

Environmental Enforcement Actions and Corporate Green Innovation

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Contents

- 1 Introduction
- 2 Data
- 3 Research Design
- 4 Results
- 5 Conclusion

1. Introduction

Motivation

CALIFORNIA

The 1969 Santa Barbara oil spill that changed oil and gas exploration forever

By Christine Mai-Duc

May 20, 2015 6:38 PM PT



The oil spill that sent at least 21,000 gallons of crude through the waters near the Santa Barbara County coast on Tuesday brought haunting echoes of a much larger spill nearly half a century ago, one that gave birth to the modern environmental movement and forever changed the trajectory of oil and gas exploration in California.

The Santa Barbara oil spill of 1969 spewed an estimated 3-million gallons of crude oil into the ocean, creating an oil slick 35 miles long along California's coast and killing thousands of birds, fish and sea mammals.

Following the spill, the region became ground zero for some of the most significant conservation efforts of the 20th century.

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Catholic Athletic Assn. meeting ends in dispute over Mission League proposal

Figure 1: 1969 Oil Spill in the Santa Barbara of Southern California

1. Introduction

Motivation

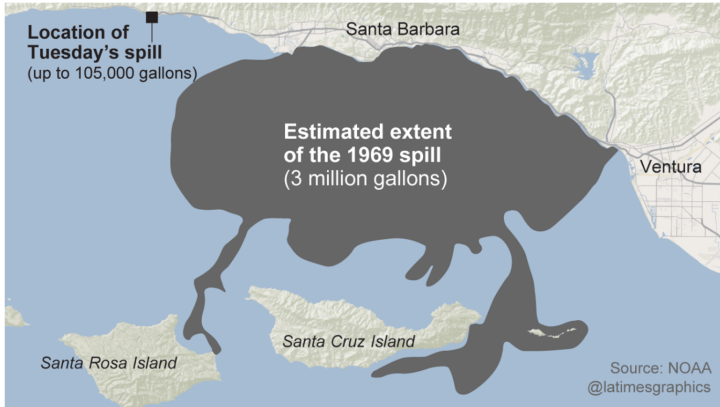


Figure 2: 1969 Oil Spill in the Santa Barbara of Southern California

1. Introduction

Motivation

- 1969 Santa Barbara oil spill → Growing public concerns about environmental pollution
⇒ Environmental Protection Agency (EPA) in 1970!
- EPA has **enforced** regulations on firms' production plants that violate environmental standards.
 - ▶ Serves as an external authority monitoring corporate environmental behaviors
- Enforcement actions
 - ▶ Informal: Letters or verbal (calls)
 - ▶ Formal: Administrative orders, legal actions, and monetary penalties (EPA, 2010; Shimshack, 2014)

1. Introduction

Motivation

- Firms can also internalize environmental externalities by adopting green technologies.
 - ▶ Reduce negative impacts on environments in their production processes/productions
- Research gap on whether the EPA's enforcement actions stimulate or hinder corporate green innovation outcomes

1. Introduction

Hypothesis Development

- Compliance costs
 - ▶ Enforcement → Inspections by the EPA on a plant ↑ ⇒ Oversight ↑
 - ▶ No corrective actions → More violations → Penalties
 - ▶ Monetary fines, environmental liabilities, or civil judicial and criminal actions (Mintz, 2012)
 - ▶ A firm's management has to respond!
⇒ Investments in innovative green technologies
- Reputational penalty
 - ▶ Negative impact on a firm's reputation
 - ▶ Abnormal returns ↓ (Karpoff et al., 2005)
 - ▶ Cost of capital ↑ (Hong and Kacperczyk, 2009)
 - ▶ CEOs' job security and future labor market reputation ↓ (Lel, 2023)
 - ▶ Violating firms may allocate more resources to green efforts and disclose these green investments to public ⇒ Good signal
- H1A: EPA enforcement actions will lead to an **increase** in corporate green innovation.

1. Introduction

Hypothesis Development

- Regulatory pressures
 - ▶ EPA enforcement on a plant $\rightarrow$ Regulatory pressures $\uparrow$
 - ▶ Current and future penalties and compliance costs
 - ▶ Performance $\downarrow$ & Future CF uncertainty $\uparrow \rightarrow$ Fewer financial resources
- Corporate innovation vs. Corporate managers
 - ▶ Innovation is followed by a long-term commitment and some short-term failures (Manso, 2011).
 - ▶ Corporate managers often exhibit risk aversion and a short-term orientation (Laux, 2012).
- H1B: EPA enforcement actions will lead to a **decrease** in corporate green innovation.

1. Introduction

Research Question

- Do environmental enforcement actions from the U.S. EPA affect corporate green innovation outcomes?
- Answer: Yes, by enhancing green innovation efficiency and hiring of green inventors

2. Data

- Patent data
 - ▶ U.S. patent data from Google Patent
 - ▶ Publicly available on Noah Stoffman's website (Kogan et al., 2017)
- EPA Plant-level enforcement cases
 - ▶ EPA's Integrated Compliance Information website Historical compliance records for each plant under various environmental statutes
 - ▶ Publicly available
- Firm-related financial data
 - ▶ Compustat/CRSP Merged dataset
- Final sample: 13,033 firm-year obs between 1968 and 2020

2. Data

Patent Data

- Following the OECD definition, patents are identified as "green" based on a patent's technology class (Hascic and Migotto, 2015).
 - ▶ 9 broad technological classes are considered as green patents.
- Two measures
 - ① **Count** of green patents the firm applied for in a year $\Rightarrow$ **Quantity**
 - ② Total number of forward **citations** received by the green patents that the firm applied for in a year $\Rightarrow$ **Quality**
- Scaling the green innovation measures by book value of total assets
 - ▶ To ensure that the variation in green innovation outputs is not driven by the fluctuation in firm size

2. Data

EPA Plant-level Enforcement Cases

- EPA enforcement data
 - ▶ ICIS-Air: Clean Air Act
 - ▶ ICIS-NPDES: Clean Water Act
 - ▶ RCRAInfo: Resource Conservation and Recovery Act
 - ▶ SDWA: Safe Drinking Water Act
 - ▶ ICIS-FE&C: Federal-level administrative and judicial cases
- The data contains the case number, the enforcement settlement date, the total penalty amount, the violating plant's name and its registry ID.
- Use fuzzy-matching methods to merge plant-level enforcement cases with a Compustat parent firm
 - ▶ Along with manual screening
- 20,525 formal enforcement cases related to 3,631 plants and 2,339 Compustat firms

2. Data

EPA Plant-level Enforcement Cases

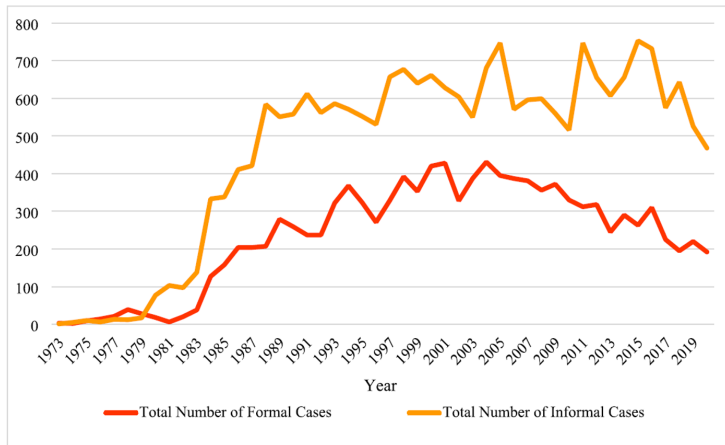


Figure 3: Total Number of Enforcement Cases of **Matched** Public Firms by Year

2. Data

EPA Plant-level Enforcement Cases

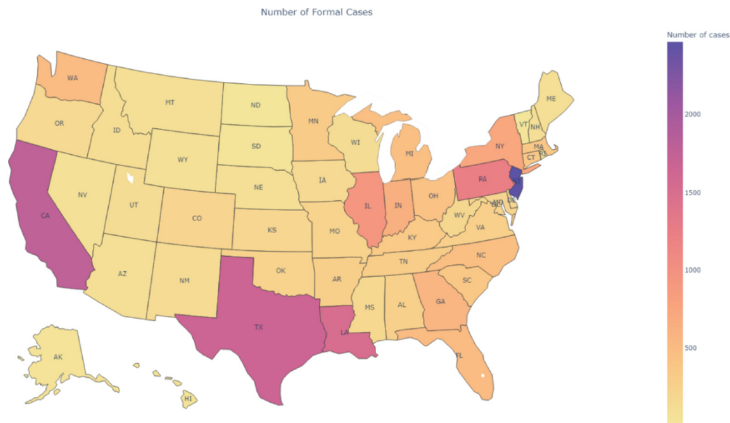


Figure 4: Cumulative Number of Formal Cases of **Matched** Public Firms by State

3. Research Design

Empirical Challenges

- ① A firm may experience EPA formal enforcements **more than once**.
 - ▶ Recent violators are more likely to violate again (Shimshack, 2014).
- ② EPA formal enforcement actions may be **non-random**.
 - ▶ Certain types of firms may be more likely to be targeted by the EPA.
- ③ The treatment effect of EPA enforcement actions on corporate green innovations can be **short-lived**.
 - ▶ Using a staggered DiD framework can lead to biased estimations (Baker et al., 2022).

3. Research Design

How to address challenges

- ① A firm may experience EPA formal enforcements **more than once**.
⇒ This paper focuses solely on the **first** EPA formal enforcement event for each affected firm.
- ② EPA formal enforcement actions may be **non-random**.
⇒ **None** of characteristics can predict next year's first-time formal enforcement events → Random..!
- ③ The treatment effect of EPA enforcement actions on corporate green innovations can be **short-lived**.
⇒ A period of each cohort is restricted between 5 years before and after the formal enforcement on the treated firm.
- Stacked-cohort DiD regression + PSM approach! (Gormley and Matsa, 2011)

3. Research Design

Solution on Challenge #2

<i>Panel C. Predicting First EPA Formal Enforcement Event</i>				
	(1)	(2)	(3)	(4)
VARIABLES	First Formal Enforcement (Treated)			
Green Patent Count/AT $t-1$	-0.001 (0.003)	-0.021 (0.028)	-0.001 (0.003)	-0.021 (0.029)
Green Patent Citations/AT $t-1$	0.002 (0.004)	0.008 (0.010)	0.002 (0.004)	0.008 (0.011)
IHS((Total Toxic Releases) $t-1$		0.004 (0.003)		0.004 (0.003)
Firm Size $t-1$			0.000 (0.003)	0.008 (0.005)
ROA $t-1$			0.004 (0.021)	0.034 (0.080)
MTB $t-1$			-0.001 (0.001)	-0.001 (0.001)
R&D/AT $t-1$			0.039 (0.037)	-0.073 (0.304)
CAPEX $t-1$			0.036 (0.062)	0.192 (0.164)
Cash $t-1$			0.002 (0.020)	0.006 (0.079)
Book Leverage $t-1$			0.009 (0.015)	0.043 (0.036)
Model	OLS	OLS	OLS	OLS
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Obs.	6539	1704	6539	1704
R2	0.179	0.200	0.180	0.203

Figure 5: How to address Challenge #2

3. Research Design

How to construct a Cohort

- Pre-matching → Post-matching sample
 - Pre-matching sample
 - ① Find a "**treated firm**" if it experiences formal enforcement for the first time
 - ② Choose "**control firms**" in the same industry (2-digit SIC) as the treated firm and **have never been enforced** in the past and in the five years after the enforcement event
 - Post-matching sample
 - ① Apply the PSM method to select the **industry peer** (2-digit SIC) control firms that have **no observable difference** in ex-ante firm characteristics as the treated firms.
 - ② Match the treated firm of that cohort with up-to-five industry peer control firms.
- ⇒ Final stacked-cohort sample: 416 cohorts and 13,033 firm-year obs

3. Research Design

Pre-Matching Results

<i>Panel A. Pre-Matching Firm Characteristics</i>					
VARIABLES	Treated Firms		Control Firms		Treated – Control
	N	Mean	N	Mean	Mean Difference
Firm Size _{t-1}	510	6.545	97,407	4.760	1.785***
ROA _{t-1}	510	0.035	97,407	-0.080	0.115***
MTB _{t-1}	510	2.999	97,407	4.012	-1.013***
R&D/AT _{t-1}	510	0.048	97,407	0.119	-0.071***
CAPEX _{t-1}	510	0.060	97,407	0.051	0.009***
Cash _{t-1}	510	0.129	97,407	0.277	-0.147***
Book Leverage _{t-1}	510	0.325	97,407	0.222	0.103***

Figure 6: Pre-Matching Firm Characteristics

3. Research Design

Post-Matching Results

Panel B. Post-Matching Firm Characteristics						
VARIABLES	Mean Value		Mean Difference	P-value	Number of Firms	
	Treated	Control			Treated	Control
Firm Size $t-1$	6.258	6.236	0.023	0.876	433	1655
ROA $t-1$	0.034	0.022	0.012	0.279	433	1655
MTB $t-1$	3.017	3.038	-0.021	0.938	433	1655
R&D/AT $t-1$	0.053	0.055	-0.002	0.748	433	1655
CAPEX $t-1$	0.060	0.060	-0.001	0.869	433	1655
Cash $t-1$	0.139	0.133	0.006	0.599	433	1655
Book Leverage $t-1$	0.299	0.307	-0.009	0.568	433	1655
Green Patent Count/AT $t-1$	0.060	0.090	-0.030	0.534	433	1655
Green Patent Citations/AT $t-1$	0.073	0.083	-0.010	0.785	433	1655
IHS(Total Toxic Releases) $t-1$	8.868	8.930	-0.061	0.853	187	354

Figure 7: Post-Matching Firm Characteristics

3. Research Design

Descriptive Statistics

<i>Panel F. Descriptive Statistics</i>						
VARIABLES	N	Mean	Std. Dev.	P25	Median	P75
<i>Dependent Variables</i>						
Green Patent Count/AT	13,033	0.090	0.580	0.000	0.000	0.000
Green Patent Citations/AT	13,033	0.107	0.749	0.000	0.000	0.000
IHS(Patent Count/R&D $t-1$)	13,033	1.248	1.350	0.000	0.863	2.099
IHS(Patent Citations/R&D $t-1$)	13,033	1.234	1.349	0.000	0.837	2.089
IHS(Green Patent Count/R&D $t-1$)	13,033	0.464	1.103	0.000	0.000	0.000
IHS(Green Patent Citations/R&D $t-1$)	13,033	0.431	1.087	0.000	0.000	0.000
Newly Hired Green	11,352	0.037	0.189	0.000	0.000	0.000
IHS(Newly Hired Green)	11,352	0.033	0.166	0.000	0.000	0.000
<i>Independent Variable</i>						
Firm Size $t-1$	13,033	5.854	2.134	4.233	5.747	7.375
ROA $t-1$	13,033	0.022	0.157	0.012	0.052	0.088
MTB $t-1$	13,033	2.969	3.707	1.188	1.964	3.330
R&D/AT $t-1$	13,033	0.063	0.084	0.017	0.038	0.077
CAPEX $t-1$	13,033	0.057	0.045	0.025	0.046	0.076
Cash $t-1$	13,033	0.160	0.184	0.033	0.090	0.219
Book Leverage $t-1$	13,033	0.271	0.212	0.082	0.256	0.408

Figure 8: Descriptive Statistics

3. Research Design

Regression Framework

- Stacked DiD

$$Y_{c,i,t} = \beta_1 Treated_{c,i} \times Post_{c,t} + \omega_{c,i} + \mu_{c,t} + \varepsilon_{c,i,t}$$

- ▶ Cohort c , Firm i , and Year t
 - ▶ $Y_{c,i,t}$: Green innovation measures
 - ① Green patent counts
 - ② Green patent citations
 - ▶ $Treated=1$ if firm i in cohort c is formally enforced by the EPA for the first time
 - ▶ $Post=1$ if year t in cohort c is after the enforcement event year
- β_1 captures the effect of first EPA formal enforcements on treated firms' green innovation relative to those of the control firms.

4. Results

Baseline Results

	(1)	(2)	(3)	(4)
VARIABLES	Green Patent Count/AT		Green Patent Citations/AT	
Treat × Post	0.058** (0.027)	0.058** (0.026)	0.099*** (0.035)	0.098*** (0.035)
<i>Lagged Firm Controls</i>				
Firm Size _{t-1}		-0.001 (0.006)		-0.001 (0.011)
ROA _{t-1}		-0.032 (0.067)		0.040 (0.127)
MTB _{t-1}		0.003 (0.003)		0.004 (0.004)
R&D/AT _{t-1}		0.024 (0.108)		0.130 (0.183)
CAPEX _{t-1}		-0.046 (0.174)		-0.258* (0.147)
Cash _{t-1}		0.123 (0.084)		0.024 (0.113)
Book Leverage _{t-1}		-0.007 (0.036)		-0.010 (0.055)
Model	OLS	OLS	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes
Obs.	13,033	13,033	13,033	13,033
R ²	0.588	0.589	0.514	0.514

Figure 9: Effect of First Formal EPA Enforcement on Corporate Green Innovation

- First formal enforcement → Green innovation ↑
 - 64% (93%) increase in patent counts (citations) compared to sample mean

4. Results

Robustness Tests

- ① Alternative green innovation measures
- ② Falsification test using **non-green** innovation outputs
 - ▶ To investigate whether the increase in green innovation among treated firms is merely coincidental
- ③ Various standard-error clustering methods
 - ▶ Cohort-firm only, firm & year, industry & year levels

4. Results

Robustness: Falsification test

Panel B. Placebo Tests on Non-green Patents						
VARIABLES	(1) Non-green Patent Count/AT	(2) Non-green Patent Citations/AT	(3) Non-green Patent Count	(4) Non-green Patent Citations	(5) IHS(Non-green Patent Count)	(6) IHS(Non-green Patent Citations)
Treat $\times$ Post	0.016 (0.011)	0.054** (0.026)	-0.076 (0.083)	-0.137 (0.095)	-0.000 (0.022)	-0.011 (0.024)
Model	OLS	OLS	Poisson	Poisson	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	13,033	13,033	12,925	12,824	13,033	13,033
R ² /Pseudo R ²	0.662	0.570	0.685	0.699	0.953	0.934

Figure 10: Placebo Tests on Non-green Patents

- The positive treatment effect on treated firms' green innovation is **unlikely** to be due to chance.

4. Results

Robustness: Standard Errors

<i>Panel C. Alternative Standard Error Clustering Structure</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Green Patent Count/AT	Green Patent Citations/AT	Green Patent Count/AT	Green Patent Citations/AT	Green Patent Count/AT	Green Patent Citations/AT
	<i>Clustered by Cohort-Firm</i>		<i>Clustered by Firm and Year</i>		<i>Clustered by Industry and Year</i>	
Treat × Post	0.058* (0.031)	0.099*** (0.038)	0.058** (0.027)	0.099*** (0.033)	0.058** (0.022)	0.099*** (0.031)
Model	OLS	OLS	OLS	OLS	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	13,033	13,033	13,033	13,033	13,033	13,033
R ²	0.662	0.570	0.919	0.888	0.953	0.934

Figure 11: Alternative Standard Error Clustering Structure

4. Results

Placebo Test: Informal Enforcements

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Green Patent Count/TA	Green Patent Citations/TA	Green Patent Count	Green Patent Citations	IHS(Green Patent Count)	IHS(Green Patent Citations)
Treat _{informal} × Post _{informal}	-0.027 (0.024)	-0.027 (0.033)	-0.112 (0.094)	-0.219* (0.116)	-0.024 (0.016)	-0.020 (0.019)
Model	OLS	OLS	Poisson	Poisson	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	23,427	23,427	5262	5116	23,427	23,427
R ² /Pseudo R ²	0.590	0.523	0.614	0.685	0.873	0.821

Figure 12: Effect of First Informal Enforcement on Corporate Green Innovation

- A firm that has undergone formal enforcement may have **already experienced** informal enforcement actions in the past (phone calls or letters).
⇒ Violation in parallel-trend assumption
- Informal actions are **not sufficient** to motivate violating firms to invest in green innovation.

4. Results

Mechanisms

- This section examines how environmental enforcements increase corporate green innovation.
 - ① R&D inputs
 - ② Innovation efficiency
 - ③ Hiring new inventors

4. Results

Mechanisms: R&D Inputs

- Do firms improve green innovation by **increasing** R&D inputs following its first formal enforcement by the EPA?
- Measures
 - ▶ R&D expenses scaled by total assets
 - ▶ R&D expenses scaled by sales revenues
 - ▶ Dollar amounts (in millions) of R&D expenses

4. Results

Mechanisms: R&D Inputs

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	R&D/AT		R&D/Sales		R&D	
Treat × Post	−0.004 (0.003)	−0.004 (0.003)	−0.029 (0.056)	−0.033 (0.053)	7.359 (10.239)	7.125 (10.191)
<i>Lagged Firm Controls</i>						
Firm Size t_{-1}		−0.001* (0.001)		−0.027 (0.021)		2.213 (1.712)
ROA t_{-1}		−0.012 (0.011)		0.777 (0.531)		10.801 (12.213)
MTB t_{-1}		−0.000 (0.000)		0.020 (0.025)		0.211 (0.599)
R&D/AT t_{-1}		−0.052* (0.032)		−0.132 (1.492)		8.543 (28.302)
CAPEX t_{-1}		0.031* (0.016)		−1.949 (1.753)		44.707 (38.669)
Cash t_{-1}		0.005 (0.008)		−0.595 (0.407)		−29.571* (15.383)
Book Leverage t_{-1}		0.001 (0.004)		−0.293 (0.338)		−10.451 (8.890)
Model	OLS	OLS	OLS	OLS	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	12,536	12,536	12,522	12,522	12,536	12,536
R ²	0.850	0.850	0.486	0.487	0.918	0.918

Figure 13: Innovation Inputs

- **No change in treated firms' R&D expenses**
 - Firms may prioritize their **existing** R&D spending rather than allocating additional resources.

4. Results

Mechanisms: Innovation Efficiency

- **No** significant change in R&D expenses
- Enforcements $\rightarrow$ Compliance costs $\uparrow$ $\rightarrow$ Higher CF uncertainty $\rightarrow$ Prioritizing the **efficient** use of R&D expenses over increasing them
- Reallocating financial resources
 - ▶ Lower-priority, lower-productivity non-green innovations $\rightarrow$ More productive and urgent green innovations
- Measures (Hirshleifer et al., 2013)
 - ▶ Patent count/citations in year t divided by accumulated R&D stock ending in year $t - 2$

4. Results

Mechanisms: Innovation Efficiency

Panel A. Overall Innovation Efficiency								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Patent Count/R&D Stock		Patent Citations/R&D Stock		IHS(Patent Count/R&D Stock)		IHS(Patent Citations/R&D Stock)	
Treat × Post	0.448*** (0.162)	0.443*** (0.160)	0.504*** (0.189)	0.498*** (0.188)	0.111*** (0.038)	0.110*** (0.037)	0.118*** (0.040)	0.117*** (0.039)
<i>Lagged Firm Controls</i>								
Firm Size _{t-1}		0.012 (0.030)		-0.005 (0.038)		0.002 (0.007)		-0.004 (0.008)
ROA _{t-1}		-0.282 (0.266)		0.138 (0.333)		-0.021 (0.067)		0.024 (0.073)
MTB _{t-1}		0.027*** (0.009)		0.019* (0.010)		0.004** (0.002)		0.003 (0.002)
R&D/AT _{t-1}		0.154 (0.450)		0.890 (0.617)		0.073 (0.121)		0.076 (0.135)
CAPEX _{t-1}		-0.466 (0.966)		-1.490 (1.116)		-0.084 (0.201)		-0.222 (0.214)
Cash _{t-1}		0.303 (0.263)		0.172 (0.329)		0.119** (0.060)		0.077 (0.066)
Book Leverage _{t-1}		-0.415** (0.211)		-0.352 (0.260)		-0.017 (0.047)		0.009 (0.052)
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	13,033	13,033	13,033	13,033	13,033	13,033	13,033	13,033
R ²	0.704	0.705	0.666	0.666	0.762	0.762	0.745	0.745

Figure 14: Overall Innovation Efficiency

- Treated firms tend to **improve** their overall innovation **efficiency** after experiencing the formal EPA enforcements for the first time.

4. Results

Mechanisms: Green Innovation Efficiency

<i>Panel B. Green Innovation Efficiency</i>								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Green Patent Count/R&D Stock		Green Patent Citations/R&D Stock		IHS(Green Patent Count/R&D Stock)		IHS(Green Patent Citations/R&D Stock)	
Treat × Post	0.348*** (0.118)	0.343*** (0.117)	0.367*** (0.140)	0.361*** (0.139)	0.106*** (0.033)	0.105*** (0.033)	0.113*** (0.034)	0.112*** (0.034)
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Lagged Firm Controls	No	Yes	No	Yes	No	Yes	No	Yes
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	13,033	13,033	13,033	13,033	13,033	13,033	13,033	13,033
R ²	0.657	0.658	0.593	0.593	0.694	0.694	0.666	0.667

Figure 15: Green Innovation Efficiency

- Treated firms significantly **increase** their efficiency in producing green innovation.

4. Results

Mechanisms: Hiring New Inventors

- A firm can also improve its innovation outputs by **redeployment** of human capital within the firm (Brav et al., 2018).
- Since green technology is a relatively new area, some firms may **lack** knowledge needed to innovate in the area.
- Source: U.S. patent inventors from the Harvard Business School USPTO database
- Measures
 - ▶ Indicator which equals one if the firm hires new inventor(s)
 - ▶ "Green" inventor if the inventor has produced at least one green patent before

4. Results

Mechanisms: Hiring New Inventors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Newly Hired (1/0)		IHS(Newly Hired)		Newly Hired (1/0)		IHS(Newly Hired)	
	Green Inventor				Non-Green Inventor			
Treat × Post	0.021** (0.010)	0.022** (0.009)	0.019** (0.008)	0.019** (0.008)	−0.028** (0.013)	−0.028** (0.013)	−0.025** (0.012)	−0.025** (0.012)
Lagged Firm Controls								
Firm Size _{t-1}		−0.003 (0.002)		−0.003 (0.002)		0.001 (0.003)		0.001 (0.003)
ROA _{t-1}		−0.014 (0.016)		−0.012 (0.014)		0.059* (0.031)		0.052* (0.028)
MTB _{t-1}		−0.001* (0.001)		−0.001* (0.000)		−0.001 (0.001)		−0.001 (0.001)
R&D/AT _{t-1}		0.034 (0.043)		0.030 (0.038)		−0.081 (0.069)		−0.071 (0.061)
CAPEX _{t-1}		−0.035 (0.051)		−0.031 (0.045)		−0.008 (0.078)		−0.007 (0.069)
Cash _{t-1}		−0.027 (0.018)		−0.024 (0.016)		0.024 (0.030)		0.022 (0.026)
Book Leverage _{t-1}		−0.007 (0.012)		−0.006 (0.011)		0.039** (0.020)		0.035** (0.017)
Model	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Cohort-firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	11,352	11,352	11,352	11,352	11,352	11,352	11,352	11,352
R ² /Pseudo R ²	0.474	0.474	0.474	0.474	0.426	0.428	0.426	0.428

Figure 16: Newly Hired Inventors

- Violating firms may have reallocated their human capital resources from non-green innovation projects to **green** innovation projects.

4. Results

Heterogeneity Tests and Implications

- Cross-sectional test results: The treatment effect is more pronounced in firms with -
 - ① Greater state enforcement intensity
 - ② Higher institutional ownership
 - ③ Less financially constrained
- Implications: Green innovation can help treated firms -
 - ① Avoid future EPA enforcements.
 - ② Reduce their future toxic chemical releases.

5. Conclusion

- This paper investigates whether and how EPA formal enforcement actions affect a firm's green innovation.
- Mechanisms
 - ▶ Innovation efficiency
 - ▶ Hiring green inventors
- Despite imposing short-term compliance costs, strict environmental enforcement effectively stimulates firms' green innovation, leading to sustained environmental and economic gains.