The impact of Car Pollution on Infant and Child Health: Evidence from Emissions Cheating
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Environmental Reading Group

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Introduction

- The introduction of "Clean Diesel" cars by Volkswagen (VW) in 2008 was marketed as an environmentally conscious choice for U.S. consumers.
- These vehicles were later discovered to contain "defeat devices," enabling them to emit pollutants at levels up to 150 times higher than comparable gasoline-fueled cars during real-world driving.
- This event provides a unique natural experiment to examine the causal impact of moderate levels of car pollution on public health.

Motivation and Research Question

- **Motivation:** Despite significant regulatory efforts and public awareness campaigns, the precise causal effects of car pollution on population health, particularly for moderate exposure levels and broader populations, remain challenging to identify due to confounding factors like socioeconomic selection and measurement error.
- The VW emissions scandal offers an exogenous shock to local air pollution, allowing for a robust quasi-experimental design.
- **Research Question:** What was the impact of the rollout of emissions-cheating diesel cars across the United States from 2008 to 2015 on ambient air pollution and infant and child health?

Key Findings (Preview)

- An additional cheating diesel car per 1,000 cars is associated with:
  - Increases in $PM_{2.5}$, PM_{10}, and ozone by 2%, 2.2%, and 1.3%, respectively.
  - Increases in low birth weight rates by 1.9% and infant mortality rates by 1.7%.
  - Similar impacts observed for acute asthma attacks in children.
- These health impacts occur at all pollution levels and across the socioeconomic spectrum, suggesting a broad public health threat.
- The findings underscore the importance of robust enforcement in environmental regulation.

Diesel vs. Gasoline Emissions

- Diesel engines are known for higher fuel efficiency but also higher emissions of particulate matter ($PM_{2.5}$, PM_{10}) and nitrogen oxides (NO_X).
- NO_X is a crucial precursor to fine particulate matter and ground-level ozone, both of which are linked to respiratory issues and mortality.
- Historically, diesel cars had low demand in the U.S. due to consumer preferences and stricter emission standards compared to Europe.

The Emissions Cheating Scandal

- Volkswagen introduced "TDI Clean Diesel" engines in the mid-2000s, marketed as meeting U.S. emission standards while offering performance and fuel efficiency.
- By 2015, over 600,000 VW and 63,000 Fiat Chrysler Automobiles (FCA) EcoDiesel vehicles with this technology were registered in the U.S.
- In Fall 2015, the EPA revealed that these cars contained "defeat devices" – software that reduced NO_X emissions during tests but allowed emissions up to 4,000% above legal limits in real-world driving.
- A single cheating VW diesel car emitted as much NO_X as 44-150 equivalent gasoline cars.

Expected Contribution to Ambient Air Quality

- On-road mobile sources contribute significantly to NO_X emissions (e.g., 43% in 2014 EPA report).
- $PM_{2.5}$ is directly emitted and secondarily formed from precursors like NO_X.
- Ground-level ozone formation involves complex reactions between NO_X and volatile organic compounds (VOCs).
- Back-of-the-envelope calculations suggest an additional cheating car per 1,000 could increase ambient $PM_{2.5}$ by 0.2% to 6%.
- The study empirically measures this link, rather than modeling complex pathways.

Data Sources

- **Vehicle Registration Data:**
  - Source: IHS Markit (2015).
  - Content: County-level snapshots (2007, 2011, 2015) of passenger cars and light trucks, identifying cheating diesel cars and "cheating" gas analogues.
  - Key variable: Number of cheating diesel cars per 1,000 cars in a county.
- **Pollution Data:**
  - Source: EPA Air Quality System (2021).
  - Content: Daily readings of pmtwofive, pmten, oiii, co, nox. Collapsed to county-month level (average concentration, AQI, poor air quality days).
  - Complementary: Satellite-based estimates (van Donkelaar et al., 2019) for full county coverage.

Data Sources (Continued)

- **Infant Health Data:**
  - Source: US National Vital Statistics System's birth records (2007-2016).
  - Content: Conception-level data (county, month, maternal demographics, infant health outcomes). Collapsed to county-conception month.
  - Measures: Average birth weight, low birth weight rate ($< 2,500$g), gestational age, preterm birth, infant mortality rate.
- **Child Health Data (Asthma):**
  - Source: HCUP State Emergency Department Databases (SEDD) (2007-2015).
  - Content: Number of ED visits with primary diagnosis of asthma (ICD-9 code 493, ICD-10 code J45) per 1,000 people at county-quarter level, by age group.
  - Limitation: Only available for a subsample of five states.
- **Other Data:** County characteristics (Census Bureau), vehicle-miles driven (FHWA).

Summary Statistics (See paper for full table) I

	All Counties	PM2.5 Monitor	Tercile 1	Tercile 2	Tercile 3
			(By frac. cheating in 2015)		
Vehicle characteristics					
Cheating diesel per 1,000 cars	0.70	0.89	0.28	0.60	1.21
Non-cheating diesel per 1,000 cars	44.86	29.78	39.88	43.56	51.13
"Cheating" gas per 1,000 cars	1.49	2.28	0.96	1.45	2.06
Census/SAIPE					
Total population	99,082	370,174	38,356	101,134	157,764
Pct. in poverty	16.46	15.08	20.23	15.72	13.44
Median income	44,040	50,041	37,486	43,838	50,784
Pollution outcomes (1 monitor/county)					
PM2.5: $\mu g/m^3$	9.34	9.34	9.89	9.93	8.68
Ozone: ppm	0.031	0.030	0.030	0.031	0.031
Infant health outcomes					
Birth weight (g)	3,300	3,294	3,249	3,287	3,320
Low birth weight ($< 2,500$ g)	6.35	6.63	7.40	6.70	5.89
Infant mortality rate (per 100 births)	0.523	0.517	0.663	0.557	0.465

Conceptual Framework

- The study aims to estimate the effect of car pollution on health.
- A key challenge is the endogeneity of pollution and measurement error.
- The number of cheating diesel cars is argued to provide a conditionally exogenous source of variation in car pollution.
- The relationship between changes in cheating diesel cars (D_{ct}) and total car pollution (P_{ct}) is conceptualized:

$$P_{ct} = \left(1 - \frac{D_{ct}}{1000}\right) \cdot p_c \cdot C_{ct} + 100 \cdot \frac{D_{ct}}{1000} \cdot p_c \cdot C_{ct} = \left(1 + 99\frac{D_{ct}}{1000}\right) \cdot p_c \cdot C_{ct} \tag{1}$$

  where p_c is pollution from a gasoline car, and C_{ct} is total cars.
- This implies that an increase of one cheating diesel car per 1,000 cars increases total car pollution by approximately 10% for small baseline shares:

$$\frac{\partial \ln(P_{ct})}{\partial D_{ct}} = \frac{1}{9.9 + D_{ct}} \approx 0.1 \tag{2}$$

Difference-in-Differences (DiD) Specification

- The core regression model is a difference-in-differences approach:

$$\text{Outcome}_{ct} = \alpha + \beta_1 D_{ct} + \beta_2 G_{ct} + \lambda_c + \lambda_t + \delta X_{ct} + \varepsilon_{ct} \tag{3}$$

  - Outcome_{ct}: Pollution, infant, or child health outcomes for county c at time t.
  - D_{ct}: Number of cheating diesel cars per 1,000 registered cars in county c at time t.
  - G_{ct}: Share of "cheating" gas cars per 1,000 cars (placebo control).
  - λ_c: County fixed effects (controls for time-invariant county characteristics).
  - λ_t: Time fixed effects (month-by-year, controls for common time trends).
  - X_{ct}: Time-varying county characteristics (e.g., population, poverty rate, median income, non-cheating diesel share, total cars, maternal characteristics).
  - ε_{ct}: Error term.
- Data are collapsed at county-month level (county-quarter for asthma), weighted by number of births for birth outcomes. Standard errors clustered at the county level.

Identification Strategy and Threats

- **Identifying Assumption:** The common trends assumption, implying that any trend deviations in "treatment counties" (with increasing cheating diesel shares) are driven by changes in the cheating diesel share.
- **Threats and Robustness Checks:**
  - **Differential Pre-existing Trends:** Explored using event study approach.
  - **Confounding Socioeconomic Changes:** Addressed with balancing regressions and inclusion of extensive controls.
  - **Unobserved Selection:** Use of "cheating" gas cars as a placebo. These were marketed to similar populations but did not cheat on emissions. If selection drives results, similar effects for both types of cars would be expected.
  - **Endogenous "Clean Diesel" Adoption:** Addressed using a Bartik shift-share instrument, interacting 2007 county-level VW market shares with the national "Clean Diesel" rollout.
  - **Reverse Experiment:** Analysis of the post-scandal period (2015-2017) and the effect of buybacks/repairs on outcomes.

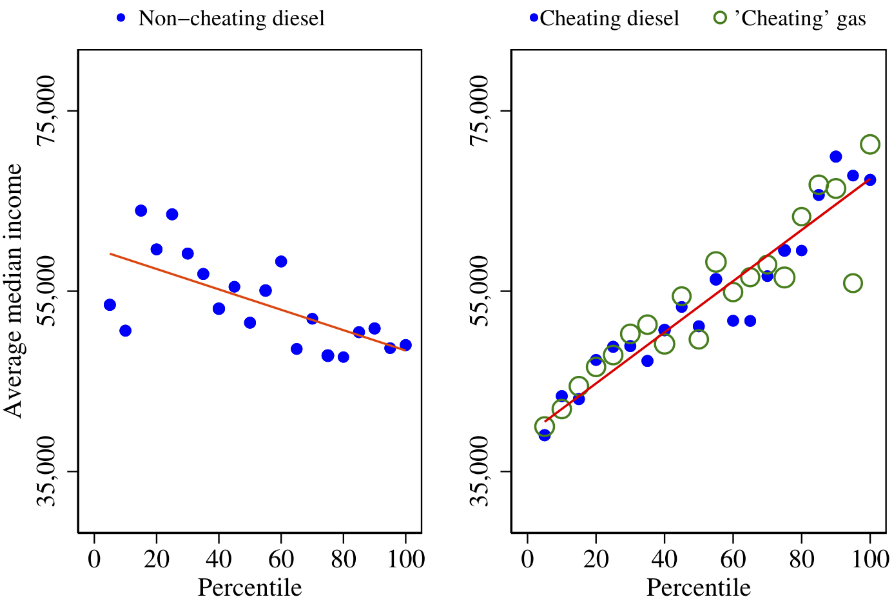

Non−cheating diesel
Cheating diesel
'Cheating' gas
Average median income
75,000
55,000
35,000
0
20
40
60
80
100
Percentile

FIGURE 2

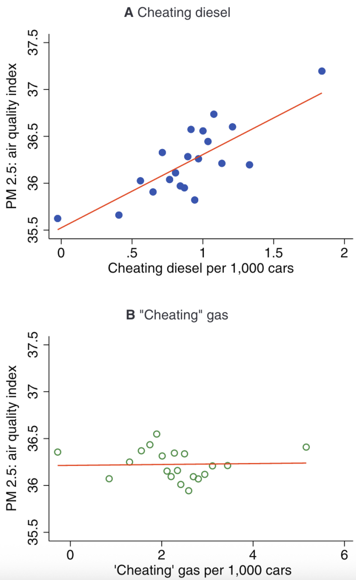
Effect of Diesel Emissions on Pollution (Regression Results) I

Table 1: Effect of Vehicle Composition on Pollution (Air Quality Index)

	PM2.5 (1)	PM10 (2)	Ozone (3)	CO (4)	NO2 (5)
Cheating diesel per 1,000 cars	0.78***	0.41***	0.55***	0.15*	0.020
	(0.16)	(0.14)	(0.12)	(0.090)	(0.093)
"Cheating" gas per 1,000 cars	-0.046	-0.10*	-0.0085	-0.046	-0.012
	(0.050)	(0.056)	(0.041)	(0.042)	(0.033)
FEs: county, time	Yes	Yes	Yes	Yes	Yes
Observations	55,940	34,766	64,206	18,392	23,401
R^2	0.531	0.582	0.613	0.675	0.868
Mean dep. var.	39.66	19.11	41.79	8.392	20.26
p-value ($\beta_1 = \beta_2$)	0.000	0.003	0.000	0.075	0.767

Effect of Diesel Emissions on Pollution (Regression Results) II

- Table 1 (based on Table 2 from the paper) shows statistically significant increases in Air Quality Index (AQI) for $PM_{2.5}$, PM_{10}, and ozone due to cheating diesel cars.
- For instance, an additional cheating car per 1,000 increases AQI for $PM_{2.5}$ by 0.78 points, which translates to a 1.97% increase relative to the mean.
- Coefficients for "cheating" gas cars are small, often negative, and generally not significant, supporting the placebo argument.
- Robustness checks confirm effects are concentrated within the county, with no significant spillovers to neighboring counties.


A Cheating diesel
PM 2.5: air quality index
35.5
36
36.5
37
37.5
0
.5
1
1.5
2
Cheating diesel per 1,000 cars
B "Cheating" gas
PM 2.5: air quality index
35.5
36
36.5
37
37.5
0
2
4
6
'Cheating' gas per 1,000 cars

Effect of Diesel Emissions on Infant Health (Regression Results)

Table 2: Effect of Vehicle Composition on Birth Outcomes

	Birth weight (g) (1)	Low birth weight (< 2,500 g) (2)	Gestational age (weeks) (3)	Infant mortality rate (4)
Cheating diesel per 1,000 cars	-6.229***	0.121***	-0.016***	0.009**
	(0.761)	(0.022)	(0.004)	(0.004)
"Cheating" gas per 1,000 cars	-0.358	-0.006	0.003***	-0.003***
	(0.228)	(0.006)	(0.001)	(0.001)
FEs: county, time	Yes	Yes	Yes	Yes
Observations	191,094	191,094	191,114	190,932
R^2	0.734	0.559	0.616	0.084
Mean dep. var.	3,302	6.314	38.74	0.5151
p-value ($\beta_1 = \beta_2$)	0.000	0.000	0.000	0.003

- significant negative impacts on average birth weight (-6.2g per 1,000 cheating cars), increases in low birth weight rates (0.12 percentage points), and decreases in gestational age.
- A smaller, but statistically significant, increase in infant mortality rate is also observed.
- The "cheating" gas coefficients are consistently insignificant or have opposite signs, reinforcing the causal interpretation.

Effects for Socioeconomic Subgroups I

Table 3: Effect of Vehicle Composition on Birth Weight by Subgroups (Micro Data)

	nHwhite (1)	Black (2)	College degree (3)	No college (4)	nHwhite college (5)	Black no college (6)
Panel A: Birth weight (in grams)						
Cheating diesel per 1,000 cars	-6.69***	-4.32**	-6.34***	-6.07***	-6.29***	-2.65
	(0.78)	(1.86)	(0.84)	(0.91)	(0.84)	(1.94)
"Cheating" gas per 1,000 cars	-0.23	-0.12	-0.40	-0.18	-0.50*	-0.30
	(0.24)	(0.40)	(0.30)	(0.27)	(0.28)	(0.51)
Panel B: Low birth weight ($< 2,500$ g)						
Cheating diesel per 1,000 cars	0.12***	0.13*	0.091***	0.16***	0.077***	0.089
	(0.022)	(0.070)	(0.024)	(0.029)	(0.023)	(0.089)
"Cheating" gas per 1,000 cars	-0.016***	0.0026	-0.0043	-0.0078	-0.0051	0.027
	(0.0054)	(0.017)	(0.0071)	(0.011)	(0.0058)	(0.024)

Notes: This table is based on Table 4 from the paper. nHwhite refers to non-Hispanic white mothers. Standard errors are clustered at the county level. ***, **, * indicate significance at 1%, 5%, and 10% levels, respectively.

Effects for Socioeconomic Subgroups II

- It reveals that effects on birth weight are larger for non-Hispanic white mothers than for black mothers.
- While point estimates are slightly larger for college-educated mothers, the difference is not statistically significant.
- This finding contrasts with literature often showing larger effects on disadvantaged populations, potentially due to spatial segregation and effective exposure.

Interaction with Pollution Baseline Levels

Table 4: Main Birth Results by Baseline Pollution Levels

	Birth weight (1)	Low birth weight (2)	Gestational age (3)	Preterm birth (4)
Cheating diesel per 1,000 cars	-6.163***	0.116***	-0.015**	-0.016
	(1.051)	(0.027)	(0.006)	(0.064)
Cheating diesel * 07/08 mean PM2.5	0.076	-0.011	-0.000	-0.073**
	(0.376)	(0.009)	(0.003)	(0.032)
Cheating diesel * out of compliance	-0.420	-0.016	-0.001	-0.122**
	(0.941)	(0.021)	(0.005)	(0.052)

- It indicates that the effects of cheating diesel cars on birth outcomes do not significantly differ across areas with higher or lower baseline $PM_{2.5}$ levels, or in areas compliant/non-compliant with EPA standards.
- This suggests that car pollution harms health even when overall pollution is below EPA-allowed concentrations, and effects are approximately linear.

Effect of Diesel Emissions on Asthma I

Table 5: Effect of Vehicle Composition on Asthma Visits to the Emergency Department

	PM2.5 (mean)	Visits to ED per 1,000		
	HCUP sample	All ages	Ages 0-4	Ages 5-25
	(1)	(2)	(3)	(4)
Cheating diesel per 1,000 cars	0.60***	-0.04	0.24**	-0.01
	(0.15)	(0.02)	(0.12)	(0.04)
"Cheating" gas per 1,000 cars	0.02	-0.00	-0.05*	-0.01*
	(0.02)	(0.01)	(0.03)	(0.01)
FEs: county, time	Yes	Yes	Yes	Yes
Observations	5,657	6,756	6,756	6,756
R^2	0.629	0.864	0.789	0.752
Mean dep. var.	8.556	1.212	3.384	1.727
p-value ($\beta_1 = \beta_2$)	0.000	0.173	0.037	0.857

Effect of Diesel Emissions on Asthma II

- It shows that even in the limited HCUP subsample, cheating cars significantly increased $PM_{2.5}$.
- An additional cheating diesel car per 1,000 is associated with a significant increase of 0.24 asthma ED visits per quarter per 1,000 children aged 0-4 (a 7% increase).
- This effect is not significant for all ages, highlighting the vulnerability of young children.

Summary of Key Findings

- Emissions-cheating diesel cars significantly increased ambient air pollution ($PM_{2.5}$, O_3).
- This led to measurable adverse health outcomes in infants and children:
  - Increased low birth weight rates (1.9%)
  - Increased infant mortality (1.7%)
  - Increased asthma ED visits for young children (8%)
- These effects were observed across all pollution levels and socioeconomic strata, highlighting car pollution as a broad societal health threat.

Policy Implications

- **Society-wide Health Threat:** Car pollution affects the general population, not just those in highly disadvantaged areas.
- **Informed Policy and Consumer Choice:** The full health costs of car pollution, particularly from diesel exhaust, need to be better communicated to regulators and the public.
- **Importance of Enforcement:** Strong environmental regulation requires robust enforcement. The scandal demonstrates that lax enforcement can incentivize firms to cheat, undermining regulatory goals.
- **Justification for Regulation:** Even moderate reductions in car pollution can yield significant societal benefits, justifying policies aimed at reducing emissions, including potentially restrictive ones like bans on high-emissions vehicles.
- No "safe level" of pollution: Health impacts occur even below EPA thresholds.