How Effective Are Low-Emission Vehicle Standards?

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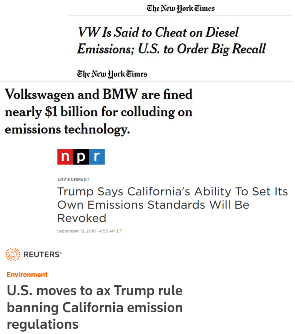
Vehicle Emissions are Regulated by Per-mile Standards

Figure 1: A car is tested on a chassis dynamometer in a lab (Source: Pittsburgh Post-Gazette).

Standards Stricter, Air Cleaner?

- Ongoing policy debates:
  - Tighten federal standards?
  - Continue to allow CA standards?
  - States adopt CA standards?
- Costly for industry
- Potentially large health benefits
- Policy spillovers: from CA to other states, from USA to other countries


The New York Times
VW Is Said to Cheat on Diesel Emissions; U.S. to Order Big Recall
The New York Times
Volkswagen and BMW are fined nearly $1 billion for colluding on emissions technology.
npr
ENVIRONMENT
Trump Says California's Ability To Set Its Own Emissions Standards Will Be Revoked
September 18, 2019 · 4:53 AM ET
REUTERS
Environment
U.S. moves to ax Trump rule banning California emission regulations

- Research Question:
  - How does stricter state emission standards affect air pollution?
  - Does this regulation generate observable health benefits?

The Staggered Adoption of LEV

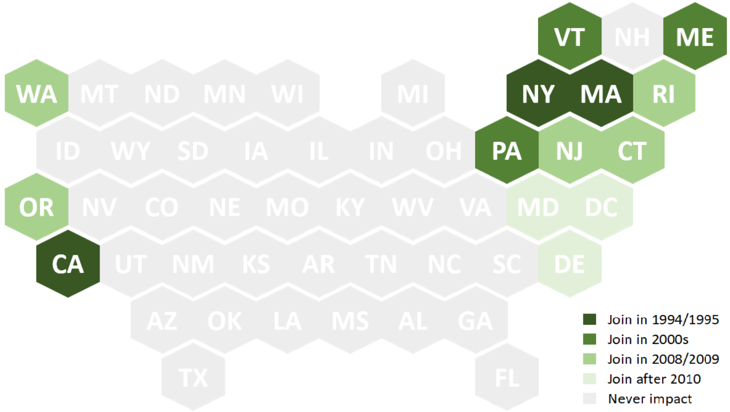


Figure 2: Map of "CARB State": states that adopted stricter emission standards designed by California Air Resources Board.

Example: vehicle categories under LEV

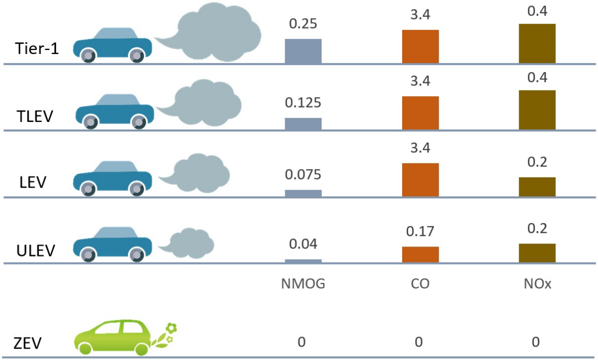


Figure 3: California LEV Program: vehicle categories in 1998

Note: Tier-1: Federal Tier 1; TLEV: Transitional low-emission vehicle; LEV: Low-emission vehicle; ULEV: Ultra-low-emission vehicle; ZEV: Zero emission vehicle. NMOG: Non-Methane Organic Gases, this and the NOx are the precursors of ground level ozone pollution.

Example: fleet average NMOG requirement under LEV

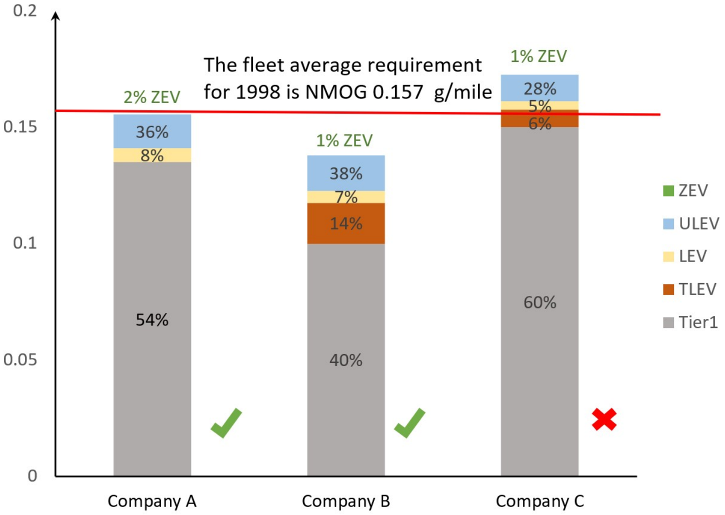


Figure 4: California LEV Program: fleet average requirement in 1998

The Simulated Benefit of Adopting LEV

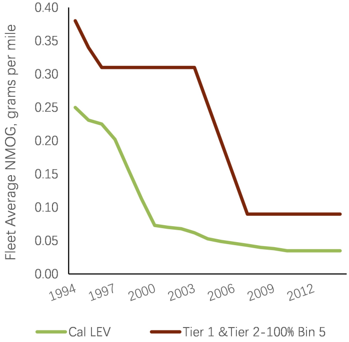


Figure 5: LEV fleet-average requirement vs. federal standards

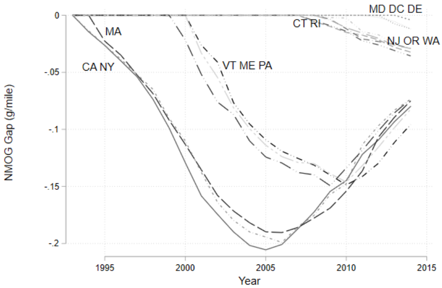


Figure 6: Simulated NMOG gap (g/mile): LEV states vs. non-adopting states

▸ Event

Pollution reduction

Table 1: The Impact of LEV on Log(*Ozone*) [1990-2003]

The ozone pollution level decrease about 5.7% in states with LEV during the period of 1990 to 2003.

	(1)	(2)	(3)	(4)	(5)
LEV	-0.082***	-0.067***	-0.058***	-0.057***	-0.057***
	(0.019)	(0.017)	(0.015)	(0.015)	(0.014)
Year FE	Y	Y	Y	Y	Y
Monitor FE	Y	Y	Y	Y	Y
Month, day of wk.		Y	Y	Y	Y
Weather(linear)			Y	Y	Y
Weather(poly.)				Y	Y
Weather*Month					Y
Weather*day of wk.					Y
Groups					
Obs	3989482	3989482	3989482	3989482	3989482
R^2	0.004	0.309	0.392	0.416	0.441

Note: This table displays the regression results corresponding to Eq.(1). The dependent variable is the nature logarithm of the daily maximum ozone concentration. All standard errors are clustered at the state-year level. The regression is weighted by the representative population of monitors. $* \; p < 0.10$, $** \; p < 0.05$, $*** \; p < 0.01$.

Pollution reduction

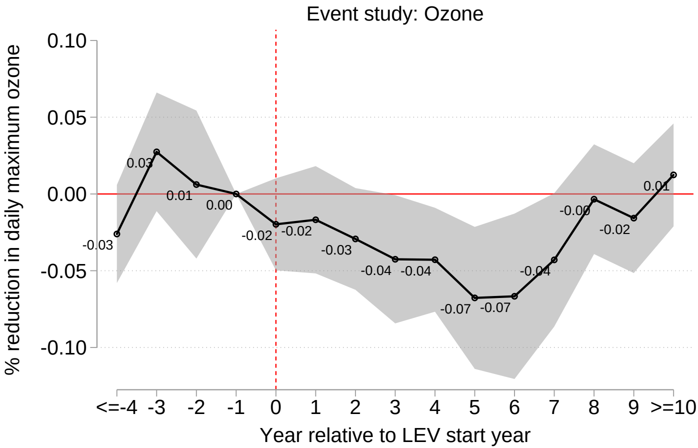
Table 2: The Impact of LEV on Log(*Ozone*) [1990-2014]

The ozone pollution level decrease about 2.2% in states with LEV during the period of 1990 to 2014.

	(1)	(2)	(3)	(4)	(5)
LEV	-0.035***	-0.031***	-0.020*	-0.020*	-0.022**
	(0.013)	(0.011)	(0.011)	(0.010)	(0.010)
Year FE	Y	Y	Y	Y	Y
Monitor FE	Y	Y	Y	Y	Y
Month, day of wk.		Y	Y	Y	Y
Weather(linear)			Y	Y	Y
Weather(poly.)				Y	Y
Weather*Month					Y
Weather*day of wk.					Y
Groups					
Obs	7526896	7526896	7526896	7526896	7526896
R^2	0.004	0.289	0.368	0.392	0.418

Note: This table displays the regression results corresponding to Eq.(1). The dependent variable is the nature logarithm of the daily maximum ozone concentration. The regression is weighted by the representative population of monitors. All standard errors are clustered at the state-year level. $* \, p < 0.1$, $** \, p < 0.05$, $*** \, p < 0.01$.

Event study



▸ Gap

Heterogeneous and Robustness

- Heterogeneous in ozone reduction
  - Geographic: more reduction in urban and suburban region. GEO
  - Impact is driven by CA and NY. CANY
  - Month: more pollution reduction in summer. Month
- Robustness
  - 14-years continuous working monitors. 14-year
  - Drop the state border monitors. NoBorder

Mortality Reduction

In the US, respiratory mortality is about 59 deaths per 100,000, so a 5.7% reduction in mortality would prevent around 11081 deaths per year.

Table 3: The Impact of LEV on Mortality of Respiratory Diseases

	(1) All resp.	(2) All resp.	(3) Unadj. Resp	(4) Unadj. Resp
LEV	-0.057***	-0.057***	-0.063***	-0.063***
	(0.018)	(0.018)	(0.021)	(0.021)
TRI_ozone		0.001		0.001
		(0.002)		(0.004)
County FE	Y	Y	Y	Y
N	74275	74275	74027	74027
R-sq	0.92	0.92	0.80	0.80

Notes: The table presents the results from Eq.(2). Regressions are weighted by population. Standard errors are in parentheses and clustered at the state level. The "All resp." data comes from Dwyer-Lindgren et al. (2016), and the "Unadj. resp." data comes from CDC Wonder database. (*p<0.10, ** p<0.05, *** p<0.01)

Placebo: mortality reduction

Table 4: The impact of LEV on other unrelated Diseases

	(1) Diabetes	(2) Diabetes	(3) Neuro.	(4) Neuro.	(5) Unint. injuries	(6) Unint. injuries
LEV	-0.002	-0.003	-0.011	-0.011	-0.045	-0.046
	(0.026)	(0.026)	(0.021)	(0.021)	(0.028)	(0.028)
TRI_ozone		0.004		-0.002		0.007
		(0.003)		(0.003)		(0.006)
County FE	Y	Y	Y	Y	Y	Y
N	74275	74275	74275	74275	74275	74275
R-sq	0.94	0.94	0.94	0.94	0.94	0.94

Notes: The table presents the results from Eq.(2). Regressions are weighted by population. The four diseases that are tested as placebo here are: Diabetes, neurological disorders, and unintended injuries. Standard errors are in parentheses and clustered at the state level. (*p<0.10, ** p<0.05, *** p<0.01).

Conclusion

1. **Pollution impact**
    - Ozone pollution concentration is significantly reduced by LEV program
    - Evidence of dynamics in the LEV's impact on ozone.
2. **Health impact**
    - Mortality rate related to the respiratory diseases is reduced by 5.7% with the introducing of LEV program.

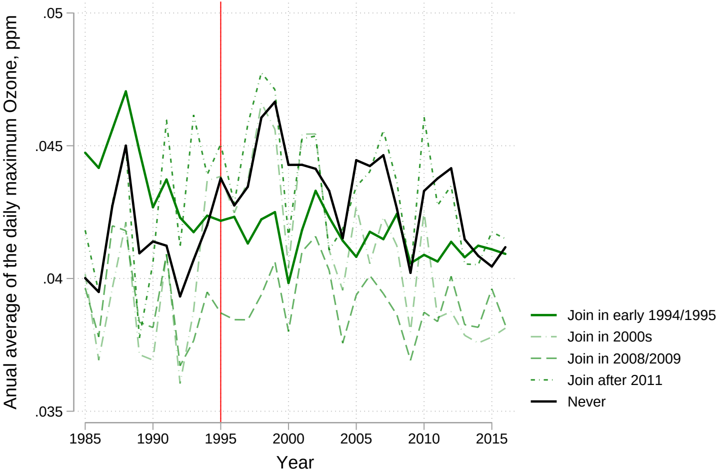
Thank you!

Question & Comments

Data

- Pollution analysis (1990-2014)
  - Pollution: monitor-days ozone pollution data from EPA's Air Quality System (AQS).
  - Weather: max and min of the temperature, precipitation, and snow from National Climatic Data Center's Cooperative Station.
- Health Analysis (1990-2014)
  - County-level age standardized mortality data.
    - From Dwyer-Lindgren et al. (2016) and Dwyer-Lindgren et al. (2017).
    - Used in top medical journals, but not economics journals (O'Connor et al., 2018; Nosrati et al., 2019).
  - Original county-level respiratory mortality data from CDC Wonder.
  - County-level Volatile Organic Compounds (VOCs) emission: Toxics Release Inventory (TRI), facility-year emission records on VOCs, aggregated to county level.

Data: ozone


Anual average of the daily maximum Ozone, ppm
.05
.045
.04
.035
1985
1990
1995
2000
2005
2010
2015
Year
Join in early 1994/1995
Join in 2000s
Join in 2008/2009
Join after 2011
Never

Data: health data

Table 5: Summary statistics on health analysis data

Variable	Obs	Mean	Std	Min	Max
Adjusted Mortality rates					
(death per 100,000)					
All respiratory diseases	74,275	58.747	14.136	14.272	160.972
COPD	74,275	50.760	13.214	9.941	152.292
PNEU	74,275	0.748	1.624	0.101	46.415
Silicosis	74,275	0.054	0.084	0.001	2.472
Asbestosis	74,275	0.186	0.252	0.008	10.810
CWP	74,275	0.258	1.531	0.001	44.897
Asthma	74,275	1.785	0.631	0.488	7.029
Raw Mortality rates					
(death per 100,000)					
Unadj. respiratory diseases	74,275	104.613	44.969	0	731.835
Other adj. mortality rate (for placebo test)					
(death per 100,000)					
Mental	74,275	8.357	5.485	1.278	73.154
Diabetes	74,275	60.453	16.362	11.548	183.462
Neuro.	74,275	90.566	20.752	14.481	212.162
Unint. injuries	74,275	23.434	4.803	7.621	78.018
Stationary source emission					
TRI-VOCs (ton)	74,275	0.176	0.741	0	48.269

Note: COPD - Chronic obstructive pulmonary disease; PNEU - pneumonia; CWP - coal workers' pneumoconiosis, Neuro. - neurological disorders.

Pollution analysis

$$ln(ozone)_{icst} = \beta \cdot LEV_{st} + \gamma Weather_{icst} + \alpha_i + \Delta_t + \epsilon_{icst} \quad (1)$$

- $ln(ozone)_{icst}$: the nature logarithm of the daily ozone concentration measure of monitor i county c state s in date t.
- LEV_{st}: dummy of LEV policy.
- $Weather_{icst}$: maximum and minimum of temperature, rain, and snow (levels, squares, cubes, and interactions)
- α_i: monitor fixed effect.
- Δ_t: day of week, month of year, year fixed effect.

Health analysis

$$ln(Mortality)_{cst} = \beta \cdot LEV_{st} + \gamma VOC_{cst} + \alpha_c + year_t + \epsilon_{cst} \quad (2)$$

- $ln(Mortality)_{cst}$: the log of the mortality rate in county c.
- VOC_{cst}: the VOCs emission from stationary sources in county c.
- α_c: county fixed effect.
- $year_t$ year fixed effect.

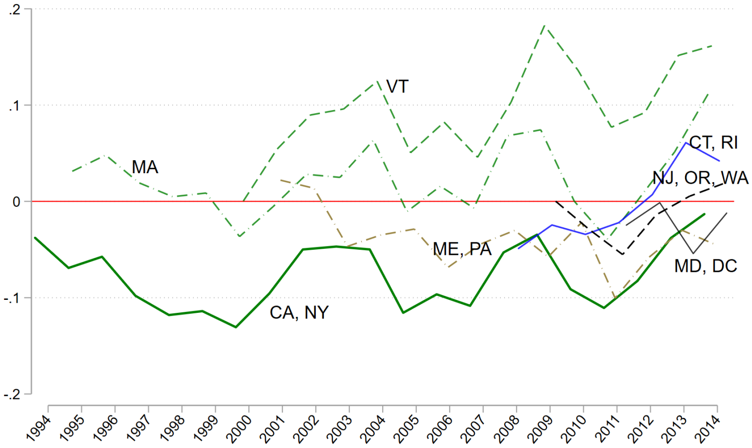
BJS Imputation

Table 6: BJS Imputation with yearly data

	(1) BJS	(2) DiD
Panel A: 1990-2003		
LEV	-0.069***	-0.055***
	(0.017)	(0.022)
Obs	13,770	13,907
Panel B: 1990-2014		
LEV	-0.052***	-0.038***
	(0.012)	(0.012)
Obs	25,225	25,366
Monitor FE	Y	Y
Year FE	Y	Y

Note: This table displays the regression results corresponding to Eq.(1). The dependent variable is the nature logarithm of the daily maximum ozone concentration. All standard errors are clustered at the state-year level. $* \ p < 0.1$, $** \ p < 0.05$, $*** \ p < 0.01$.

Wooldridge's TWFE



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Mortality Reduction

Table 7: The Impact of LEV on Mortality of Respiratory Diseases (by subcategory)

Panel B	(1)	(2)	(3)	(4)	(5)	(6)
	COPD	PNEU	Silicosis	Asbestosis	CWP	Asthma
LEV	-0.066***	-0.123**	-0.305***	-0.131***	-0.456***	-0.115***
	(0.021)	(0.061)	(0.066)	(0.049)	(0.056)	(0.035)
TRI_ozone	0.002	-0.003	0.017	0.001	0.017	0.006
	(0.002)	(0.003)	(0.013)	(0.007)	(0.014)	(0.004)
County FE	Y	Y	Y	Y	Y	Y
N	74275	74275	74275	74275	74275	74275
R-sq	0.92	0.97	0.94	0.96	0.97	0.93

Notes: The table presents the results from Eq.(2). Regressions are weighted by population. Standard errors are in parentheses and clustered at the state level. COPD-Chronic obstructive pulmonary disease; PNEU- pneumonia; CWP - coal workers' pneumoconiosis (black lung). (*p<0.10, ** p<0.05, *** p<0.01)

Table 8: The Impact of LEV on $ln(Ozone)$ [Rural vs. Suburban vs. Urban; 1990-2003]

	(1) Urban	(2) Suburban	(3) Rural
levpostD	-0.067*	-0.053***	-0.012*
	(0.032)	(0.011)	(0.006)
Monitor FE	Y	Y	Y
Month, day of wk.	Y	Y	Y
Weather(linear)	Y	Y	Y
Weather(poly.)	Y	Y	Y
Weather*Month	Y	Y	Y
Weather*day of wk.	Y	Y	Y
Obs	683578	1613574	1651062
R^2	0.459	0.455	0.416

Note: This table displays the regression results corresponding to Eq.(1). The dependent variable is the nature logarithm of the daily maximum ozone concentration. All standard errors are clustered at the state-year level. $* \ p < 0.10$, $* \ p < 0.05$, $*** \ p < 0.01$.

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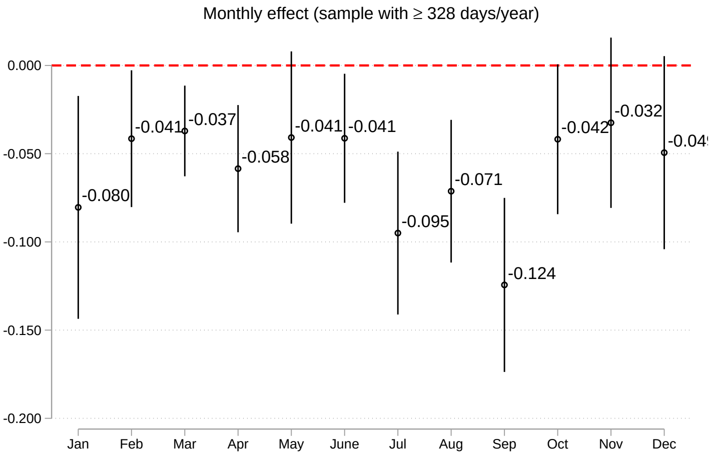

Figure 7: The LEV's impact: by month

Note: This figure plots the regression results obtained by using Eq.(1) on 12 sub-samples of each month. The dots represent the point estimates of β, and the vertical lines represent the 95% confidence intervals. ▸ Back

Table 9: The Impact of LEV on Log of ozone Pollution (14-years monitors only)

	(1)	(2)	(3)	(4)	(5)
LEV	-0.089***	-0.077***	-0.068***	-0.067***	-0.068***
	(0.020)	(0.018)	(0.016)	(0.016)	(0.015)
Year FE	Y	Y	Y	Y	Y
Monitor FE	Y	Y	Y	Y	Y
Month, day of wk.		Y	Y	Y	Y
Weather(linear)			Y	Y	Y
Weather(poly.)				Y	Y
Weather*Month					Y
Weather*day of wk.					Y
Groups					
Obs	2137615	2137615	2137615	2137615	2137615
R^2	0.005	0.325	0.401	0.426	0.457

Note: This table displays the regression results corresponding to Eq.(1), but only includes monitors which have continuously worked for 14 years. The dependent variable is the nature logarithm of the daily maximum ozone concentration. All standard errors are clustered at the state-year level. $*\ p < 0.10$, $*\ p < 0.05$, $*\!*\!*\ p < 0.01$.

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Table 10: The Impact of LEV on $ln(Ozone)$ [drop border monitors; 1990-2003]

	(1)	(2)	(3)	(4)	(5)
LEV	-0.086***	-0.074***	-0.064***	-0.062***	-0.062***
	(0.019)	(0.017)	(0.016)	(0.016)	(0.015)
Year FE	Y	Y	Y	Y	Y
Monitor FE	Y	Y	Y	Y	Y
Month, day of wk.		Y	Y	Y	Y
Weather(linear)			Y	Y	Y
Weather(poly.)				Y	Y
Weather*Month					Y
Weather*day of wk.					Y
Groups					
Obs	3680725	3680725	3680725	3680725	3680725
R^2	0.004	0.298	0.385	0.409	0.438

Note: This table displays the regression results corresponding to Eq.(1). The dependent variable is the nature logarithm of the daily maximum ozone concentration. All standard errors are clustered at the state-year level. $* \, p < 0.10$, $* \, p < 0.05$, $* * * \, p < 0.01$.

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