

Policy uncertainty reduces green innovation

Mengyu Wang (SMU)
Jeffrey Wurgler (NYU)
Hong Zhang(SMU)

Journal of Financial Economics, 2026
Presented by Byunghun Han

03/20/2026

Contents

- 1 Introduction
- 2 Institutional Setting
- 3 Data
- 4 Empirical Results
- 5 Conclusion

1. Introduction

Motivation



Figure 1: Namsan Tower: Good vs. Bad Air Quality (Source: Greenpeace)

1. Introduction

Motivation

- Airborne particulates impose pervasive health and economic impacts, contributing to an estimated 17% of all deaths in China.
 - ▶ Reduced productivity, human capital formation, and altered investor behavior (Graff Zivin and Neidell, 2012; Hanna and Oliva, 2015; Zou, 2021; Li et al., 2021)
- **Subsidies** are intended to overcome the failure to incorporate negative externalities, making environmentally friendly projects **attractive** that would otherwise be unprofitable.
- When these subsidies become **unreliable**, firms use an "option-to-wait" to gather more information about their true persistence.
⇒ Investments ↓ (Dixit and Pindyck, 1994; Baker et al., 2016; Gulen and Ion, 2016)

1. Introduction

Motivation

- This paper investigates the effectiveness of environmental subsidies on green investments that they are intended to stimulate.
 - ▶ Relatively little research on its effect on green investment
- Central planners rely on **Air Quality Index (AQI)** readings from a limited number of devices to establish targets and allocate subsidies down to firms.
- Policymakers often react to immediate, **salient** conditions, even when the underlying causes are difficult to disentangle.
 - ▶ The attribution of pollution becomes difficult because **weather "noise"** (e.g., wind and rain) heavily distorts AQI readings.
 - ▶ This creates an **unintended, weather-induced policy uncertainty** that can discourage the green R&D.

1. Introduction

Motivation

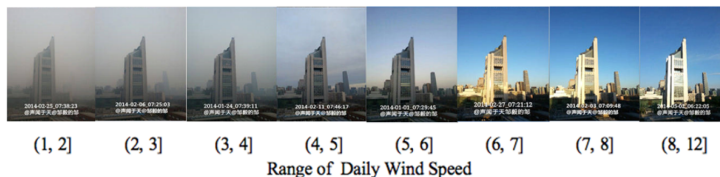


Figure 2: Photos from Beijing vs. Wind Speed, 2014

1. Introduction

Motivation

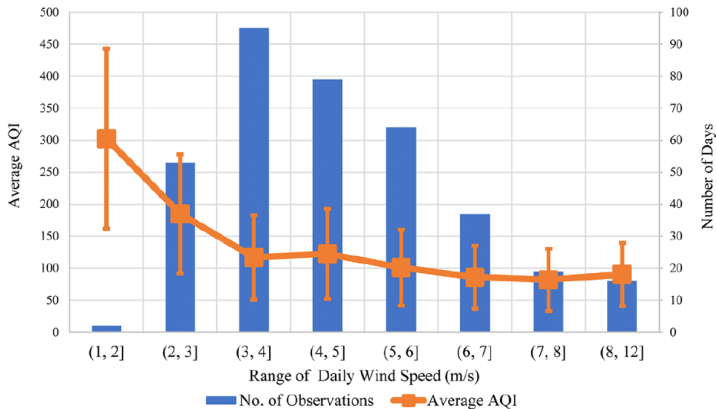


Figure 3: AQI and Wind Speed in Beijing, 2014

1. Introduction

Research Question

- How does unintended policy uncertainty affect the real green investments that subsidies are meant to stimulate?
 - ▶ Uncertainty driven by weather noise and government behavioral biases
 - **Answer:**
 - ① Significant reduction in green R&D expenditures
 - ② Significant reduction in environment-related technical employment
- ⇒ Through the "Option-to-Wait / Irreversibility Channel"

2. Institutional Setting

Environmental Subsidies in China

- Two Main Forms of Environmental Subsidies

- ▶ Directly subsidizing R&D or investment costs (e.g., funding 20–30% of total investment for energy conservation projects)
- ▶ Reimbursing firms for selling qualified green products at subsidized prices (e.g., New Energy Vehicles)

- Top-Down Allocation Mechanism

- ▶ Central government sets explicit air quality targets, typically based on **AQI metrics**, in five-year plans.
- ▶ Provincial and local (city) governments oversee implementation and distribute subsidies to firms to meet these top-down targets.

- High Policy Uncertainty

- ▶ Targets frequently shift across different five-year plans, and interim policies are often abruptly adopted or suspended.
- ▶ Firms experience extreme year-over-year volatility in received environmental subsidies.

2. Institutional Setting

Examples: Environmental Subsidies in China

- Considerable year-over-year fluctuations in received environmental subsidies
- Example 1: Shandong Lukang Pharmaceutical
 - ▶ 2009–2010: 3.8M → 5.1M RMB (Peak)
 - ▶ 2011–2012: Dropped to 1.5M → 1.1M RMB
 - ▶ 2013–2016: Plunged to ≤ 0.2 M RMB
 - ▶ 2017–2018: Rebounded to 0.6M → 2.1M RMB
- Example 2: Zijin Mining Group
 - ▶ 2008–2010: 2.9M → 8.1M RMB
 - ▶ 2011: Spiked to 39.3M RMB
 - ▶ 2012–2014: Decreased to 22.0M → 13.5M → 15.7M RMB
 - ▶ 2015–2017: Dropped to ≤ 9.0 M RMB

2. Institutional Setting

Simple model

- **Setup:** A firm raises capital (cost C) to invest in two independent technologies:
 - 1 **Green Tech (G):** Needs R&D, receives an uncertain subsidy S .
Expected Payoff $\sim N(\bar{R}_G + \bar{S}, \sigma_G^2 + \sigma_S^2)$.
 - 2 **Traditional Tech (X):** Normal capital expenditure.
Expected Payoff $\sim N(\bar{R}_X, \sigma_X^2)$.
- **Objective:** The firm determines optimal investment using mean-variance utility:

$$\max_{G,X} \left[G(\bar{R}_G + \bar{S} - C) - \frac{\gamma}{2} G^2(\sigma_G^2 + \sigma_S^2) \right] + \left[X(\bar{R}_X - C) - \frac{\gamma}{2} X^2 \sigma_X^2 \right]$$

(* γ : risk aversion penalty representing adjustment costs/irreversibility)

2. Institutional Setting & Model

Optimal Investment and Predictions

- **Optimal Green Investment (G^*):**

$$G^* = \frac{\bar{R}_G + \bar{S} - C}{\gamma(\sigma_G^2 + \sigma_S^2)}$$

$$\frac{G^*}{X^*} = \frac{\bar{R}_G + \bar{S} - C}{\gamma(\sigma_G^2 + \sigma_S^2)} \times \frac{\sigma_X^2}{\bar{R}_X - C}$$

- **Testable Predictions (Comparative Statics)**

- ① **Main Effect:** Higher subsidy policy uncertainty ($\sigma_S^2 \uparrow$) strictly **reduces** the level of green R&D.
- ② **Subsidy Reliance:** Higher average subsidies ($\bar{S} \uparrow$) increase green R&D, but they **amplify** the negative impact of policy uncertainty.
- ③ **Financial Constraints:** Higher borrowing costs ($C \uparrow$, i.e., financial pressures) **intensify** the negative impact of subsidy policy uncertainty on the share of green R&D.

3. Data

- Green R&D expenditures and Environmental government subsidies
 - ▶ Hand-collected from the footnotes of the financial statements in CSMAR
- Daily AQI readings
 - ▶ Ministry of Environmental Protection of China
- Weather data
 - ▶ China Meteorological Administration (CMA)
- City-level control variables
 - ▶ Consumption, GDP, GDP growth, population growth
 - ▶ Chinese Research Data Services Platform (CNRDS)
- Firm-level characteristics
 - ▶ Capital structure, profitability, investment opportunities
 - ▶ Wind, CSMAR, CNRDS

3. Research Design

Summary Statistics

	N	Mean	SD	5 %	25 %	50 %	75 %	95 %
Policy								
Green Subsidy	1340	12.67	6.40	0.00	12.61	15.22	16.64	18.49
Waste Gas Treatment	1340	13.96	7.93	0.00	13.48	18.07	19.24	20.32
Green Investment								
Green R&D	1340	11.00	9.54	0.00	0.00	17.03	19.44	21.62
Green R&D Employment	1340	4.00	3.70	0.00	0.00	5.09	7.30	9.16
Weather and Pollution								
AQI	1340	77.79	24.35	47.35	62.18	73.59	87.18	122.41
Wind Speed	1340	4.60	1.12	2.85	3.92	4.55	5.25	6.48
Windy Days	1340	103.03	75.20	4.00	39.50	92.50	151.00	246.00
SD Windy Days	1340	23.73	25.24	2.49	8.86	16.16	28.56	72.63
Rain Volume	1340	2.70	1.60	0.57	1.47	2.34	3.76	5.69
Rainy Days	1340	10.86	7.78	1.00	5.00	9.00	15.50	26.00
SD Rainy Days	1340	3.30	1.96	0.82	2.00	2.94	4.27	7.03
City Characteristics								
Consumption	1340	9.61	0.47	8.72	9.33	9.63	9.94	10.33
GDP	1340	10.63	0.78	9.36	10.15	10.65	11.10	11.94
GDP Growth	1340	9.83	4.82	3.89	7.60	9.30	12.50	16.00
Population Growth	1340	5.47	5.56	-2.77	2.23	5.30	8.49	14.74
City Firm Characteristics (Asset-weighted averages by headquarters city)								
Turnover	1340	0.72	0.33	0.34	0.53	0.68	0.84	1.24
ROA	1340	7.56	8.71	-0.95	4.59	7.40	10.17	15.59
Leverage	1340	0.50	0.21	0.27	0.40	0.47	0.56	0.79
Size	1340	21.87	0.90	20.43	21.30	21.86	22.43	23.28
Cash	1340	0.06	0.06	-0.02	0.03	0.05	0.08	0.14
Capex	1340	0.06	0.04	0.01	0.04	0.05	0.07	0.12
Profit Margin	1340	0.07	0.11	-0.10	0.04	0.09	0.12	0.18
Stock Return	1340	0.17	0.55	-0.36	-0.16	0.01	0.32	1.30

Figure 4: Summary Statistics

4. Empirical Results

Pollution and Subsidy Levels

- Cross-city investigation of the determinants of green subsidies
- Fama-MacBeth Specification:

$$GreenSubsidy_{j,t} = a_0 + a_1 \times AQI_{j,t-1} + A \times X_{j,t-1} + \varepsilon_{j,t}$$

- ▶ City j and Year t
- ▶ *GreenSubsidy*: Log of the total environmental subsidy provided to firm
- ▶ *AQI*: Average Air Quality Index in the previous year

4. Empirical Results

Pollution and Subsidy Levels

	(1) Green Subsidy	(2)	(3)	(4)	(5) Waste Gas Treatment	(6)
AQI		0.05*** (4.88)		0.05*** (3.34)	0.04*** (5.08)	0.04*** (4.93)
Consumption	-0.31 (-0.63)	0.03 (0.06)	0.27 (0.50)	0.65 (1.17)	-1.40 (-1.29)	-1.03 (-1.08)
GDP	2.97*** (5.67)	2.93*** (5.69)	2.56*** (5.52)	2.54*** (5.43)	2.37** (2.58)	2.22** (2.49)
GDP Growth	-0.02 (-0.65)	-0.02 (-0.62)	-0.01 (-0.23)	-0.00 (-0.03)	0.04 (1.09)	0.05 (1.23)
Population Growth	-0.01 (-0.29)	0.02 (0.86)	0.01 (0.44)	0.05 (1.43)	-0.11*** (-3.77)	-0.10*** (-3.68)
Average firm characteristics	NO	NO	YES	YES	NO	YES
Avg R ²	0.15	0.18	0.24	0.26	0.22	0.33
Observations	1825	1825	1813	1825	1825	1813

Figure 5: AQI as a Determinant of Green Subsidies

- On average, environmental subsidies are higher in cities with worse air pollution in previous year.
 - Consistent with another government-guided environmental program
 - ▶ City-level expenditures on treatment of industrial waste gas
- ⇒ Subsidies ↔ Local bureaucratic attention to environmental conditions

4. Empirical Results

Preliminary: Effect of Weather on AQI

- Does weather have a causal effect on city-year AQI?

$$AQI_{j,t,s} = b_0 + b_1 \times WindSpeed_{j,t,s} + b_2 \times RainVolume_{j,t,s} \\ + B \times X_{j,t} + \delta_j + \delta_t + \varepsilon_{j,t,s}$$

- ▶ City j , heating or non-heating season s , and year t
- ▶ *WindSpeed*: Average daily wind speed in the same city and period
- ▶ *RainVolume*: Average daily rain volume in the same city and period

4. Empirical Results

Preliminary: Effect of Weather on AQI

	(1) AQI	(2)	(3)	(4)
	All Cities		Northern Cities	
	Heating	Non-heating	Heating	Non-heating
Wind Speed	-3.15*** (-3.52)	-2.63*** (-3.48)	-5.13*** (-3.09)	-2.34* (-1.78)
Rain Volume	-2.62*** (-4.82)	-1.73*** (-4.62)	-1.60 (-0.49)	-3.33*** (-2.41)
Consumption	10.19** (2.20)	-0.68 (-0.16)	-22.44** (-2.04)	-13.87 (-1.40)
GDP	-2.34 (-1.36)	-1.78 (-1.40)	-1.09 (-0.40)	-0.42 (-0.24)
GDP Growth	-0.09 (-1.18)	0.00 (0.04)	0.45** (2.26)	0.41** (2.27)
Population Growth	0.08 (0.71)	0.08 (0.79)	0.49*** (2.68)	0.17 (0.94)
City and year fixed effects	YES	YES	YES	YES
City and year clustering	YES	YES	YES	YES
Adj R ²	0.98	0.98	0.98	0.97
Observations	1699	1699	845	845

Figure 6: Influence of Weather on the Air Quality Index (AQI)

- Weather has a negative effect on city-year AQI, controlling for city and year fixed effects.
 - Heating and non-heating seasons
 - Northern cities as well

4. Empirical Results

Policy Uncertainty and Green R&D

- **The Endogeneity Challenge:** Policy uncertainty and investment are often endogenously connected.
- A Motivating Anecdote
 - ▶ Nov 2010: U.S. Embassy in Beijing recorded a "crazy bad" AQI of 562.
 - ▶ Although the exact causes were unclear (a mix of weather, traffic, coal), environment-related subsidies to Beijing firms surged by **78%** the next year.
- **The Behavioral Mechanism**
 - ▶ Bureaucrats face institutional imperatives to simply 'do something' about high pollution.
 - ▶ They are subject to cognitive biases: *salience, recency, and availability*.
 - ▶ Policymakers overreact to extreme, highly visible pollution readings while underappreciating the less salient role of weather (wind/rain).

⇒ This behavioral channel effectively transfers exogenous **weather uncertainty** into endogenous **policy uncertainty**.

4. Empirical Results

Policy Uncertainty and Green R&D

- First stage: Weather $\rightarrow$ Policy Uncertainty

$$PU_{j,t-5:t} = c_0 + c_1 \times SD\ Windy\ Days_{j,t-6:t-1} \\ + c_2 \times SD\ Rainy\ Days_{j,t-6:t-1} + G \times X_{j,t} + \delta_j + \delta_t + \varepsilon_{j,t}$$

- *PU*: City-characteristics-adjusted S.D. of the green subsidies in the six-year window
- *SD Windy Days*: S.D. of the number of windy days in the city j in a six-year window
- *SD Rainy Days*: S.D. of the number of rainy days in the city j in a six-year window

- Second stage: Policy Uncertainty $\rightarrow$ Green R&D

$$GreenR\&D_{j,t+1} = d_0 + d_1 \times \hat{PU}_{j,t-5:t} + d_2 \times AvgSubsidy_{j,t-5:t} \\ + D \times X_{j,t} + \delta_j + \delta_t + \eta_{j,t}$$

4. Empirical Results

Policy Uncertainty and Green R&D

	(1) Green R&D OLS regression	(2) PU 1 st Stage	(3) Green R&D 2 nd Stage	(4)	(5)
$\widehat{PU}$ (or PU for OLS)	-0.29** (-2.02)		-2.39*** (-2.82)		-2.23*** (-2.64)
Avg Green Subsidy				0.36*** (2.91)	0.34*** (2.76)
SD Windy Days		0.01*** (3.27)			
SD Rainy Days		0.16*** (3.71)			
AQI	0.01 (0.44)	-0.00 (-1.10)	0.02 (1.45)	0.03** (2.02)	0.02 (1.41)
Consumption	0.38 (0.11)	-0.07 (-0.08)	-0.97 (-0.34)	-0.83 (-0.30)	-1.17 (-0.41)
GDP	1.32* (1.89)	-0.56*** (-2.76)	0.15 (0.16)	1.64** (2.20)	0.28 (0.32)
GDP Growth	0.05 (1.50)	0.01 (0.50)	0.01 (0.29)	0.00 (0.05)	0.01 (0.19)
Population Growth	0.04 (0.64)	-0.05*** (-3.91)	-0.08 (-1.11)	0.04 (0.67)	-0.07 (-0.98)
City and firm control variables	YES	YES	YES	YES	YES
City and year fixed effects	YES	YES	YES	YES	YES
City and year clustering	YES	YES	YES	YES	YES
1 st Stage F		14.5			
Adj R2	0.84	0.89	0.84	0.84	0.84
Observations	1340	1340	1340	1340	1340

Figure 7: Policy Uncertainty and Green R&D

4. Empirical Results

Robustness: Placebo test

	(6)	(7)	(8)
	Placebo Dependent Variables		
	Y = Total R&D - Green R&D	Y = Capital Expenditure	Y = Capital expenditure of real- estate firms
$\widehat{\rho}_U$	0.83 (1.48)	-0.00 (-0.44)	0.03 (0.32)
Avg Green Subsidy	0.01 (0.11)	-0.00 (-0.11)	0.02** (2.06)
City and aggregated firm-level characteristics	YES	YES	YES
City and year fixed effects	YES	YES	YES
City and year clustering	YES	YES	YES
Adj R ²	0.96	0.86	0.96
Observations	1340	1340	1340

Figure 8: Placebo Test

- Weather-induced green policy uncertainty does **not** affect:
 - Non-green R&D
 - Capital expenditures
 - Capex of real estate firms

4. Empirical Results

Heterogeneous Impacts of Policy Uncertainty

- To further validate the theoretical mechanisms, this paper investigates which types of firms are most sensitive to policy uncertainty.
- The fundamental purpose of the policy is to bridge the profitability gap for green projects.
⇒ Firms that **inherently depend** on these subsidies to innovate should exhibit a much sharper decline in green R&D when uncertainty rises.
- Subsidies act as a crucial external funding source that relaxes the cost of capital for highly specific R&D.
⇒ Firms facing severe **financial pressures** should be more vulnerable to the uncertainty of external government support.

4. Empirical Results

Heterogeneous Impacts of Policy Uncertainty

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Green R&D (Firm)											
$\widehat{PU}$	-0.40*** (-2.72)	-0.17 (-1.09)	-0.38** (-2.43)	-0.41*** (-2.75)	-0.39** (-2.53)	-0.18 (-1.19)	-0.40*** (-2.61)	0.10 (0.63)	-0.32** (-2.11)	-0.37** (-2.50)	-0.40*** (-2.69)	0.58*** (3.31)
$\widehat{PU} \times \text{Green Tech}$		-0.58*** (-7.47)										-0.48*** (-6.02)
$\widehat{PU} \times \text{Metropolitan}$			-0.07 (-0.73)									-0.22** (-2.41)
$\widehat{PU} \times \text{Large}$				0.11 (0.71)								-0.08 (-0.60)
$\widehat{PU} \times \text{SOE}$					-0.04 (-0.46)							-0.07 (-0.85)
$\widehat{PU} \times \text{Subsidy Reliant}$						-0.62*** (-7.77)						-0.35*** (-4.20)
$\widehat{PU} \times \text{Different Cities}$							-0.01 (-0.10)					-0.10 (-0.99)
$\widehat{PU} \times \text{Manufacturing (C)}$								-0.78*** (-10.13)				-0.66*** (-7.70)
$\widehat{PU} \times \text{Chemical (C25, C26, C28, C29, C41, C43)}$									-0.76*** (-5.07)			-0.41*** (-2.59)
$\widehat{PU} \times \text{Metal (C31, C32, C65, C67, C33)}$										-0.92*** (-4.44)		-0.51** (-2.39)
$\widehat{PU} \times \text{Public Facility (N)}$											-0.91** (-2.52)	-1.12*** (-3.02)
Avg Green Subsidy	0.06* (1.74)	0.05 (1.56)	0.06* (1.74)	0.06* (1.78)	0.06* (1.76)	0.06* (1.72)	0.06* (1.77)	0.06* (1.87)	0.05* (1.67)	0.06* (1.75)	0.06* (1.70)	0.05 (1.48)
City and firm characteristics	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm and year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Adj R2	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Observations	26189	26189	26189	26189	26189	26189	26189	26189	26189	26189	26189	26189

Figure 9: Policy Uncertainty and Green R&D: Firm Differences

- Green-tech, More subsidy-reliant, and Polluting industries

4. Empirical Results

Heterogeneous Impacts of Policy Uncertainty

	(1)	(2)	(3)	(4)
		Green R&D (Firm)		
$\widehat{PU}$	-0.04	-0.21	-0.19	-0.19
	(-0.24)	(-1.28)	(-1.21)	(-1.21)
$\widehat{PU} * \text{Green Tech}$	-0.39***	-0.60***	-0.57***	-0.57***
	(-3.95)	(-7.11)	(-6.99)	(-6.99)
$\widehat{PU} * \text{Green Tech} * \text{Subsidy Reliant}$	-0.33**			
	(-2.02)			
$\widehat{PU} * \text{Green Tech} * \text{Over-indebtedness}$		-0.55**		
		(-2.09)		
$\widehat{PU} * \text{Green Tech} * \text{Interest Coverage Ratio A}$			0.30*	
			(1.81)	
$\widehat{PU} * \text{Green Tech} * \text{Interest Coverage Ratio B}$				0.33*
				(1.91)
Avg Green Subsidy	0.05	0.06	0.06	0.06
	(1.54)	(1.63)	(1.62)	(1.62)
Double interactions and firm characteristics	YES	YES	YES	YES
City and firm characteristics	YES	YES	YES	YES
Firm and year fixed effects	YES	YES	YES	YES
Adj R2	0.43	0.43	0.43	0.43
Observations	26189	24068	24681	24681

Figure 10: Policy Uncertainty and Green R&D: Subsidy Reliance and Financing

- Column 2: Over-Indebtedness $\uparrow \Rightarrow$ More constrained
- Column 3-4: Interest Coverage Ratio $\uparrow \Rightarrow$ Less constrained

4. Empirical Results

Green R&D Employment

	(1)	(2)	(3)
	Green R&D Employment		
$\widehat{PU}$	-1.07*** (-3.41)		-1.00*** (-3.22)
Avg Green Subsidy		0.16*** (3.61)	0.15*** (3.42)
City and average firm characteristics	YES	YES	YES
City and year fixed effects	YES	YES	YES
City and year clustering	YES	YES	YES
Adj R2	0.85	0.85	0.85
Observations	1340	1340	1340

Figure 11: Policy Uncertainty and Green R&D Employment

- To examine the effect of green subsidies on labor input
- Shocks to policy uncertainty appear to reduce green employments.

5. Conclusion

- This paper investigates whether and how environmental subsidy policy uncertainty affects a firm's green innovation.
- IV strategy using AQI as an instrument
- Mechanisms
 - ▶ Bureaucratic behavioral biases (Salience and recency)
 - ▶ Option-to-wait (Irreversibility of green RD)
- Unintended policy uncertainty significantly undermines government subsidies, highlighting the hidden real costs of noisy, behaviorally-driven policymaking on green investments.