The Impact of Corporate Climate Action on Financial Markets: Evidence from Climate-Related Patents

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GT Chaire FDIR Seminar
22 June 2023

Motivation: The Role of Climate Innovation

- Climate innovation expected to be crucial for transition to net zero
  - IEA (2020), IPCC (6th AR, 2021 and 2022)
  - Acemoglu, Aghion, Bursztyn and Hemous (2012), Acemoglu, Aghion, Barrage, Hemous (2020)
- What are the incentives for firms to invest in climate innovation?
  - Corporate sector by far the largest source of greenhouse gas (GHG) emissions (CDP, 2017)
  - Innovation an important vector of corporate decarbonization effort
  - Corporate climate action under increasing scrutiny from financial markets: valuations, votes, ESG ratings
    - ★ 2/3 of S&P500 firms with CO2 targets, 29% SBTi certified (Morgan Stanley, 2021)
    - ★ challenge for investors to obtain accurate information: misleading information abounds (greenwashing, noisy ratings, etc.)

Research Questions: Climate Innovation and Markets

- We study the financial markets reaction to climate patent grants
- Two types of effects of climate patents:
  - Social benefits: contribution to the reduction in GHG emissions
  - Private benefits: effect on (financial and social) firm performance and incentives for decision-makers
- We ask: do financial markets pay attention to climate innovation?
- Do investors consider climate patents as a form of climate or social performance and accept lower financial returns?
  - realized vs. expected performance
- Are there ESG-related transmission channels in financial markets?
- Do climate patents contribute to climate mitigation (social benefits)?
  - mitigation effects of climate innovation are uncertain, in spite of high expectations and public investment
  - the "CO2 Question" (Bolton, Kacperczyk, and Wiedemann, 2022): does energy efficiency simply contribute to more energy use?

Corporate Climate Action and Performance: Identification and Lucky Patents

- True impact of corporate climate action on firms' financial performance? Growing research, but 2 major challenges:
  - Problem #1: Endogeneity (firm-level characteristics correlated with ESG ratings)
  - Problem #2: Noise in ESG scores and greenwashing (BP, Coca-Cola, Starbucks, ...)
- Climate patents offer 2 major methodological advantages:
  - patent approval process allows to exploit quasi-random variation: instrumental variable approach
    - ★ unique among corporate climate policies
  - grant by USPTO or EPO: rigorous scrutiny, mitigates concerns about greenwashing

Introduction: Empirical Strategy

- USPTO and EPO identify climate-related patents with tag ("Y02") as part of Cooperative Patent Classification (CPC)
  - e.g. for renewable energy, storage, energy efficiency, smart grids

- Patent examination process: quasi-random variation in patent approvals
  - Some patent examiners are more lenient and grant patents more easily
  - Patent applications are assigned to examiners in a quasi-random way
    - ★ Sampat and Williams (2019), Farre-Mensa, Hegde, Ljungqvist (2020), Melero, Palomeras, Wehrheim (2020)
    - ★ We compare innovative firms with patents granted by luck to similarly innovative firms with patents rejected by luck
  - This enables us to study causal impact of climate patent grants (endogeneity issues in analyses of ESG-financial performance link)

Preview of Results

- Financial markets react positively to lucky climate patents
  - positive cumulative abnormal returns in the next 12 months
  - Firms with lucky climate patents enjoy lower cost of capital
  - Heightened concerns to climate change amplify effects
  - No effect for the granting of other green patents
- Evidence on ESG-related transmission channels:
  - ESG rating agencies react favorably, increase in Environmental Score
  - Environment-focused institutional investors increase holdings by 5%
- Findings consistent with a rational signaling effect
- Firms with climate innovations reduce carbon emissions, but effect does not depend on patent granting

Literature Review

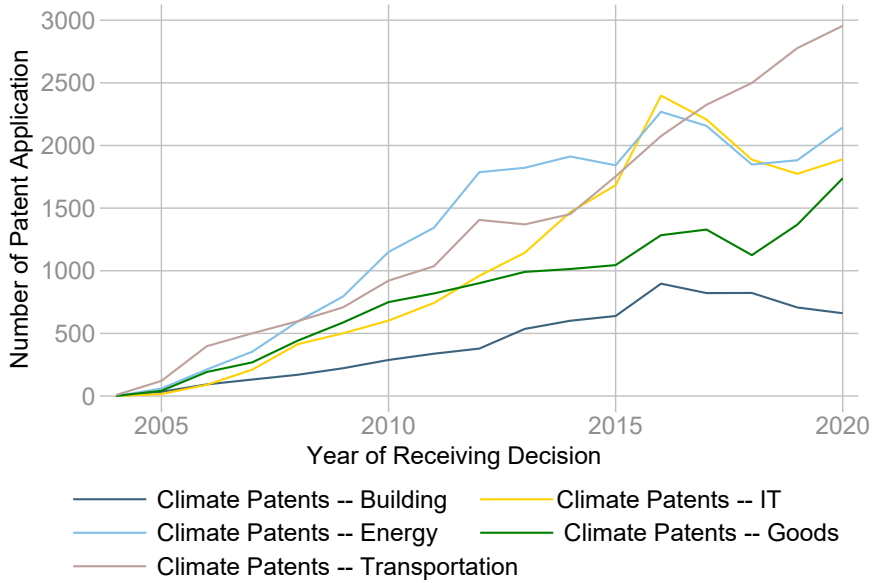
- Corporate climate performance and financial market reaction
  - Realized and expected returns: Chava (2014); In, Park, and Monk (2019); Bolton and Kacperczyk (2021, 2023); Pastor, Stambaugh, and Taylor (2021)
  - Institutional investors: Starks, Venkat, and Zhu (2017); Gibson, Glossner, Krueger, Matos, and Steffen (2020); Krueger, Sautner, and Starks (2020); Gibson Brandon, Krueger, and Mitali (2020); Atta-Darkua, Glossner, Krueger, and Matos (2022)
- Green patents and climate-related patents
  - Cohen, Gurun, and Nguyen (2021); Dechezleprêtre, Muckley, and Neelakantan (2019); Bolton, Kacperczyk, and Wiedemann (2022)
- Patents and financial markets
  - Hall, Jaffe, and Trajtenberg (2005); Cohen, Diether, and Malloy (2013); Hirshleifer, Hsu, and Li (2013); Kogan, Papanikolaou, Seru, and Stoffman (2017); Fitzgerald, Balsmeier, Fleming, and Manso (2021)

Data and Sample Construction

- Focus on listed US-headquartered firms from 2004 to 2020
- Patent applications data
  - USPTO Patent Examination Research Dataset (PatEx)
  - USPTO Patent assignment database (Assignees)
  - PatentsView (CPC codes)
- Identify climate-related patents following "Y02" label of CPC scheme
- Identify other green patents following OECD (Haščič and Migotto, 2015)
- Refinitiv ESG database
  - Within-industry percentile-rank ESG scores
  - Direct CO2 emissions, renewable energy usage, clean energy usage
- CRSP and Compustat
- Refinitiv 13F for institutional stock holdings

Summary Statistics (1)

Panel A: Sample of Green Patent Applications	
Number of Green Patents Applications	86,363
Number of Granted Green Patents	63,691 (73%)
Average Years between Application and Granting	3.09
Climate-Related Patents Only (CPC: Y02)	
Number of Green Patents Applications	66,796
Number of Granted Green Patents	48,814 (73%)
Average Years between Application and Granting	3.14
Other (Non-Climate) Green Patents Only	
Number of Green Patents Applications	19,567
Number of Granted Green Patents	14,877 (75%)
Average Years between Application and Granting	2.93



Summary Statistics (2)

- Firm-years (firm-months) with decisions on climate patent applications

Panel C: Refinitiv ESG Sample (Merged with Climate-Related Patents)

Number of Firms:	419
Number of Climate-Related Patent Applications:	56,150

Variable	Mean	Median	sd	min	max	N
Firm-Year Sample						
Num Climate Pat. App. (receiving decisions)	22.72	4	70.02	1	1042	2471
Num Climate Patent Grants	16.67	3	52.49	0	670	2471
Average Relative Leniency	0.00	0.00	0.09	-0.51	0.37	2471
Environmental Score	0.68	0.84	0.30	0.08	0.97	2471
Market Cap (Log)	9.31	9.19	1.70	2.66	14.49	2471
Tobin's Q	2.27	1.83	1.49	0.66	16.48	2200
CAPX	0.04	0.03	0.04	0.00	0.42	2461
R&D	0.07	0.04	0.09	0.00	0.83	2398
Firm-Month Sample						
Num Climate Pat. App. (receiving decisions)	5.26	2	10.26	1	184	11993
Num Climate Patent Granted	3.90	1	7.94	0	115	11993
Average Relative Leniency	0.00	0.00	0.11	-0.72	0.40	11993

Identification Strategy: Examiner Leniency

- Patent examination process
  1. USPTO attaches set of technology classes and assign to an "art unit"
  2. Quasi-randomly assigns an examiner within art unit
- First stage regression:

$$Num\_Climate\_Pats\_Granted_{i,t} = \delta Avr\_Leniency_{i,t} + \pi \mathbf{X}_{i,t} + \tau_{app,t} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{i,t}$$

$$Avr\_Leniency_{i,t} = \frac{1}{N_P} \sum_{p \in P_{i,t}} \Big(\overbrace{\frac{Num\_Pat\_Granted_{e,p} - I(Granted)_p}{Num\_Pat\_Examined_{e,p} - 1}}^{\text{granting ratio of the examiner } e} - \underbrace{\frac{Num\_Pat\_Granted_{a,p} - I(Granted)_p}{Num\_Pat\_Examined_{a,p} - 1}}_{\text{granting ratio in the art unit } a} \Big) \quad (2)$$

- $\tau_{app,t}$: F.E. for number of climate patent decisions in year t
- $\iota_{a,t}$: art unit $\times$ year F.E.; $\nu_{j,t}$: industry $\times$ year F.E.
- S.E. double-clustered at firm and industry $\times$ year level

Test of Instrument Validity (1)

- Relevance condition: Instrument is strong

Panel A: First Stage Regression Dependent Var.	Num Green Patents Granted		
Sample	Firm-Year	Firm-Quarter	Firm-Month
Average Relative Leniency	1.127***	0.856***	0.868***
	(0.164)	(0.0732)	(0.0489)
Firm Controls	Y	Y	Y
Industry × Year F.E.	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y
Num Obs.	1,351	5,005	110,666
Adj. R^2	0.914	0.912	0.882

Test of Instrument Validity (2)

- Exclusion condition: instrument is not correlated with firm characteristics

Panel B: Exogenous Tests Dependent Var.	Average Relative Leniency [t]						
Environmental Score [t-1]	-0.0162 (0.0115)						
Firm Size [t-1]		0.0051 (0.0026)					
Cash [t-1]			-0.0262 (0.0202)				
ROA [t-1]				0.0268 (0.0245)			
CAPX [t-1]					-0.0408 (0.1641)		
R&D [t-1]						-0.0537 (0.0407)	
Average Leniency [t-1]							0.0269 (0.0526)
Industry × Year F.E.	Y	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y	Y
Num Pat Applications F.E.	Y	Y	Y	Y	Y	Y	Y
Num Obs.	1286	1286	1286	1267	1267	1224	943
Adj. R^2	0.291	0.291	0.290	0.292	0.287	0.297	0.342

Second Stage: Financial Market Outcomes

- In the second stage, we regress the outcome variable onto the instrumented number of patents and control variables
- Example: Cumulative Abnormal Return (FF 5-factor model):

$$2SLS: \quad CAR[t+1:t+k]_{t,s} = \alpha \widehat{Num\_Climate\_Pats\_Granted}_{t,s} + \beta \mathbf{X}_{t,s} + \tau_{app,t} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{t,s}$$

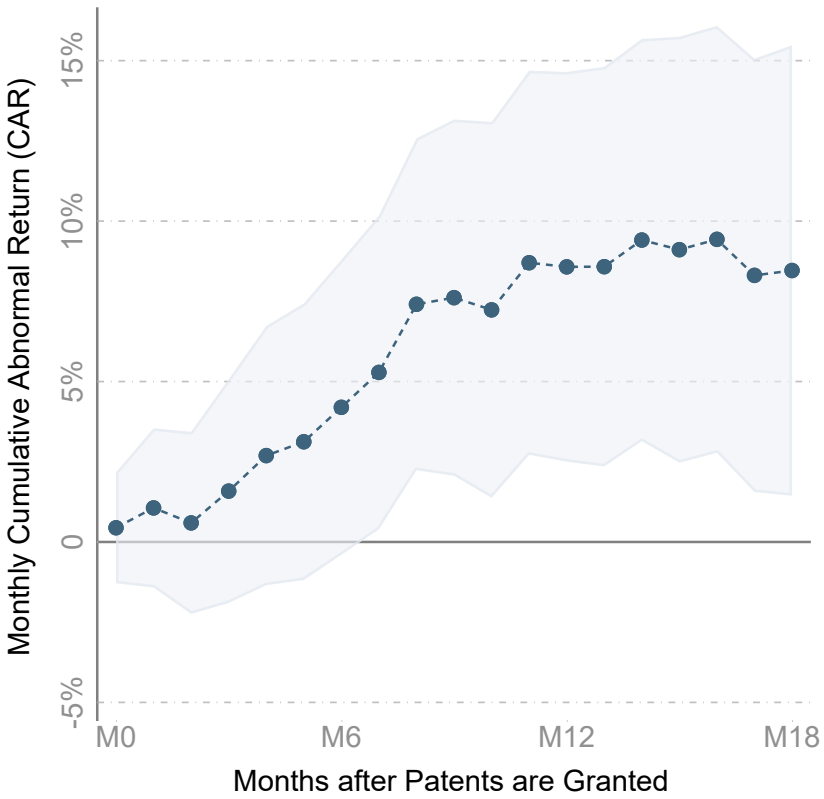
- $\tau_{app,t}$: number of climate patent decisions in month t F.E.
- $\nu_{j,t}$: industry $\times$ month F.E.
- $\iota_{a,t}$: art unit $\times$ year F.E.
- Controls $\mathbf{X}_{t,s}$ include market cap., Tobin's Q, Cash, ROA, R&D, past 12-month stock performance, and environmental score, all measured in year $t-1$
- S.E. double-clustered (firm and industry $\times$ year level)

Climate Patents and Medium-Term Stock Returns

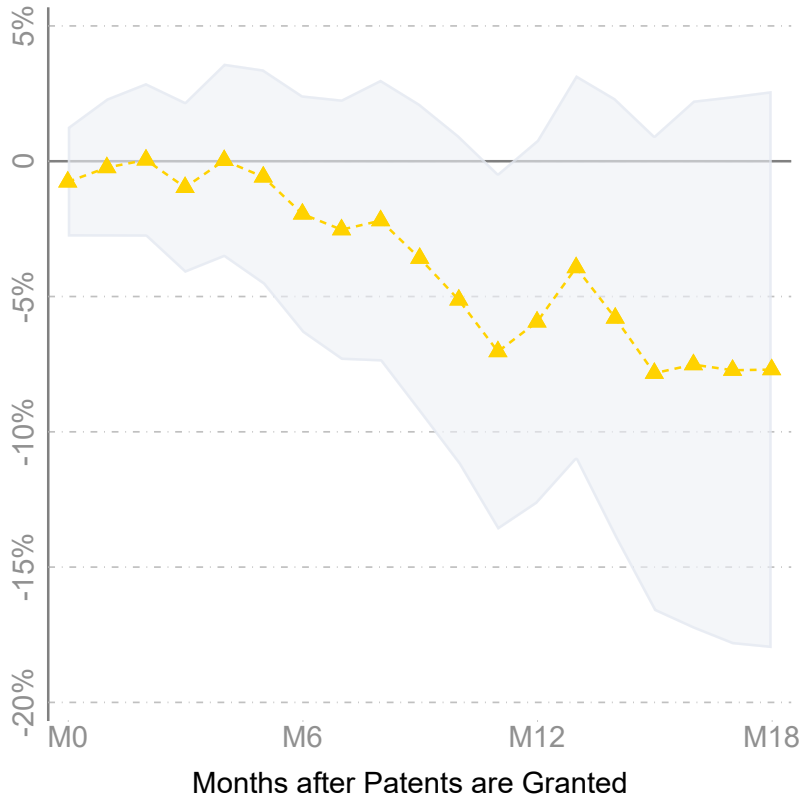
- How do lucky climate patents affect realized returns?
- 2SLS of CAR on # of climate patents over $k = 1, 2, 3, \cdots, 18$ months (firm-month sample):

$$CAR[t+1, t+k]_{t,s} = \alpha \widehat{Num\_Climate\_Pats\_Granted}_{t,s} + \beta \mathbf{X}_{t,s} + \tau_{app,t} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{t,s}$$

Panel A: Climate Patents



Panel B: Other Green Patents



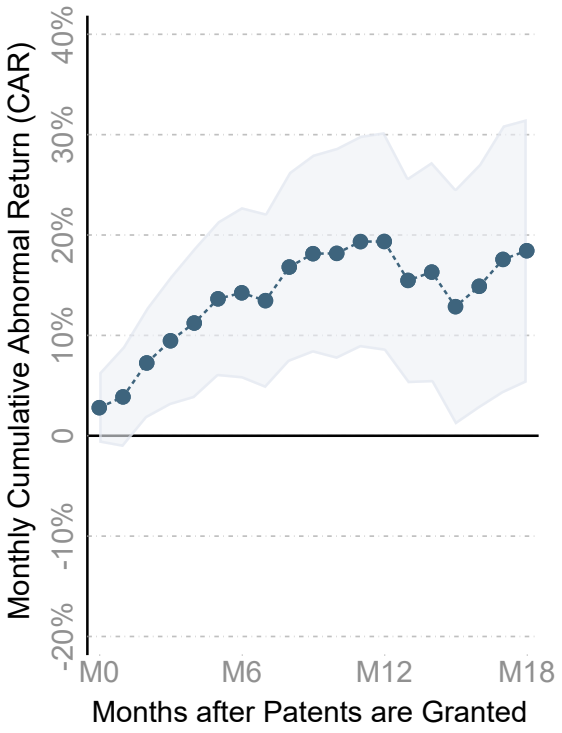
Climate Patents and Medium-Term Stock Returns (2)

- Our results are robust when:
  - we use only past patents to measure Average Leniency and construct our instrumental variable
  - we study abnormal returns over a longer window of 36-month (even if confidence intervals widen, there is no reversal)
  - we consider changes in log-prices instead of abnormal returns
- As a placebo test, we studied abnormal returns for the 4-month period before the granting date and found no effect of lucky climate patents

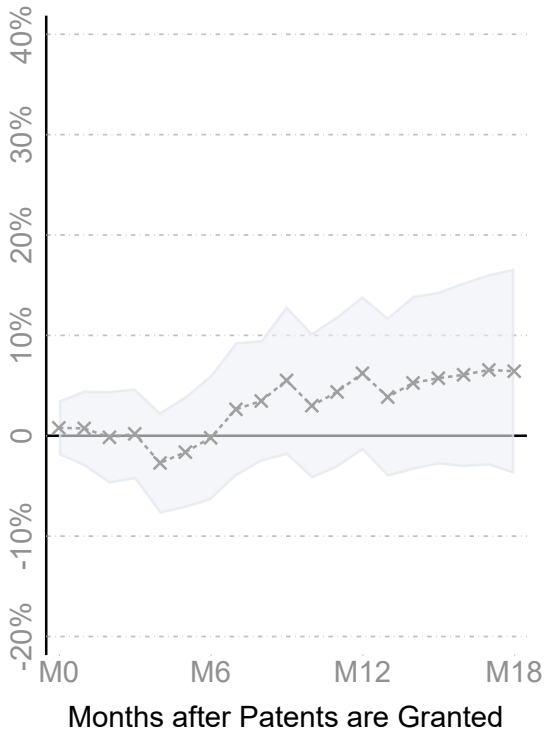
Concern About Climate Change and Stock Returns

- Effect should be stronger when more attention to climate change
- Interact with MCCC index (Media Climate Change Concerns) of Ardia, Bluteau, Boudt, and Inghelbrecht (2021), that reflects number and level of concern of climate news in major 8 US newspapers

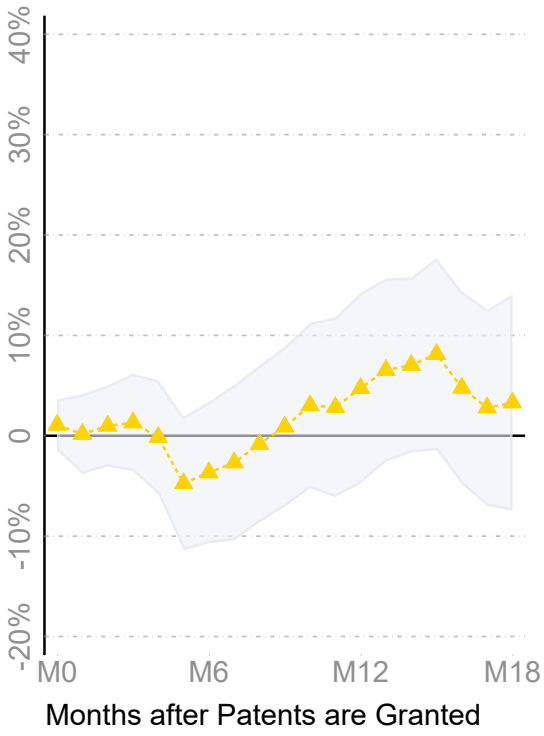
Panel A: Coeff. MCCI_High (High Tercile)



Panel B: Coeff. MCCI_Mid (Mid Tercile)



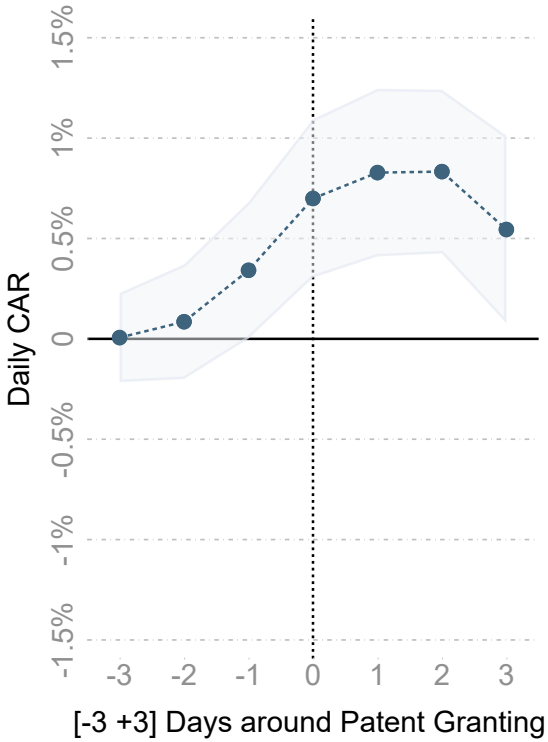
Panel C: Coeff. MCCI_Low (Low Tercile)



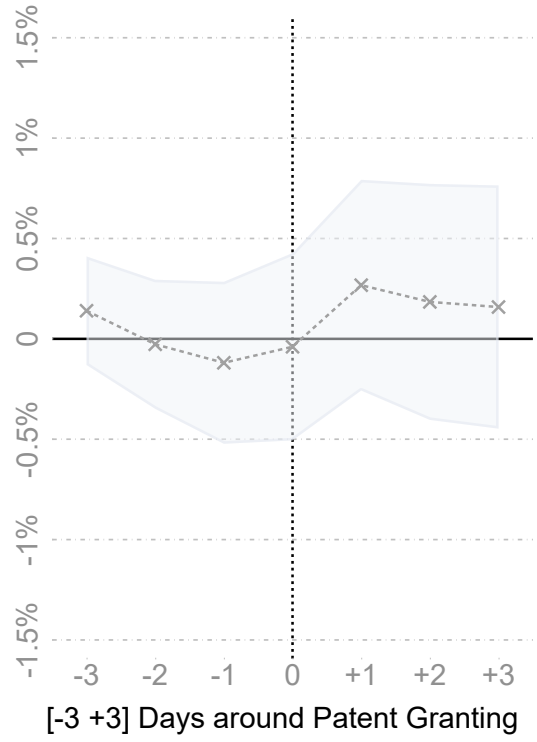
Climate Patent Announcements and Daily Stock Returns

- Consider daily stock returns around patent announcement
- Interact again with MCCC index

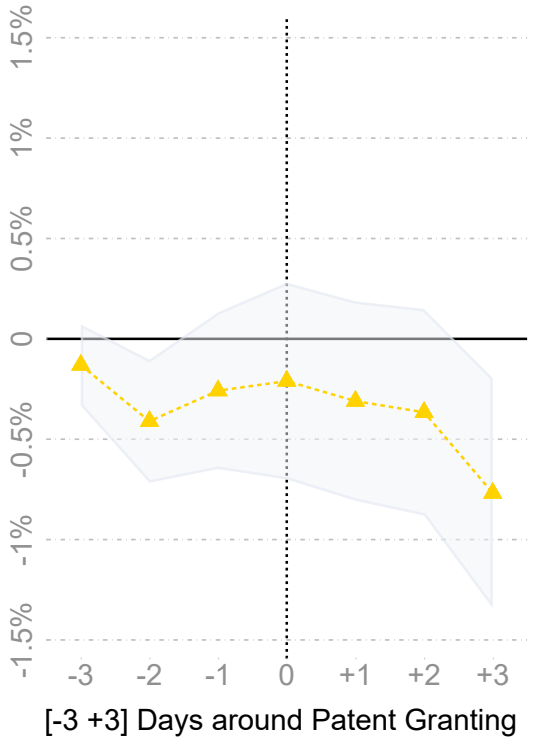
Panel A: Coeff. MCCI_High (High Tercile)



Panel B: Coeff. MCCI_Mid (Mid Tercile)



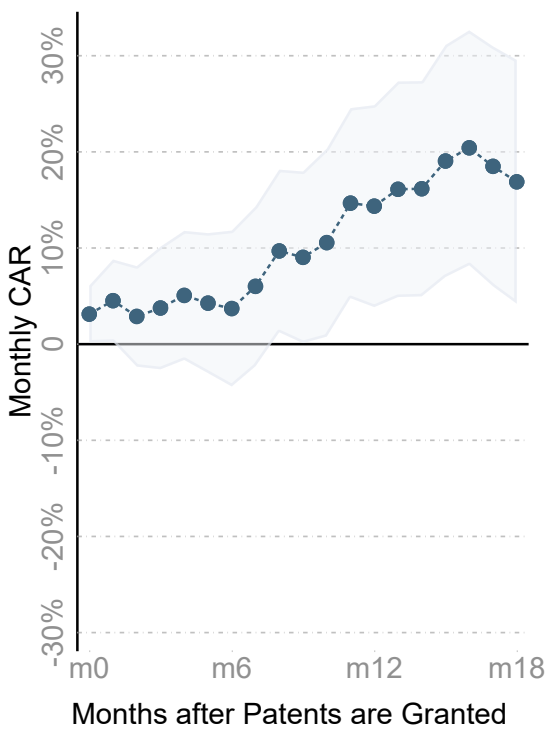
Panel C: Coeff. MCCI_Low (Low Tercile)



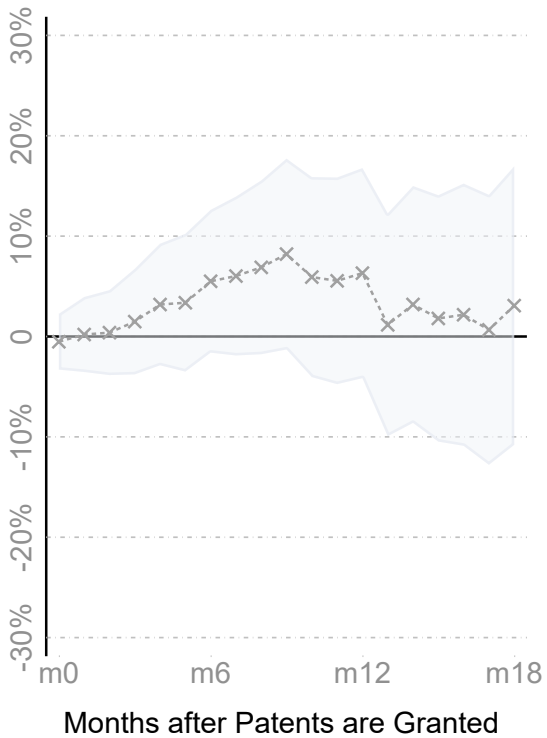
Climate Patent Stock and Stock Returns

- If patent signal to ESG audience: effect should be stronger for first green patents
- Follows argument of Farre-Mensa et al. (2020)

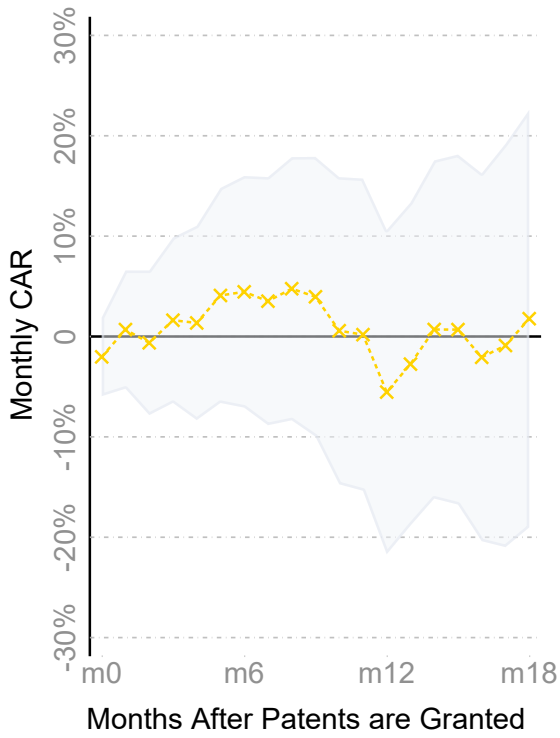
Panel A: Low Clim PatStock (Low Tercile)



Panel B: Mid Clim PatStock (Mid Tercile)



Panel C: High Low Clim PatStock (Low Tercile)



Implied Cost of Capital

- We turn to measure of expected stock return
- Calculation of implied cost of capital (ICC) follows Hou, Van Dijk, and Zhang (2012), Lee, So, and Wang (2021), and Pastor, Stambaugh and Taylor (2022)

$$P_t \times Num\_Shares_t = B_t + \sum_{\tau=1}^{11} \frac{E_t[ROE_{t+\tau} - r]B_{t+\tau-1}}{(1+r)^{\tau}} + \frac{E_t[ROE_{t+12} - r]B_{t+11}}{r(1+r)^{11}}$$

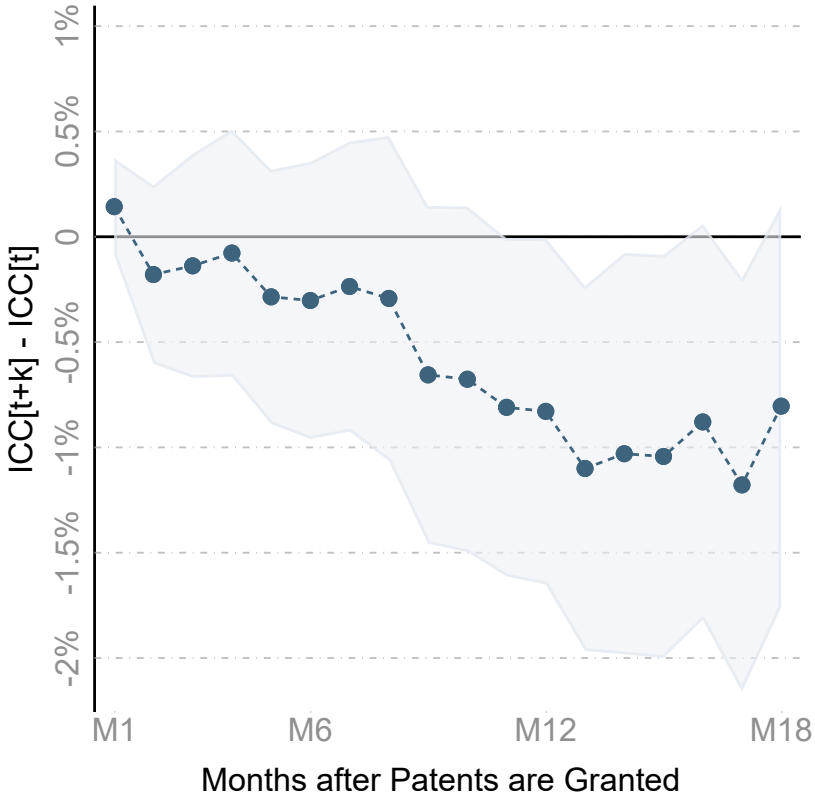
- $ROE_{t+\tau}$ is the predicted ROE = earnings forecast in USD, scaled by book equity in previous year $(B_{t+\tau-1})$
- earnings forecast obtained as:
  - year 1 to 3: regression-based method
  - year 4 to year 11: linear interpolation to the industry average
  - year 12 and after: industry average
- We numerically solve for ICC r in eq. (1) for each firm-month

Climate Patents and Implied Cost of Capital

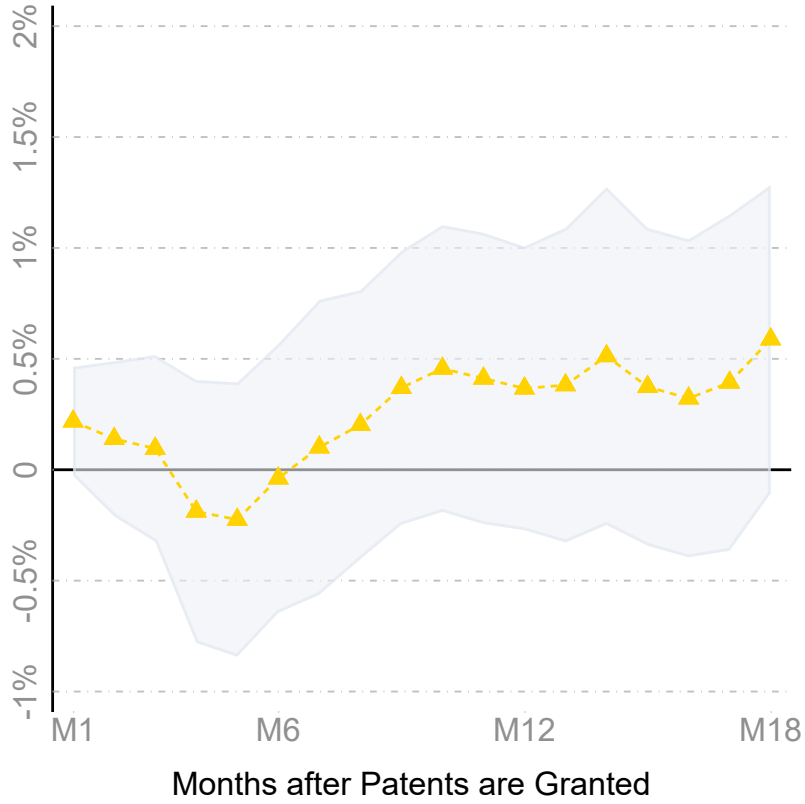
- Focus on climate patents; $k = 1, 2, \cdots, 18$

$$2SLS: \quad ICC_{t+k,s} - ICC_{t,s} = \alpha \widehat{Num\_Climate\_Pats\_Granted}_{t,s} + \beta \mathbf{X}_{t,s} + \tau_{app,t} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{t,s}$$

Panel A: Climate Patents



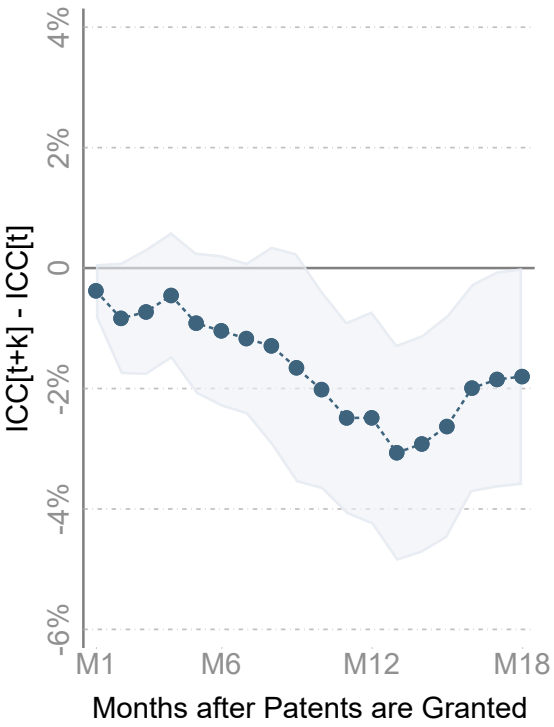
Panel B: Other Green Patents



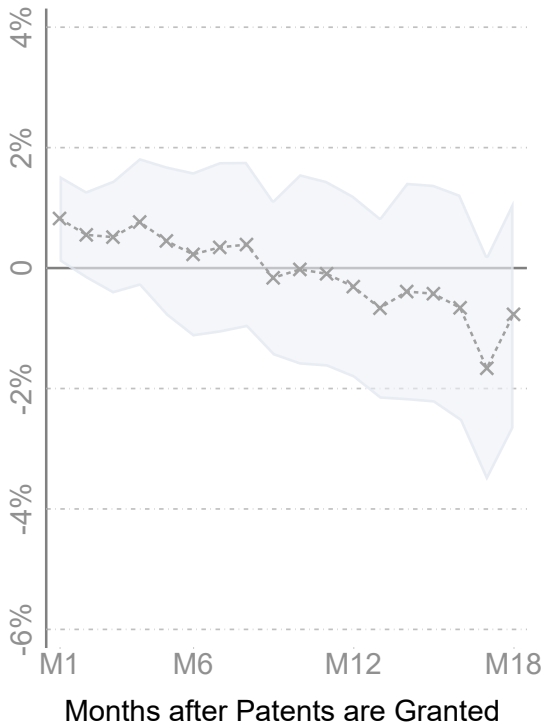
Implied Cost of Capital and Climate Change Concerns

- Focus on climate patents; $k = 1, 2, \cdots, 18$
- Interact with MCCC index

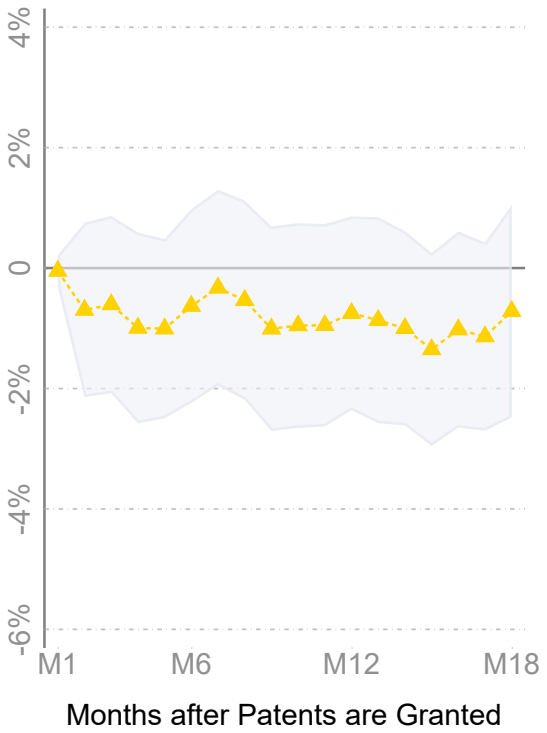
Panel A: Coefficients of α_1 (High Tercile)



Panel B: Coefficients of α_2 (Mid Tercile)



Panel C: Coefficients of α_3 (Low Tercile)



Underlying Channels?

- Results so far: lucky climate patents positively associated with realized return (CAR) and negatively with expected return (ICC)
- We study two potential (non-exclusive) transmission channels
  - ESG rating agencies may react positively (lucky) climate patent grants
  - Investors' demand for stocks may follow (lucky) climate patent grants

Climate Patents and Environmental Score

$$\Delta_{(t+k,t)} Env\_Score_i = \alpha \widehat{Num\_Clim\_Pats}_{i,t} + \beta \mathbf{X}_{i,t} + \tau_{app} + \mu_{j,t} + \nu_{a,t} + \varepsilon_{i,t}$$

Panel A: Climate Related Patents

Dependent Var.	(1) Environmental Score	(2) Environmental Score	(3) Emission Score	(4) Emission Score	(5) Resource Use Score	(6) Resource Use Score
	t+1 - t	t+2 - t	t+1 - t	t+2 - t	t+1 - t	t+2 - t
Num Climate-related Patent Grants	0.139**	0.166**	0.0554	0.253***	0.0789	0.115
(Instrumented by Leniency)	(0.0625)	(0.0799)	(0.0531)	(0.0830)	(0.0545)	(0.0780)
F Statistic for Weak Instrument	58.56	50.97	58.56	50.97	58.56	50.97
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y	Y
Num Obs.	1132	965	1132	965	1132	965

Panel B: Other Green Patents

Dependent Var.	(1) Environmental Score	(2) Environmental Score	(3) Emission Score	(4) Emission Score	(5) Resource Use Score	(6) Resource Use Score
	t+1 - t	t+2 - t	t+1 - t	t+2 - t	t+1 - t	t+2 - t
Num Other Green Patent Grants	-0.0337	-0.0493	0.00670	0.0132	0.0761	0.0751
(Instrumented by Leniency)	(0.107)	(0.0962)	(0.112)	(0.0924)	(0.114)	(0.104)
F Statistic for Weak Instrument	22.86	30.12	22.86	30.12	22.86	30.12
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y	Y
Num Obs.	537	464	537	464	537	464

Climate Patents and Institutional Ownership

Panel A: Climate-related Patents							
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Change of Institutional Ownership				
Period	t-1 - t-2	t - t-1	t+1 - t-1	t+2 - t-1	t+3 - t-1	t+1 - t-1	t+2- t-1
Num Clim. Pat. Grants	-0.0117	0.0416***	0.0629**	0.0710**	0.0708**		
(Instrumented)	(0.0173)	(0.0160)	(0.0265)	(0.0302)	(0.0307)		
Num ClimPat× MCCC_High						0.0390**	0.0359*
Num ClimPat × MCCC_Mid						-0.00271	0.0169
Num ClimPat × MCCC_Low						0.00176	0.00725
Firm Controls	Y	Y	Y	Y	Y	Y	Y
Ind×Qtr, Art U×Yr F.E.	Y	Y	Y	Y	Y	Y	Y
Num Patent App. F.E.	Y	Y	Y	Y	Y	Y	Y
Num Obs.	4745	4741	4598	4456	4327	4132	4114

Panel B: Other Green Patents							
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Change of Institutional Ownership				
Period	t-1 - t-2	t - t-1	t+1 - t-1	t+2 - t-1	t+3 - t-1	t+1 - t-1	t+2- t-1
Num Other Green Pat. Grants	-0.0262	0.00286	0.00225	0.00888	0.0228		
(Instrumented)	(0.0225)	(0.0157)	(0.0251)	(0.0311)	(0.0328)		
Firm Controls	Y	Y	Y	Y	Y		
Ind×Qtr, Art U×Yr F.E.	Y	Y	Y	Y	Y		
Num Patent App. F.E.	Y	Y	Y	Y	Y		
Num Obs.	1911	1910	1841	1776	1707		

Climate Patents and Environment-Focused Investor Change

$$ln(Shares_{i,t+k,s}) - ln(Shares_{i,t-1,s}) = \alpha \widehat{Num\_ClimPats}_{t,s} + \beta \mathbf{X}_{i,t,s} + \mu_{i,t} + \nu_{j,t} + \iota_{a,t} + \tau_{app} + \varepsilon_{i,t,s}$$

Panel A: Institutions with Top Quintile Environmental Score Footprint

Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Change of Stock Holding by Institution					
Period	t - t-1	t - t-1	t+1 - t-1	t+1 - t-1	t+2 - t-1	t+2 - t-1
Num Clim. Pat. Granted	0.0375***	0.0506***	0.0451***	0.0538***	0.0534***	0.0569***
(Instrum. Leniency)	(0.00878)	(0.00992)	(0.0145)	(0.0159)	(0.0186)	(0.0203)
Firm Controls	Y	Y	Y	Y	Y	Y
Ind × Year F.E.	Y	Y	Y	Y	Y	Y
Art U. × Year F.E.	Y	Y	Y	Y	Y	Y
Num ClimPat. App. F.E.	Y	Y	Y	Y	Y	Y
Investor F.E.	Y		Y		Y	
Num Obs.	682528	667878	581729	568384	500584	488291

Panel B: Institutions with Bottom Quintile Environmental Score Footprint

Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Change of Stock Holding by Institution					
Period	t - t-1	t - t-1	t+1 - t-1	t+1 - t-1	t+2 - t-1	t+2 - t-1
Num ClimPat. Granted	-0.0100	-0.00571	0.00560	-0.0129	-0.0324	-0.0633
(Instrum. Leniency)	(0.0257)	(0.0312)	(0.0353)	(0.0412)	(0.0439)	(0.0497)
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y
Num ClimPat. App. F.E.	Y	Y	Y	Y	Y	Y
Investor F.E.	Y		Y		Y	
Num Obs.	403962	381445	304237	287046	237191	222946

Transmission Channels

- We conclude: ESG ratings and environment-minded investor demand react positively to the granting of lucky climate patents
- Other investors (without environmental concerns) do not react to lucky climate patents
  - this mechanism is viable even if climate patents do not improve the profitability of firms
  - consistent with our result (not shown here) that lucky climate patents do not affect operating performance
- ESG ratings reaction to lucky climate patents reflects the fact that firms may become greener
  - Do firms with climate patents indeed reduce their carbon emissions?
  - This is what we study next

Impact on CO2 Emissions

- Does climate innovation have an impact on the innovator's CO2 emissions?
  - The ultimately relevant question: do climate patents create a net positive impact on climate change mitigation?
  - Not clear due to issues with follow-on innovation and knowledge diffusion, reduction in competition (e.g., Boldrin and Levine, 2013)
  - climate patents could be mostly embedded in products and lead to mitigation gain elsewhere (Scope 3)
  - In this paper, we undertake a limited analysis of effect on innovators
- We consider two different patent shocks:
  - 2SLS: effect on direct CO2 emissions (Scope 1) on lucky climate patents: value of patent *protection*, measured by the examiner lottery
  - OLS: effect on direct CO2 emissions (Scope 1) on number of climate patents sorted by application year: measure of firm's climate *innovativeness*

Impact on CO2 Emissions: Examiner Leniency (2SLS)

Panel A: Estimated CO2 Emissions					
Δ (Estimated CO2 $\div$ Output)	(1) t+1 - t	(2) t+2 - t	(3) t+3 - t	(4) t+4 - t	(5) t+5 - t
Num Climate Related Patents Granted	-0.130	-0.455	-0.854	-0.477	-0.810
Instrumented by Leniency	(0.314)	(0.849)	(1.724)	(0.748)	(0.729)
Industry $\times$ Year F.E.	Y	Y	Y	Y	Y
Art Unit $\times$ Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	417	395	374	338	299

Panel B: Use Renewable Energy					
I(Renewable Energy)	(1) t+1	(2) t+2	(3) t+3	(4) t+4	(5) t+5
Num Climate Related Patents Granted	0.0716	0.276	-0.313	0.153	-0.0131
Instrumented by Leniency	(0.270)	(0.241)	(0.403)	(0.358)	(0.416)
Industry $\times$ Year F.E.	Y	Y	Y	Y	Y
Art Unit $\times$ Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	475	454	435	404	385

Panel C: Develop and Use Clean Energy					
I(Use Clean Energy)	(1) t+1	(2) t+2	(3) t+3	(4) t+4	(5) t+5
Num Climate Related Patents Granted	0.129	0.300	0.371	0.411	0.477
Instrumented by Leniency	(0.325)	(0.277)	(0.390)	(0.403)	(0.445)
Industry $\times$ Year F.E.	Y	Y	Y	Y	Y
Art Unit $\times$ Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	475	454	435	404	385

Impact on CO2 Emissions: Climate Technology (OLS)

Panel A: All Climate Patents

	(1)	(2)	(3)	(4)	(5)
Dependent Var.	Δ (Scope 1 CO2 Emissions / Output)				
Period	t+1 - t	t+2 - t	t+3 - t	t+4 - t	t+5 - t
Num Climate Patents	-0.00301	-0.00823	-0.0186**	-0.0312**	-0.0358**
	(0.00298)	(0.00622)	(0.00906)	(0.0131)	(0.0157)
Firm Controls	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y
Num Obs.	2386	1931	1599	1322	1094
Adj. R^2	0.030	0.022	0.016	0.004	0.018

Panel B: Climate Patents – Transports (Y02T)

	(1)	(2)	(3)	(4)	(5)
Dependent Var.	Δ (Scope 1 CO2 Emissions / Output)				
Period	t+1 - t	t+2 - t	t+3 - t	t+4 - t	t+5 - t
Num Climate Patents	-0.00171*	-0.00419**	-0.00877***	-0.0154***	-0.0177***
	(0.00126)	(0.00197)	(0.00317)	(0.0587)	(0.0738)
Firm Controls	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y
Num Obs.	2386	1931	1599	1322	1094
Adj. R^2	0.030	0.023	0.016	0.006	0.018

- We find significant results only for climate technology (OLS), not for the value of patent grants (examiner leniency)
  - This suggests that the underlying climate-related technology, and not patent granting per se, is associated with decrease in carbon emissions

Conclusion

- We explore exogenous shocks in the granting of climate patents
- We document that financial markets pay attention to climate innovation
  - CARs $\uparrow$; ICC $\downarrow$; E-Score $\uparrow$; environment-focused investor holdings $\uparrow$
- Effects on realized and expected returns are substantial, amplified by climate concerns, and offer innovation incentives
- Climate patents perceived as credible signal of climate action
  - but financial markets do not correct for examiner lottery
- Impact on direct carbon emissions depends on climate technology, not on patent grant

Future Research

- We are planning to work on the GHG emission effect of climate patents:
  - Effect should not be limited to innovator
  - Study link between climate patents and climate mitigation effects in supply chains
    - ★ Climate innovation in new categories (IT, goods)
  - Distinguish between climate process innovation (Scope 1) and climate product innovation (Scope 3)
  - Effects on switching suppliers to climate innovators

Example of Climate Patent in USPTO Patent Assignment Dataset

Photovoltaic Module Connector For Solar Tracker

DOCUMENT ID	DATE PUBLISHED
US 11190129 B2	2021-11-30

INVENTOR INFORMATION

NAME	CITY	STATE	ZIP CODE	COUNTRY
Pesce; Kathryn Austin	San Francisco	CA	N/A	US
Almy; Charles Bernardo	Berkeley	CA	N/A	US

ASSIGNEE INFORMATION

NAME	CITY	STATE	ZIP CODE	COUNTRY
Tesla, Inc.	Palo Alto	CA	N/A	US

APPLICATION NO	DATE FILED
15/092602	2016-04-06

US CLASS CURRENT:

1/1

CPC CURRENT

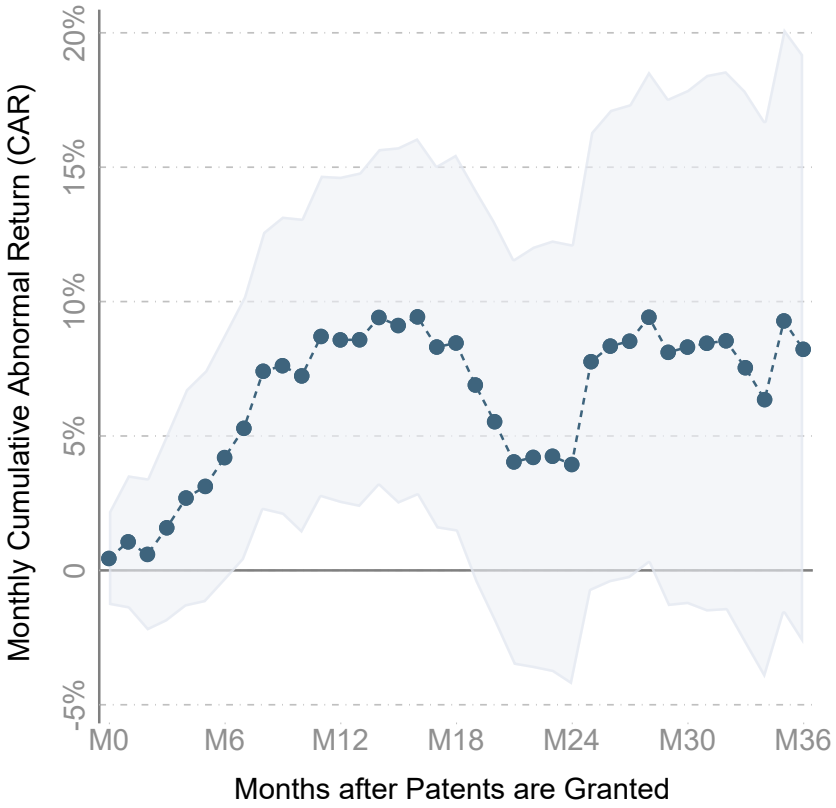
TYPE	CPC	DATE
CPCI	F 24 S 30/425	2018-05-01
CPCI	F 24 S 25/63	2018-05-01
CPCI	H 02 S 20/32	2014-12-01
CPCA	Y 02 E 10/50	2013-01-01
CPCA	Y 02 E 10/47	2013-01-01

Appendix 1: Climate Patents and Stock Returns

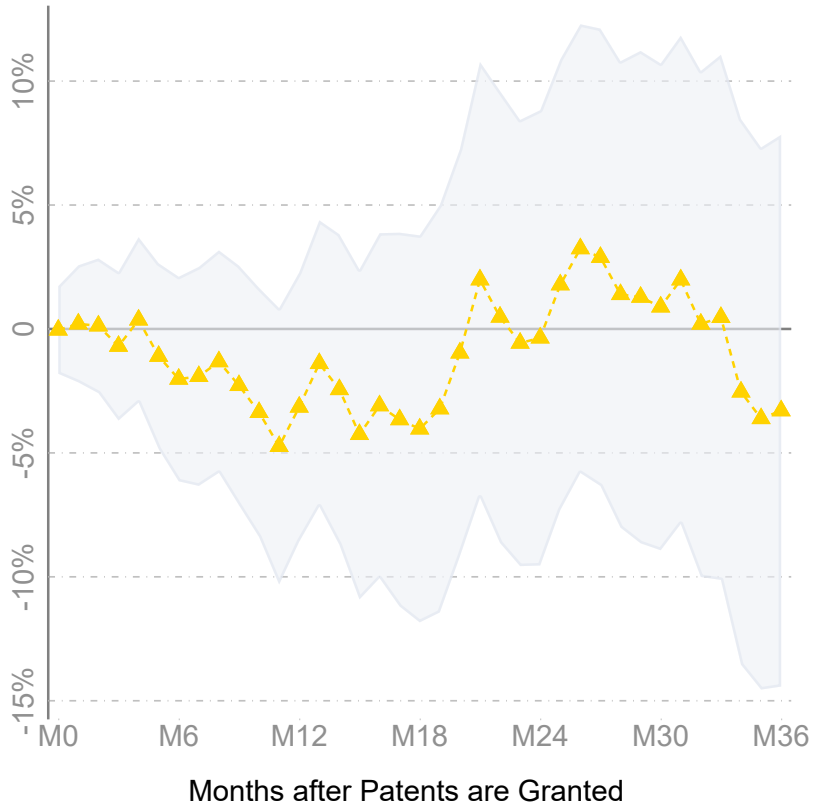
- Focus on climate-related green patents; $k = 1, 2, 3, \cdots, 36$

$$2SLS: \quad CAR[t+1:t+k]_{t,s} = \alpha \widehat{Num\_Climate\_Pats\_Granted}_{t,s} + \beta \mathbf{X}_{t,s} + \mu_{app} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{t,s} \quad (1)$$

Panel A: Climate-related Green Patents



Panel B: Other Green Patents

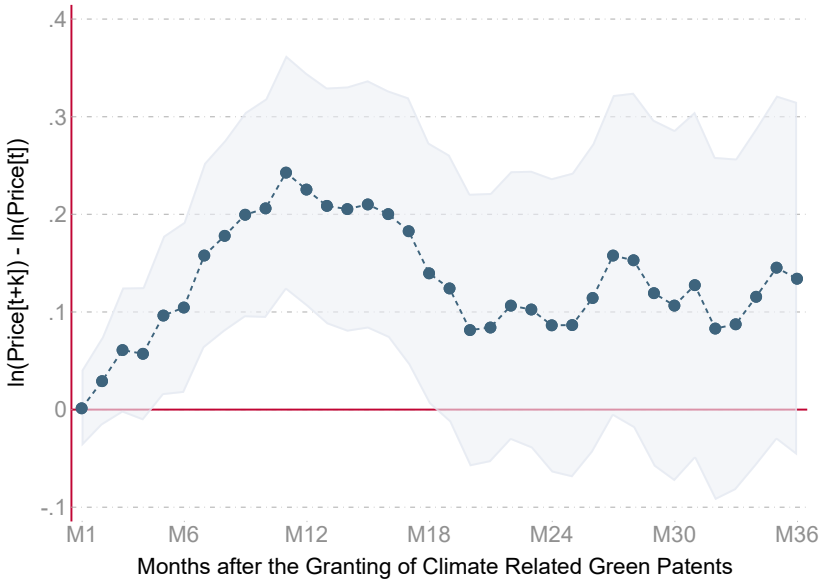


Appendix 2: Climate Patents and Stock Prices

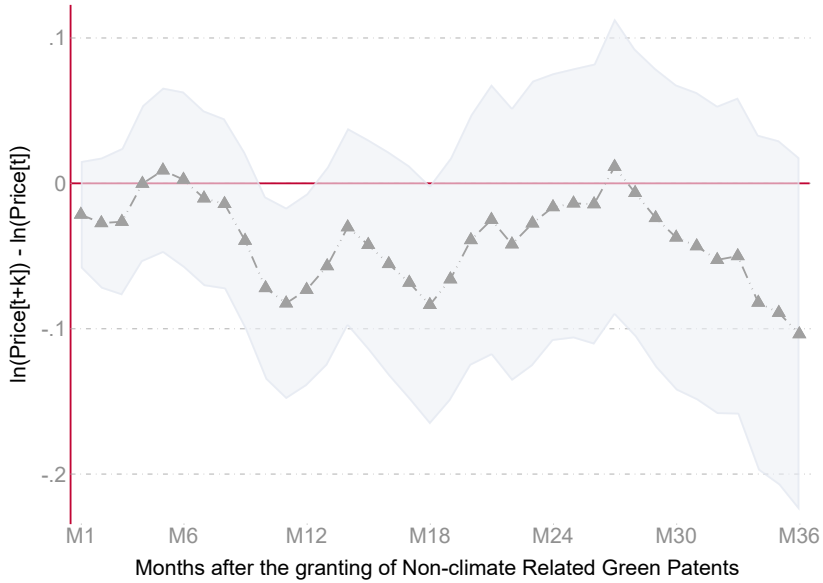
- Focus on climate-related green patents; $k = 1, 2, 3, \cdots, 18$

$$2SLS: \quad ln(Price_{t+k,s}) - ln(Price_{t-1,s}) = \alpha \widehat{Num\_Green\_Pats\_Granted}_{t,s} + \beta \mathbf{X}_{t,s} + \tau_{app} + \nu_{j,t} + \iota_{a,t} + \varepsilon_{t,s} \quad (2)$$

Panel A: Climate-related Green Patents



Panel B: Other Green Patents



Appendix 3: S&P Global ESG Score

Panel A: Climate Related Green Patents

Dependent Var.	(1) Environmental Score	(2) Environmental Score	(3) Climate Strategy Score	(4) Climate Strategy Score	(5) Environmental Policy Score	(6) Environmental Policy Score
	t+1 - t	t+2 - t	t+1 - t	t+2 - t	t+1 - t	t+2 - t
Num Climate-related Patents Granted	-5.479	0.538	11.63	4.594**	-16.23	0.573
(Instrumented by Leniency)	(10.44)	(0.806)	(22.41)	(2.172)	(31.30)	(1.238)
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y	Y
Num Obs.	169	116	159	105	169	116

Panel B: Other Green Patents

Dependent Var.	(1) Environmental Score	(2) Environmental Score	(3) Climate Strategy Score	(4) Climate Strategy Score	(5) Environmental Policy Score	(6) Environmental Policy Score
	t+1 - t	t+2 - t	t+1 - t	t+2 - t	t+1 - t	t+2 - t
Num Other Green Patents Granted	-0.185	-1.493	-2.098	-0.859	-1.520	-1.556
(Instrumented by Leniency)	(1.785)	(0.953)	(3.102)	(3.715)	(1.543)	(1.594)
Firm Controls	Y	Y	Y	Y	Y	Y
Industry × Year F.E.	Y	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y	Y
Num Obs.	160	123	123	80	160	123

Appendix 4: Impact of lucky climate patents on operating performance (2SLS)

Panel A	ln(Sale[t+k]) − ln(Sale[t])				
	k=1	k=2	k=3	k=4	k=5
Num Climate Related Patents Granted	-0.0728	0.150	0.221	0.320	0.259
Instrumented by Leniency	(0.147)	(0.263)	(0.307)	(0.299)	(0.405)
Industry × Year F.E.	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	904	843	785	746	633

Panel B	ln(Profits[t+k]) − ln(Profits[t])				
	k=1	k=2	k=3	k=4	k=5
Num Climate Related Patents Granted	0.114	-0.0551	-0.0615	-0.0336	0.393
Instrumented by Leniency	(0.164)	(0.271)	(0.304)	(0.357)	(0.543)
Industry × Year F.E.	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	904	843	785	746	633

Panel C	ln(Employments[t+k]) − ln(Employments[t])				
	k=1	k=2	k=3	k=4	k=5
Num Climate Related Patents Granted	0.0413	-0.0524	-0.0273	0.00132	0.0207
Instrumented by Leniency	(0.100)	(0.152)	(0.197)	(0.215)	(0.240)
Industry × Year F.E.	Y	Y	Y	Y	Y
Art Unit × Year F.E.	Y	Y	Y	Y	Y
Num Patent Applications F.E.	Y	Y	Y	Y	Y
Num Obs.	1039	982	934	885	741