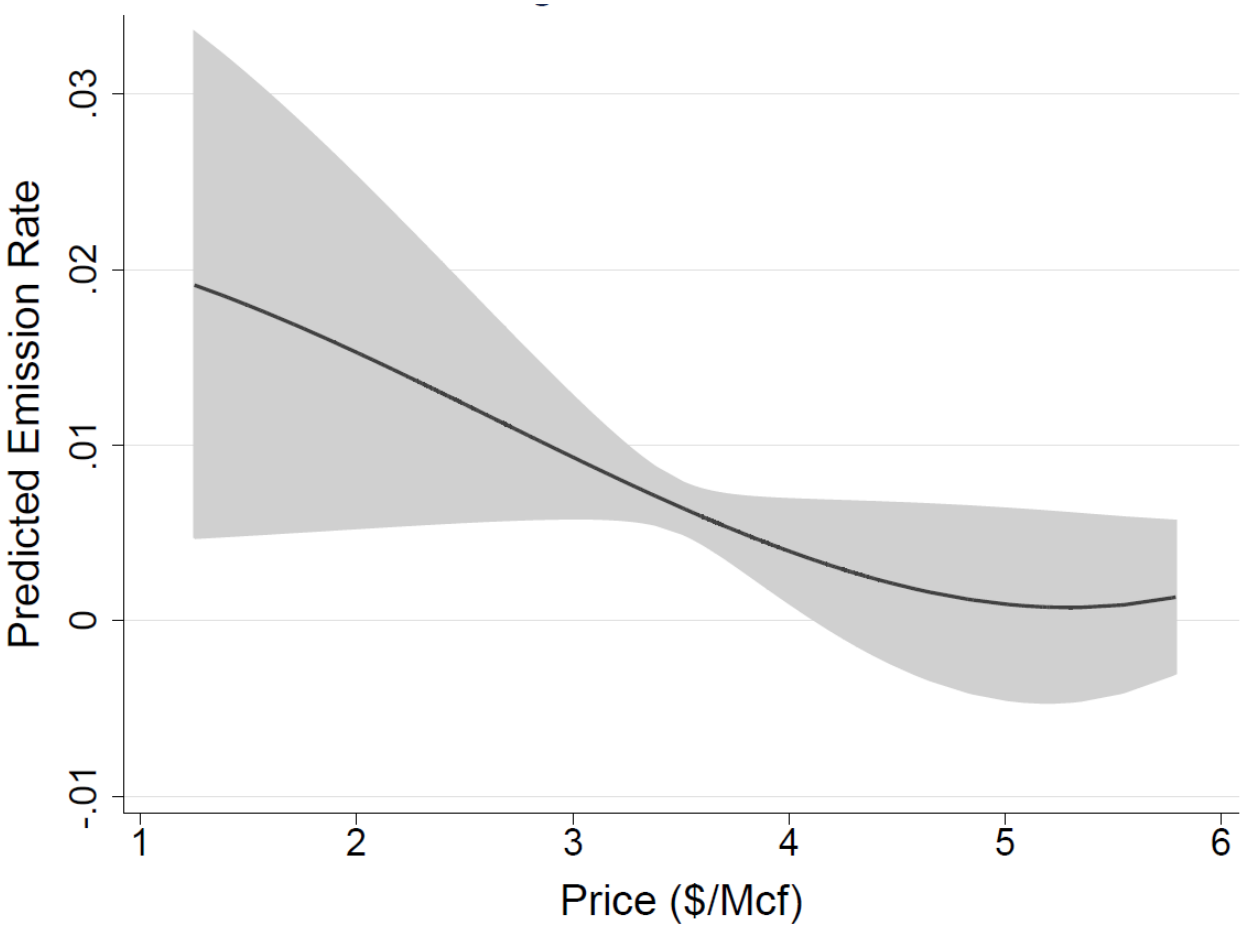
Robustness Check: Negative Binomial Model



Robustness Check: Unweighted Regression



Robustness Check: Trimming Emission Rates at 1%



Results: Abatement Mechanisms

	Low-Bleed Pneumatic Controllers	High-Bleed Pneumatic Controllers	Intermittent Pneumatic Controllers	Pneumatic Pumps	Venting Days	Gas Recovered For Sales
P_{it}	-78.1	0.13	-380.7*	-206.0**	-6.687	67,064,000
	(171.5)	(20.11)	(206.4)	(86.7)	(5.893)	(71,686,000)
Wells	0.331	0.0343	1.492	0.0665	0.0124	-4,868
	(1.677)	(0.0434)	(1.038)	(0.332)	(0.0176)	(4,852)
Oil (MMbbl)	-14.91	3.481***	61.27*	17.88	-0.181	-6,722
	(32.34)	(1.246)	(33.01)	(17.17)	(0.328)	(79,525)
Completions	6.291*	-0.0305	-5.930***	0.468	0.0218	-11,509
	(3.662)	(0.0961)	(2.049)	(0.729)	(0.0403)	(16,272)
Colorado_{2014+}	-459.4	-26.50	861.8	-211.5	-4.653	5,201,000
	(831.1)	(54.30)	(652.2)	(154.3)	(5.635)	(5,609,000)
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes
Region-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	1,055	1,055	1,055	737	716	716

Standard errors in parentheses (clustered at the parent firm level)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$