Carbon emissions and Search for Renewable Energy Technology: ICT Firms' Environmental Corporate Social Responsibility

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Motivation

Environmental corporate social responsibility (ECSR) is a business practice that deliver value to the firm by mitigating its eco-harmful impacts.
(Flammer, 2013; Wang et al., 2016)

Prior works in ECSR: Extrinsic pressures

- Media Attention (Bansal, 2005)
- Stakeholders (Bansal & Roth, 2000; Berchicci & King, 2007; Kassinis & Vafeas, 2006)
- Customers, local communities (Delmas & Toffel, 2008)
- Shareholders (Flammer, 2013)
- Government and NGOs (Berrone et al., 2013)
- Local environmental norm (Dowell & Muthulingam, 2017)

Motivation

Firms, receiving similar pressures,
undertake heterogenous ECSR behaviors

(Buyesse & Verbeke, 2003; Crilly et al., 2012; Hart, 1995; Sharma & Vredenburg, 1998; Russo & Fouts, 1997)

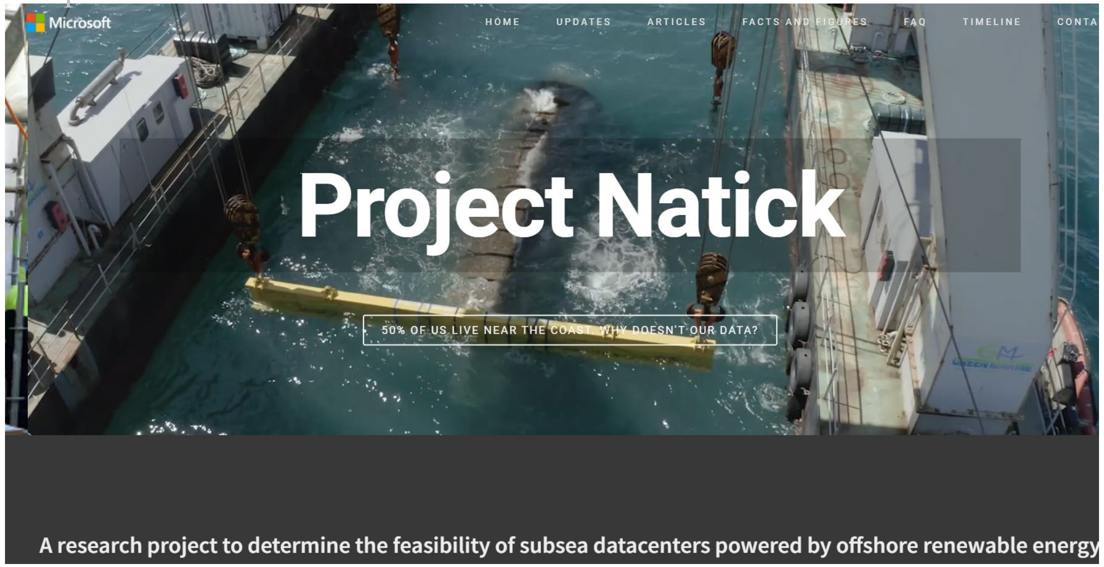
e.g., behavior that shows just minimum efforts to meet legal requirements
behavior that requires substantial amount of time and resources

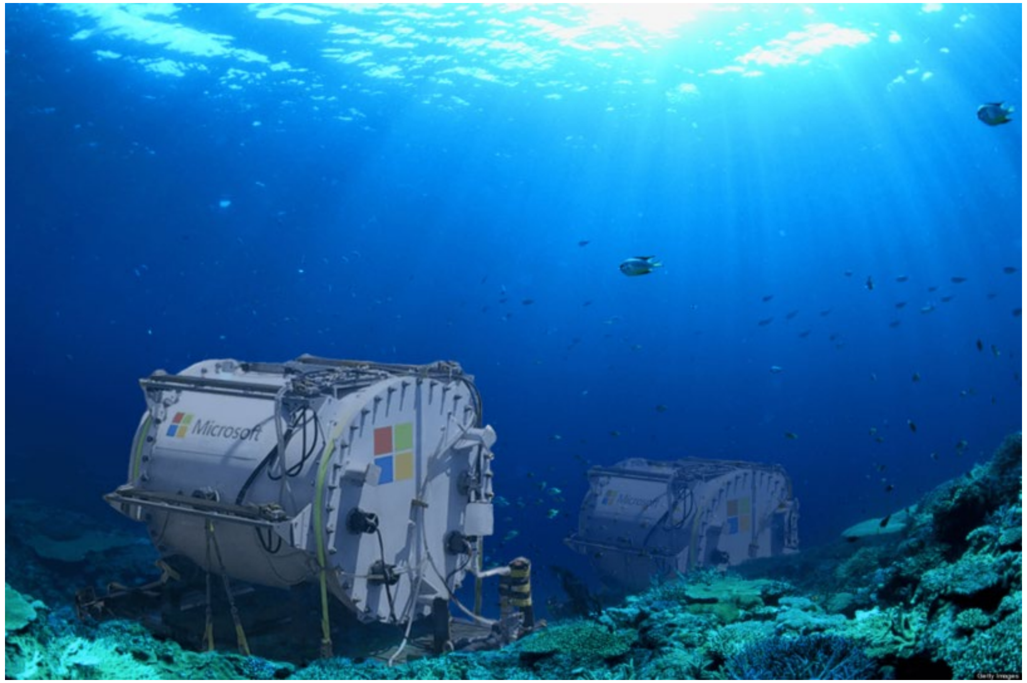
When firms are *internally* motivated to implement proactive ECSR behavior (e.g,. exploring environmental technology) is understudied.

Motivation

Information and communication technology (ICT) firms' exploration for a renewable energy technology

https://natick.research.microsoft.com/





Research Question:

When ICT firms are motivated to search for renewable energy technology?

Theory

By engaging in ECSR, firms can …

<Compliance>

… enhance their brand image and reputation
(Ambec & Lanoie, 2008; Berchicci & King, 2007; Buysse & Verbeke, 2003; Hart, 1995; Russo & Fouts, 1997; Sharma & Vredenburg, 1998)

… have a certain insurance for themselves from penalties that would be imposed by regulators or shareholders if firms would be engaged in socially irresponsible actions
(Bansal & Clelland, 2004; Flammer, 2013; Godfrey et al., 2009)

<Resource>

… generate new and competitive resources such as eco-friendly products, manufacturing processes, and novel technologies (Berrone et al., 2013; Hart, 1995; Russo & Fouts, 1997; Yang et al., 2019)

… improve their long-term profitability (Bansal & Roth, 2000; Shrivastava, 1995)

Theory

A Firm's Search for Environmental Technology

<Definition of Environmental technology>

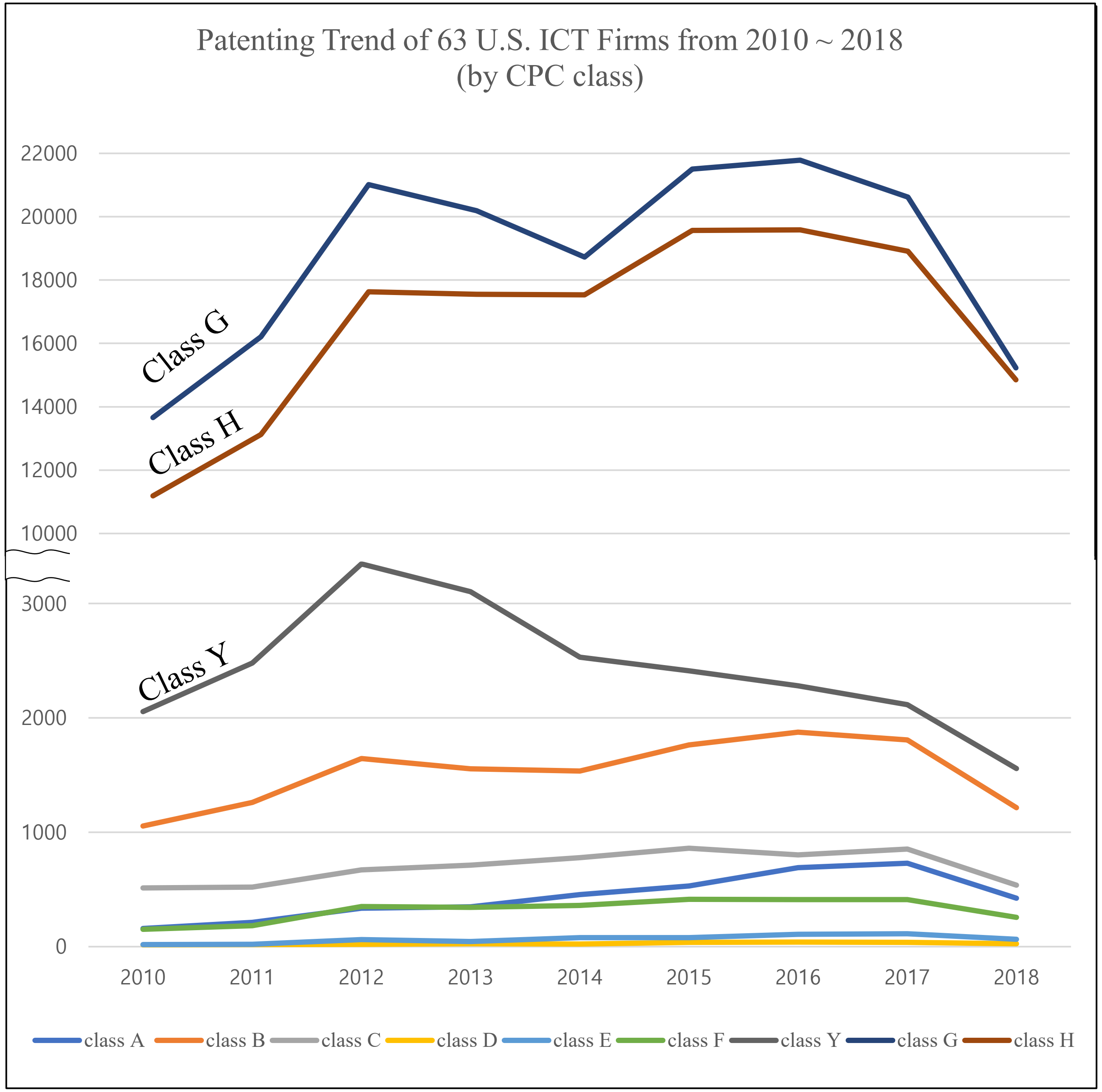
"The development of products, processes, and services aimed at reducing environmental harm by using new methods for treating emissions, recycling or reusing waste, finding cleaner energy sources, and so on." (Berrone et al., 2013)

<Characteristics of Environmental technology>

Highly novel, uncertain, and radical (Barbieri et al., 2018; Cainelli et al., 2015; Marzucchi & Montresor, 2017)

… requires knowledge and skills distant from the traditional technology base of the firm (De Marchi, 2012; Ghisetti et al., 2015)

… requires firms to commit a considerable amount of resources (Berrone et al., 2013; Hart, 1995; Harma & Vredenburg, 1998)



Notes.
Class A: Human Necessities;
Class B: Performing Operations, Transporting;
Class C: Chemistry, Metallurgy;
Class D: Textiles, Paper; Class E: Fixed Constructions,
Class F: Mechanical Engineering, Lighting, Heating, Weapons, Blasting;

Class G: Physics;
Class H: Electricity;
Class Y: General Tagging of New Technological Developments

(https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html)

Theory

A Firm's Search for Environmental Technology

Firms are reluctant to adopt environmental technology because they are accustomed to do things in a familiar way (Shrivastava, 1995)

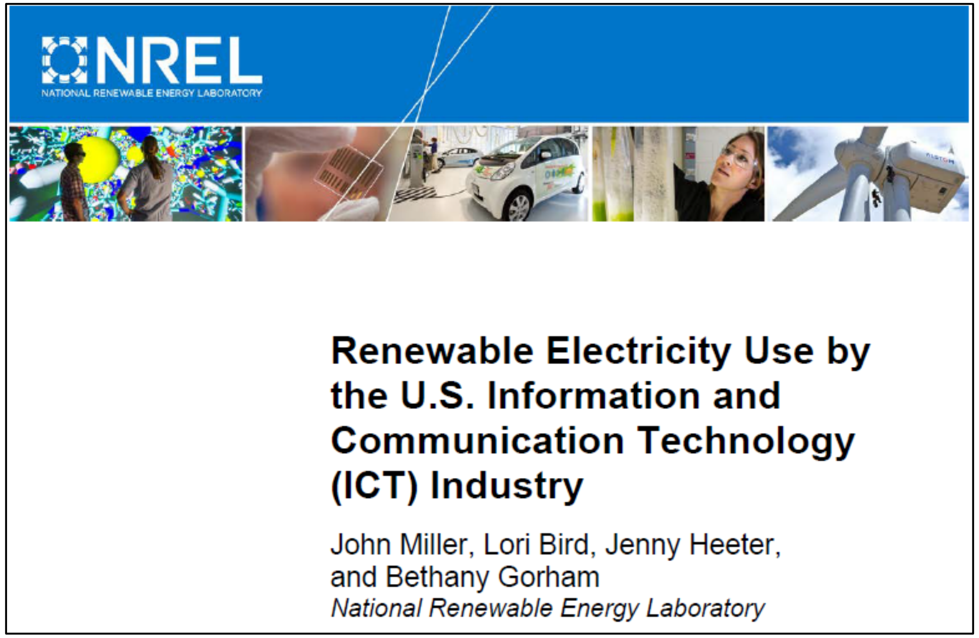
Firms tend to exploit familiar technology to avoid the uncertainty of exploring unfamiliar technology (Ahuja & Lampert, 2001)

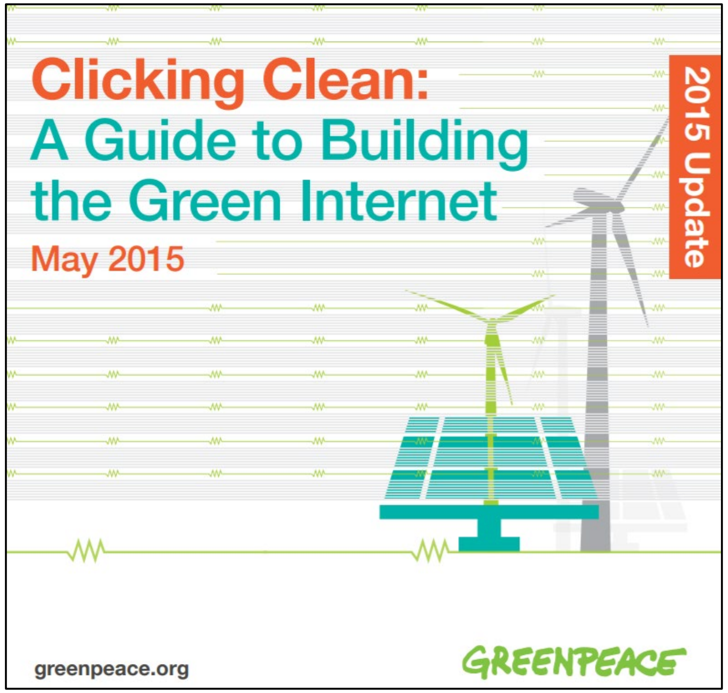
Exploring unfamiliar technology allows firm to expand their technology boundary and increase the potential to develop novel technology
(Ahuja & Katila, 2001; Jung & Lee, 2016; Rosenkopf & Nerkar, 2001)

➔ ICT firms may generate additional technological opportunities by exploring unfamiliar field of renewable energy technology.

Theory

A Firm's Search for Environmental Technology





➔ ICT firms' effort to search for renewable energy technology can be interpreted as firms striving for global needs in emission mitigation by advancing technology that can tackle the problem of CO_2 emissions.

Theory

Behavioral Theory of the Firm (BTOF): Performance vs. Aspiration

A firm's motivation for explorative behavior comes from the comparison of firm performance with a specific reference point (Cyert & March, 1963)

Aspiration level: a reference level that serves as a benchmark for performance evaluation (e.g., Greve, 2003)

While it is difficult to observe each firm's aspiration toward ECSR such as annual CO_2 emission reduction, the convention of BTOF offers reference to proxy the aspiration of each firm.

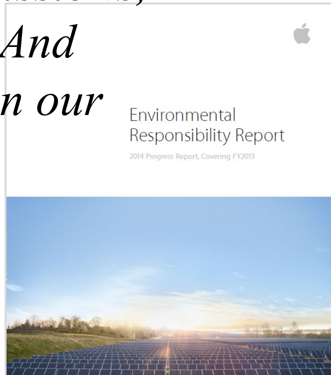
Theory

Environmental Performance: CO_2 emissions

Global environmental agreements such as the Paris Accord and a number of regulations focus on mitigating toxic emissions such as CO_2 because they are regarded as the main factor in global rises in temperature (United Nations Framework Convention on Climate Change, 2015).

Tracking CO_2 emissions allows firms to set their reference point, to evaluate their environmental performance, to decide their next environmental behaviors.

*"A portion of energy comes from burning fossil fuels, which creates carbon emissions. Those emissions make up our carbon footprint - our share of the climate change problem. We're striving to reduce that footprint. [...] **Apple accounts for greenhouse gas emissions from electricity using both default emissions and net emissions**, so **we can see the impact of our investment and recognize our contribution to the connected grid**. [...] And when our assessments reveal a material, process, or system that's making a significant negative impact on our carbon footprint, **we reexamine how we design that product, process, or facility**"*
(Apple 2014 Environmental Responsibility Report, p.4-5)



Hypothesis

Firms producing more CO_2 emissions above aspirations …

(i.e., poor environmental performance)

Face two problems

- Potentially fail to comply with environmental requirements
- Insufficient technology for emission reduction

When a problemistic situation occurs,
firms are usually motivated to explore to solve their problems
(Posen et al., 2018)

Search for renewable energy technology

- to align with environmental expectations
- to gain technology that can help firms to reduce emissions

Hypothesis 1. ICT firms with more CO_2 emissions above aspirations are more likely to search for renewable energy technology compared to ICT firms with less CO_2 emissions below aspirations.

Hypothesis

Firms producing CO_2 emissions further above aspirations …

(i.e., worse environmental performance)

Problems of non-compliance and insufficient technology are getting worse for firms.

Increasing non-compliance with environmental requirements
→ severe punishments (e.g., fines, negative media coverage, boycott movements)
→ become a considerable burden on firms' operations

Threat on business shifts firms' attention from aspiration to the other point
(e.g., Audia & Greve, 2006)

Firms focus on avoiding a point at which severe punishments would be imposed
→ firms cannot bear a long-time horizon of explorative behavior

Hypothesis 2. The higher an ICT firm's CO_2 emissions above aspiration, the less likely the firm is to search for renewable energy technology.

Hypothesis

Firms producing CO_2 emissions further below aspirations …

(i.e., good environmental performance)

Firms still cannot relax their attention on emission reduction due to increasing environmental awareness and requirements from external actors.

Much better performance is not easy to be repeated in the future (Kim et al., 2015).
Shareholders react less positively to additional environmental achievements of a firm, when the firm shows good environmental performance (Flammer, 2013).

Firms may become satisfied with their current environmental achievement, and find less incentive in engaging in explorative behavior.

Hypothesis 3. The lower an ICT firm's CO_2 emissions below aspiration, the less likely the firm is to search for renewable energy technology.

Research Context

ICT firms' Search for Renewable Energy Technology

Many ICT firms have acknowledged their significant impact on the environment and have increased their emission reduction activities (CDP, 2014)

Number of ICT firms have started to aspire to adopt renewable energy to run their operations with less CO_2 (Miller et al., 2015)

ICT firms' main expertise and business still does not lie in the field of renewable energy technology.

Data source

List of U.S. ICT firms

- Fortune 1000, CDP (Initially, 207 ICT firms)

Firms' CO_2 emissions from 2010 to 2018 (CO_2e metric tons)

- Corporate website, annual sustainability reports, firms' responses to CDP questionnaires (83 ICT firms remained)

Financial Information

- DISCERN (Arora et al., 2021) (63 ICT firms remained)

Patent data

- USPTO
- Renewable energy patent (CPC: Y02E) (Hascic & Migotto, 2015)

∴ 63 U.S. ICT firms, 363 firm-year observations

Variable Description

Dependent variable

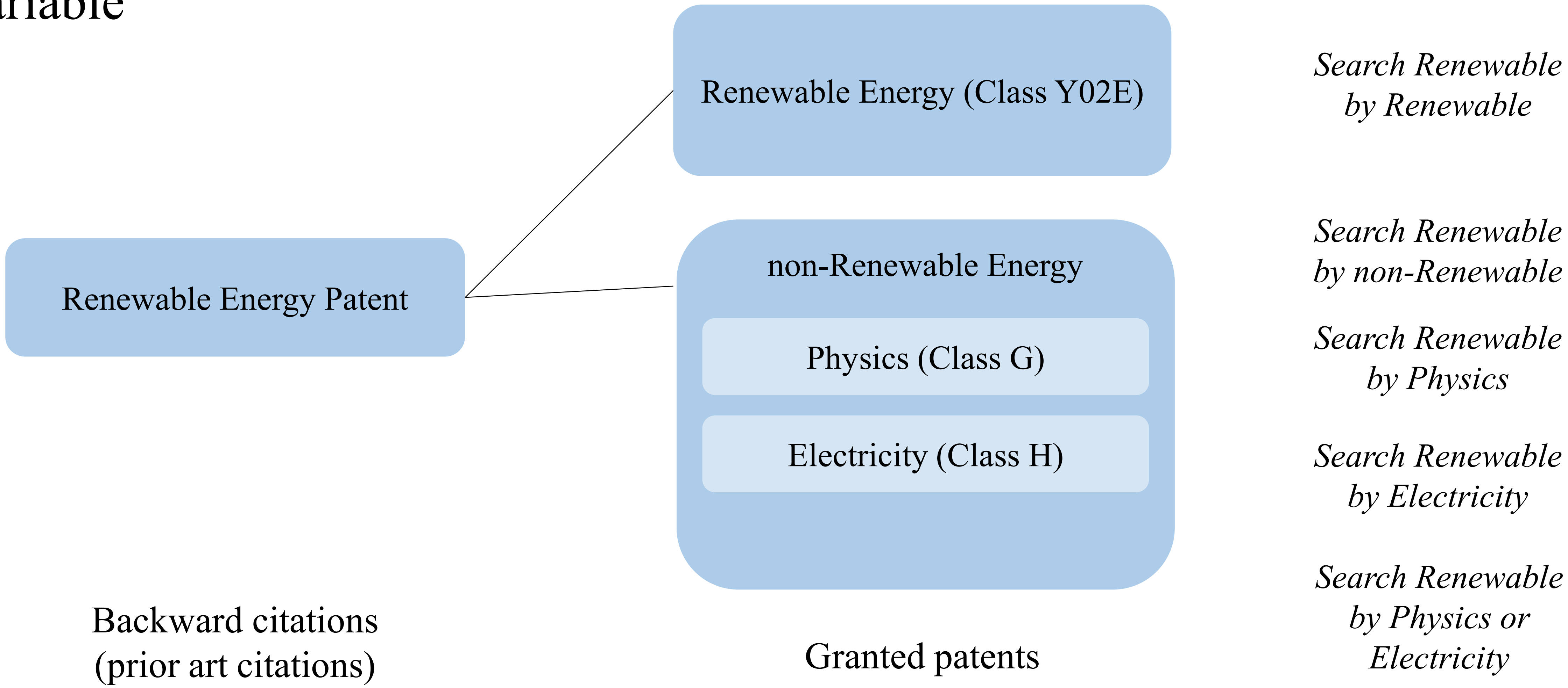
Search Renewable

= a total number of backward citations
to renewable energy patents (CPC class: Y02E) at year t
by patents that firm i made

(Ahuja & Katila, 2004; Rosenkopf & Nerkar, 2001)

Alternative dependent variable

Whether ICT firms search for renewable energy technology to develop technology for specific domain – for renewable? For ICT expertise?



Variable Description

Independent Variable – Spline based approach (e.g., Eggers & Kaul, 2018)

CO_2 Above Dummy
= 1 when a firm's CO_2 emissions is above the aspiration, 0 otherwise

CO_2 Above Aspiration
= |CO_2 emissions – Aspiration| if CO_2 emissions > Aspiration, 0 otherwise

CO_2 Below Aspiration
= |CO_2 emissions – Aspiration| if CO_2 emissions < Aspiration, 0 otherwise

Variable Description

Control Variable

Total backward citations
Regulatory pressure
Asset specificity
Slack
Firm size
R&D intensity
Return on Asset (ROA)

Empirical Method: Heckman two-stage approach (Heckman, 1979)

<Selection bias issue>
Firms reporting CO_2 emissions
may be systematically differ from who do not.

First-stage regressions (DV: 1 if a firm appears in the final sample)
: *Regulatory pressures, Asset specificity, Slack, Firm size, R&D intensity, ROA, ITI member**

Second-stage regression (DV: Search Renewable)
Negative binomial regression with firm- and year-fixed effect
Lagged one-year for independent and control variables

*ITI member: dummy variable which equals to 1 if a firm is the member of Information Technology Industry (ITI) council, 0 otherwise

Descriptive Statistics

Variable	Mean	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Search Renewable	28.992	75.620	0	651	1										
(2) CO_2 Above Dummy	0.584	0.494	0	1	-0.124	1									
(3) CO_2 Above Aspiration	0.129	0.257	0	3.720	-0.056	0.424	1								
(4) CO_2 Below Aspiration	0.150	0.479	0	6.252	0.064	-0.372	-0.158	1							
(5) Inverse Mills Ratio (Lambda)	1.498	1.649	0	8.104	-0.216	-0.033	0.022	0.054	1						
(6) Total Backward Citations[a]	7.012	2.032	0	10.815	0.480	0.065	0.023	0.098	-0.377	1					
(7) Regulatory Pressure[a]	4.423	0.532	2.639	5.694	0.196	0.030	-0.059	-0.107	-0.100	0.089	1				
(8) Asset Specificity[a]	4.089	1.012	1.176	6.543	0.118	0.115	0.048	0.113	-0.002	0.348	0.090	1			
(9) Slack[a]	6.902	0.618	5.020	9.091	0.099	0.169	0.080	-0.054	-0.359	0.491	0.005	0.273	1		
(10) Firm Size[a]	3.056	0.858	1.177	5.962	0.272	-0.065	0.053	-0.019	-0.085	-0.008	-0.009	-0.290	-0.406	1	
(11) R&D Intensity	0.076	0.056	0.002	0.339	-0.117	0.060	0.069	-0.004	-0.091	0.130	0.059	0.071	0.069	-0.402	1
(12) ROA	0.080	0.074	-0.296	0.326	0.136	0.051	-0.048	-0.048	-0.004	0.220	0.137	0.195	0.189	0.037	-0.129

N = 363

[a] Logged values used for descriptive statistics, correlations, and regressions.

Result

	Negative Binomial Estimation / Dependent Variable	(1) Search Renewable	(2) Search Renewable	(3) Search Renewable	(4) Search Renewable by Renewable	(5) Search Renewable by non-Renewable	(6) Search Renewable by Physics	(7) Search Renewable by Electricity	(8) Search Renewable by Physics or Electricity
Hypothesis 1 (+)	CO_2 Above Dummy $_{(t-1)}$		[1.293]	[1.516]	[1.470]	[1.325]	[1.303]	[1.345]	[1.347]
			0.257**	0.416***	0.385	0.281**	0.264	0.297**	0.298**
			(0.124)	(0.142)	(0.413)	(0.138)	(0.170)	(0.144)	(0.152)
Hypothesis 2 (-)	CO_2 Above Aspiration $_{(t-1)}$			[0.470]	[0.600]	[0.537]	[0.409]	[0.538]	[0.453]
				-0.755**	-0.511	-0.622*	-0.894**	-0.620*	-0.793**
				(0.316)	(0.995)	(0.334)	(0.438)	(0.330)	(0.383)
Hypothesis 3 (-)	CO_2 Below Aspiration $_{(t-1)}$			[1.002]	[0.784]	[0.907]	[0.830]	[0.919]	[0.897]
				0.002	-0.243	-0.098*	-0.186***	-0.085*	-0.108**
				(0.043)	(0.162)	(0.050)	(0.051)	(0.049)	(0.050)
	Control Variables	Included	Included	Included	Included	Included	Included	Included	Included
	Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Selection Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Log-likelihood	-774.761	-771.362	-768.233	-464.757	-822.076	-633.304	-753.210	-884.745
	N	329	329	329	329	329	329	329	329

Notes: * $p<0.10$ ** $p<0.05$ *** $p<0.01$
Incidence-Rate Ratios reported in brackets. Non-exponentiated coefficients reported without brackets. Robust standard errors in parentheses

Findings

(1) On average, ICT firms producing emissions above aspirations are 51.6% more likely to engage in search for renewable energy technology compared to firms below aspirations.

(2) ICT firms become less likely to motivated to search for renewable energy technology as
… i) their emissions further rise above aspirations
… ii) their emissions further drop below aspirations

(3) ICT firms recombine their searched-renewable energy technology for their own technology domain (i.e., physics or electricity).

- On average, ICT firms producing emissions above aspirations are 34.7% more likely to recombine renewable energy technology they searched to develop inventions in ICT technology domain compared to firms below aspirations.

Robustness check

(1) Alternative estimation methods

a. Poisson estimation

b. Zero-inflated negative binomial estimation

(2) Including controls for Financial Performance vs. Aspiration

i.e., *Financial Above Dummy, Financial Above Aspiration, Financial Below Aspiration*

(3) Including controls for Concern on Clean Energy

(4) Including controls for Incentive Payments to Managers

(5) Alternative measure for control variables

Financial performance, Slack, Firm size

Discussion

ECSR literature

- Focus on a firm internal factor, the mismatch between firms' CO_2 emissions and aspirations
- ECSR can be an instrument for generating new and competitive resources for firms (Yang et al., 2019)

ICT firms' environmental technology exploration

- ICT firms are the main actors in combining IT and environmental technologies to develop novel inventions (Cecere et al., 2014)
- Enhance scholars' understanding of when ICT firms explore inputs for such inventions

BTOF literature

- Focus on performance not directly related to firms' market strategy

Discussion

To ICT firm managers …

- not narrow down their focus merely on complying with environmental regulations but pay attention to their exploration for environmental technology
- not to become too satisfied with their emission status and to consciously engage in environmental technology exploration

To policymakers …

- should recognize a critical role of ICT firms' contribution in broad diffusion and adoption of renewable energy technology
- should consider a policy that does not simply value firms that succeed in reducing emissions in a short-term
- carbon taxation or penalty rules could be differently applied to firms who put efforts into environmental technology exploration

감사합니다 ☺

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Your suggestion and comments are always welcomed

Motivation

THE WALL STREET JOURNAL. By Sarah Krouse and Theo Francis

May 1, 2019 9:00 am ET

BUSINESS

Climate Changes as Firms Heed Investors on Social Issues

Once-reluctant companies bend to shareholder demands on the environment and other hot-button topics

Shareholder victories are the result of a confluence of events, corporate-governance advisers say. For one, investors and executives are focusing more on climate change as its effects on business and the economy become clearer.

Motivation

Information communication and technology (ICT) firms consume more electricity than before,
mainly because of increasing use of data centers.
(Greenpeace, 2012; 2015; 2017; NREL, 2016)

Accordingly, the extrinsic pressure to use clean energy source (e.g., renewable energy) on ICT firm has increased.

Motivation

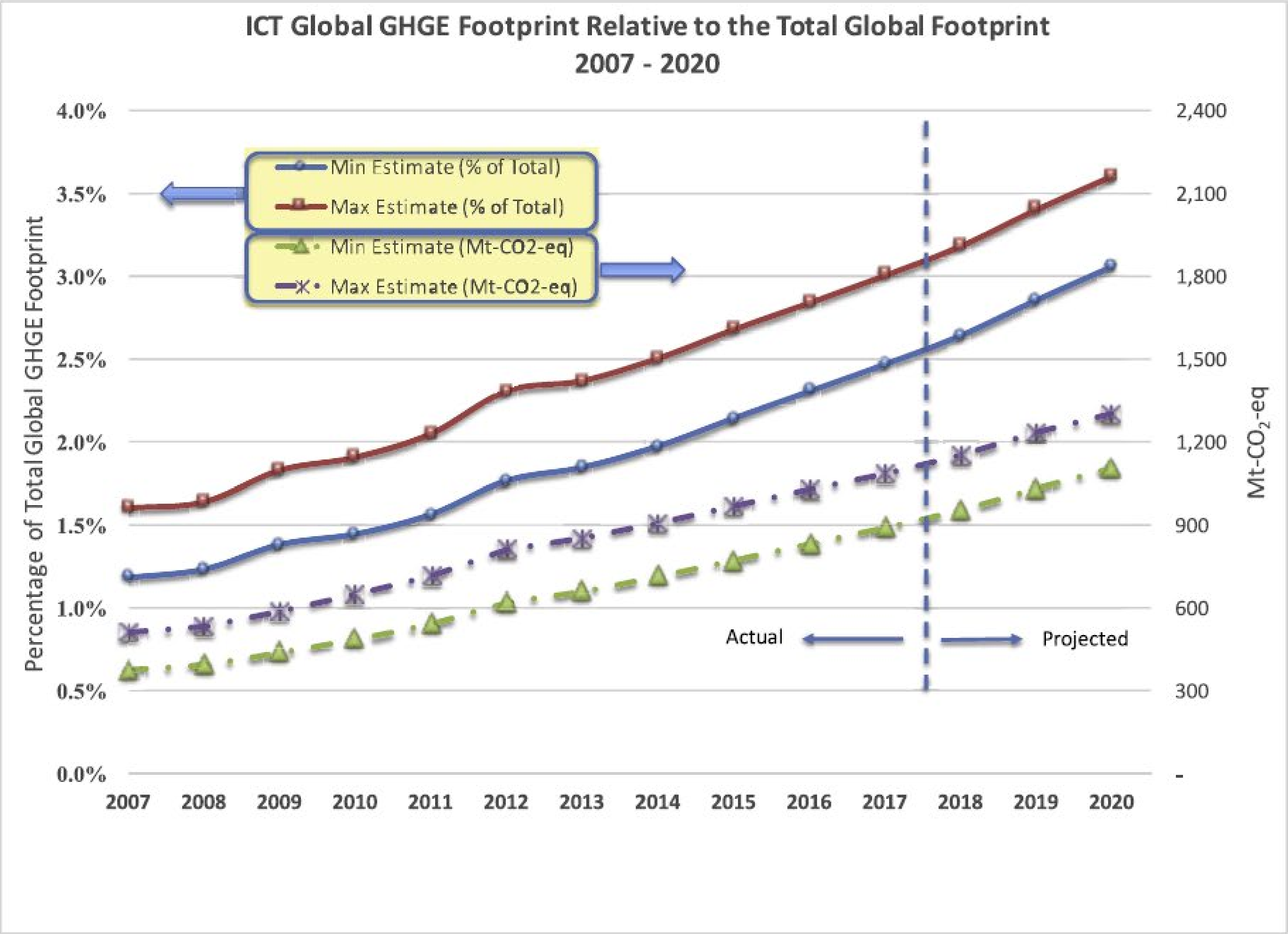


Fig. 5. ICT global GHGE footprint as a percentage of total global footprint (primary axis), and in absolute values in Mt–CO_2-eq on the secondary axis.

Belkhir, L., & Elmeligi, A. 2018. Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *Journal of Cleaner Production*, 177, 448-463.

Motivation

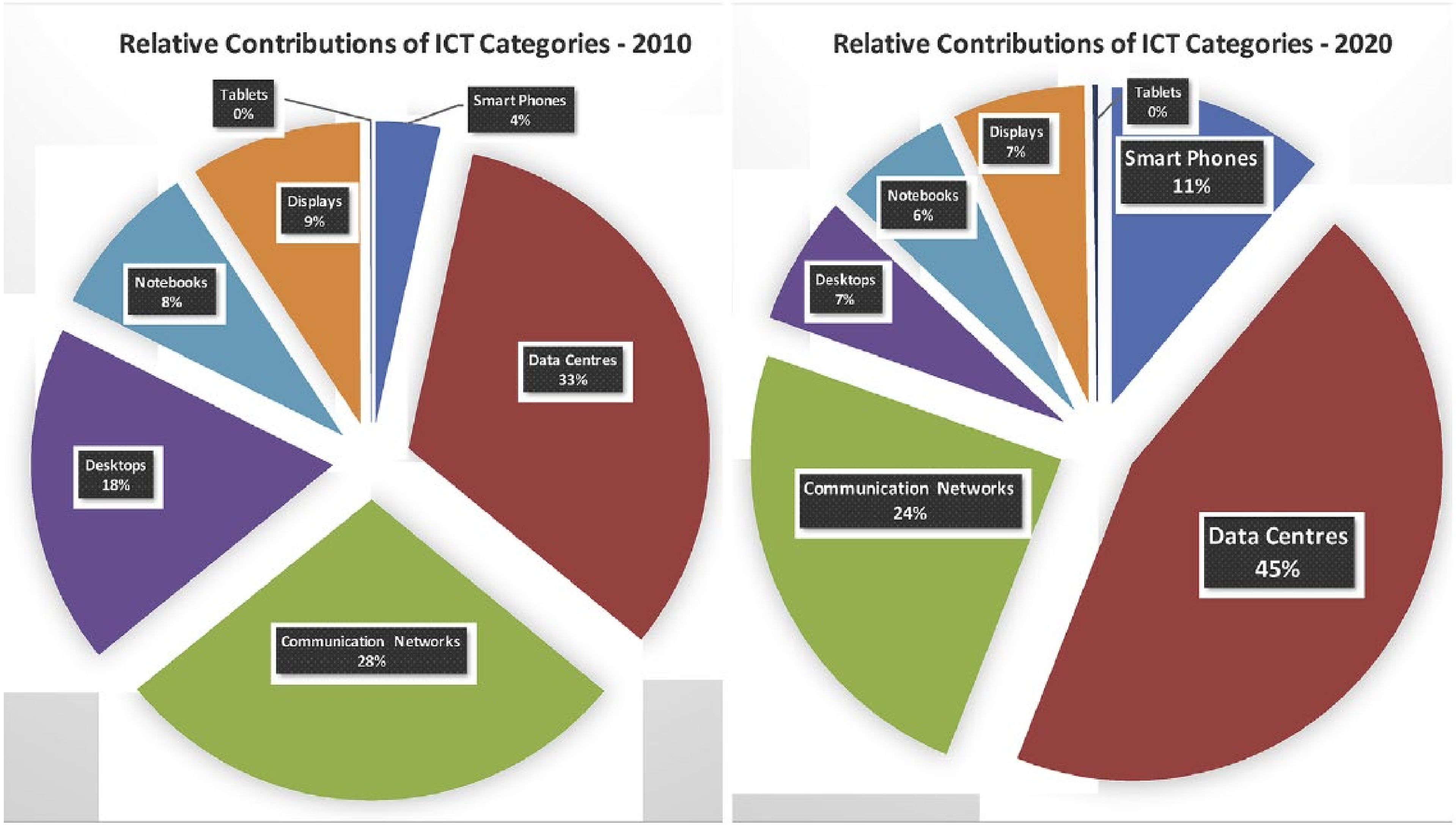


Fig. 6. (a)Relative contribution of each ICT category in 2010. (b): Relative contribution of each ICT category in 2020.

Belkhir, L., & Elmeligi, A. 2018. Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *Journal of Cleaner Production*, 177, 448-463.

Motivation

"The largest tech companies today may each consume as much electrical power as a small American state. There may come a point in just a few decades when we each may consume as much power as a mid-sized nation. This creates an obvious responsibility that we need to take seriously."

Microsoft blog. Brad Smith, the President and Chief Legal Officer of Microsoft (May, 2016)

Motivation

Colocation with marine renewable energy is a step toward realizing Microsoft's vision of datacenters with their own sustainable power supply, explained Christian Belady, general manager of cloud infrastructure strategy and architecture in Microsoft's cloud and enterprise division.

Energy self-sufficient datacenters, he noted, could be deployed anywhere within reach of a data pipe, bringing Azure cloud services, for example, to regions of the world with unreliable electricity, and eliminate the need for costly backup generators in case of power grid failures.

"Our vision is to be able to deploy compute rapidly anywhere on the planet as needed by our customers," said Belady, who has long advocated research that explores the marriage of datacenters and energy generation to simplify and accelerate the build out of cloud computing infrastructure.

Demand for datacenter resources across the computing industry is growing exponentially as corporations increasingly shift their networks and computing needs to the cloud, and internet-connected intelligent devices ranging from smartphones to robots proliferate.

"When you are in this kind of exponential growth curve, it tells you that most of the datacenters that we'll ever build we haven't built yet," said Cutler, underscoring the need for innovation in the race to build out what is fast becoming a critical piece of 21st century infrastructure.

"When you go for a moonshot, you might not ever get to the moon," Lee said. "It is great if you do, but, regardless, you learn a lot and there are unexpected spinoffs along the way. You get Velcro at some point. That is happening in this case. We are learning about disk failures, about rack design, about the mechanical engineering of cooling systems and those things will feedback into our normal datacenters."

https://news.microsoft.com/features/under-the-sea-microsoft-tests-a-datacenter-thats-quick-to-deploy-could-provide-internet-connectivity-for-years/

Methodology

Previous studies on operationalizing environmental performance

Dow Jones Sustainability Index (Eccles et al., 2014; Philippe & Durand, 2011)
KLD (Hull & Rothenberg, 2008; Ioannou & Serafeim, 2015)
Content analyses of the firm's annual reports (Bansal, 2005)
Newspaper articles covering firms' environment-related issues (Flammer, 2013)
Firms' toxic emissions (Berrone et al., 2013).

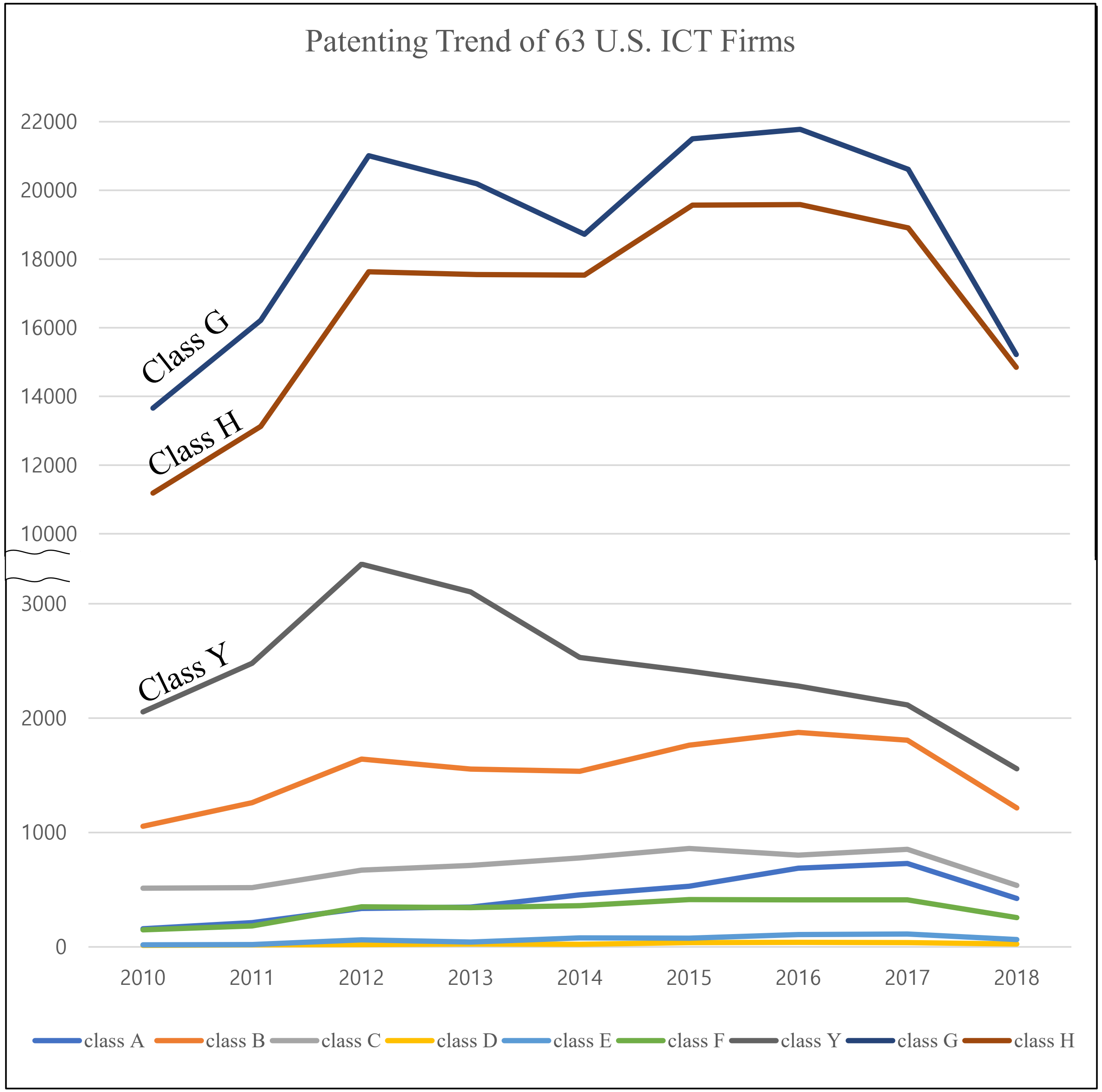
Patenting trend of sample firms

<Year 2010 ~ 2018>
266,361 granted patents
1,900,866 backward citations

1,736 granted patents in Y02E (0.65%)
12,465 backward citations to Y02E (0.65%)

168,905 granted patents in G (63%)
149,933 granted patents in H (56%)

Y02E: Renewable energy patent
G: Physics
H: Electricity



Notes. Class A: Human Necessities; Class B: Performing Operations, Transporting; Class C: Chemistry, Metallurgy; Class D: Textiles, Paper; Class E: Fixed Constructions, Class F: Mechanical Engineering, Lighting, Heating, Weapons, Blasting; Class G: Physics; Class H: Electricity; Class Y: General Tagging of New Technological Developments (https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html)

Variable Description

Independent Variable

Historical aspiration

- It is uncommon for firms to have two aspirations for the same goal
  (Bromiley & Harris, 2014)
- Firms usually report their emissions in comparison with their own past

$$
\begin{aligned}
&Historical\ Aspiration_{i,t} \\
&= \alpha\ X\ Historical\ Aspiration_{i,t-1} + (1-\alpha)\ X\ CO_2\ emissions_{i,t-1}
\end{aligned}
$$

(e.g., Eggers & Kaul, 2018)

Variable Description

Asset Specificity

A firm's resources that cannot be easily transformed or transferred from existing use and users, which enables firms to bear greater uncertainty in their businesses and engage in patenting activities (Ziedonis, 2004)

Slack

A firm's resources that enable the firm to pursue explorative behaviors
(Baum et al., 2005; Berrone et al., 2013; Greve, 2003; Tyler & Caner, 2016)

Variable Description

Dependent Variable	
Search Renewable	total number of backward citations to Y02E patent of firm *i* in year *t*
Independent Variable	
CO_2 Above Dummy	1 if a firm's CO_2 emissions is above aspirations, 0 otherwise.
CO_2 Above Aspiration	value of $\lvert CO_2$ emissions – historical aspiration$\rvert$ when CO_2 emissions > historical aspiration, 0 otherwise
CO_2 Below Aspiration	value of $\lvert CO_2$ emissions – historical aspiration$\rvert$ when CO_2 emissions < historical aspiration, 0 otherwise
Control Variable	
Total Backward Citations	total number of backward citations of firm *i* in year *t*
Regulatory Pressure	number of environmental inspections in state *j* in year *t*
Asset Specificity	book value of machinery and equipment divided by number of employees
Slack	working capital divided by sales
Firm Size	sales
R&D Intensity	total amount of R&D expenditure divided by total asset
Return on Asset (ROA)	net income divided by total asset

ITI Member: Dummy variable equals to 1 if a firm is a member of ITI council, otherwise 0

Information technology industry (ITI) council

Founded in 1916, ITI advocates on behalf of global ICT firms for policy and regulatory environments "that enable innovation and maximize all of the benefits that ICT companies provide, including economic growth, job creation, and the tools to solve the world's most pressing social, economic, and environmental challenges. (ITI) works closely with partners in government, international organizations, the business community, and civil society to achieve these objectives" http://ec.europa.eu

List of sample firms

Accenture	Lam Research
Adobe Systems	Leidos Holdings
Advanced Micro Devices	Level 3 Communications
Agilent Technologies	Lexmark International
Akamai Technologies	Maxim Integrated Products
Alphabet (Google)	Mettler-Toledo International
Analog Devices	Microchip Technology
Apple	Micron Technology
Applied Materials	Microsoft
AT&T	Motorola Solutions
ARRIS Group	NetApp
Autodesk	NVIDIA
Automatic Data Processing	ON Semiconductor
Broadcom Corporation	Oracle
CA Technologies	Pitney Bowes
Ciena	QUALCOMM
Cisco Systems	salesforce.com
CommScope Holding	Seagate Technology
Corning	SunEdison
Cypress Semiconductor	Symantec
Dell	TE Connectivity
eBay	Teradata
F5 Networks	Teradyne
Facebook	Texas Instruments
Hewlett-Packard (HP)	Thermo Fisher Scientific
Intel	Unisys
International Business Machines (IBM)	Waters
Intuit	Workday
Jabil Circuit	Xerox
Juniper Networks	Xilinx
Keysight Technologies	Yahoo!
KLA-Tencor	

Heckman 1st Stage Result

An inverse Mills ratio is created using the predicted values from the first-stage model in order to put as a control in the second stage.

Dependent variable = '1' if a firm appears in final sample, '0' otherwise	Model 1	Model 2
ITI Member $_{(t-1)}$		6.067***
		(0.820)
Regulatory Pressure $_{(t-1)}$	-0.562	-0.745*
	(0.392)	(0.389)
Asset Specificity $_{(t-1)}$	0.150	0.016
	(0.285)	(0.277)
Slack $_{(t-1)}$	1.146**	0.680
	(0.517)	(0.453)
Firm Size $_{(t-1)}$	0.994***	0.866**
	(0.361)	(0.339)
R&D Intensity $_{(t-1)}$	1.414	0.550
	(3.320)	(3.373)
ROA $_{(t-1)}$	1.218	1.165
	(1.741)	(1.766)
Year Effects	Fixed	Fixed
Firm Effects	Random	Random
Constant	-10.607**	-7.071*
	(4.424)	(4.058)
Log-likelihood	-241.513	-230.296
N	794	794

Robust standard errors in parentheses.
* $p<0.10$ ** $p<0.05$ *** $p<0.01$.

Robustness Analysis
: Alternative Estimation Methods

Estimation Method	Poisson	Zero-inflated negative binomial
Dependent Variable	Search Renewable	Search Renewable
CO_2 Above Dummy $_{(t-1)}$	[1.472]	[1.484]
	0.387***	0.395***
	(0.116)	(0.149)
CO_2 Above Aspiration $_{(t-1)}$	[0.519]	[0.542]
	-0.656**	-0.613**
	(0.277)	(0.310)
CO_2 Below Aspiration $_{(t-1)}$	[1.001]	[0.983]
	0.001	-0.017
	(0.031)	(0.038)
Control Variables	Included	Included
Firm Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Selection Control	Yes	Yes
Log-likelihood	-933.916	-764.274
N	329	329

Notes: Incidence-Rate Ratios reported in brackets. Non-exponentiated coefficients reported without brackets. Robust standard errors in parentheses.

* p<0.10 ** p<0.05 *** p<0.01

Robustness Analysis : Including controls for financial performance vs. aspiration

Negative Binomial Estimation	(1)	(2)	(3)
Dependent Variable	Search Renewable	Search Renewable	Search Renewable
CO_2 Above Dummy $_{(t-1)}$	[1.504]	[1.514]	[1.521]
	0.408***	0.415***	0.419***
	(0.137)	(0.143)	(0.139)
CO_2 Above Aspiration $_{(t-1)}$	[0.506]	[0.508]	[0.509]
	-0.682**	-0.676**	-0.675**
	(0.304)	(0.306)	(0.307)
CO_2 Below Aspiration $_{(t-1)}$	[0.987]	[0.982]	[0.997]
	-0.013	-0.018	-0.003
	(0.039)	(0.042)	(0.039)
Control Variables	Included	Included	Included
Firm Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Selection Control	Yes	Yes	Yes
Log-likelihood	-753.966	-753.727	-750.746
N	325	325	323

Notes. Incidence-Rate Ratios reported in brackets. Non-exponentiated coefficients reported without brackets. Robust standard errors in parentheses. To construct variables of Financial Performance vs. Aspiration (*Financial Above Aspiration, Financial Below Aspiration, and Financial Above Dummy*), we use ROA for Model 1, ROS for Model 2, and EPS for Model 3. Due to missing values when constructing *Financial Above Aspiration, Financial Below Aspiration, and Financial Above Dummy*, number of observations has decreased accordingly. As control variables are different from the main analysis, we re-run Heckman 1st stage for each model. Then, we re-calculate the Inverse Mills Ratio for Model 1 to 3, respectively.

* p<0.10 ** p<0.05 *** p<0.01.

Robustness Analysis : Including controls for Concern on clean energy, Incentive payments to managers

Negative Binomial Estimation	(1)	(2)	(3)
Dependent Variable: Search Renewable	Concern on Clean Energy	Monetary & non-monetary incentive	Monetary incentive
CO_2 Above Dummy $_{(t-1)}$	[1.699]	[1.579]	[1.558]
	0.530***	0.457***	0.444***
	(0.179)	(0.149)	(0.161)
CO_2 Above Aspiration $_{(t-1)}$	[0.350]	[0.294]	[0.351]
	-1.050**	-1.226***	-1.047***
	(0.440)	(0.377)	(0.382)
CO_2 Below Aspiration $_{(t-1)}$	[0.994]	[1.002]	[1.223]
	-0.006	0.002	0.201
	(0.053)	(0.650)	(0.695)
Control Variables	Included	Included	Included
Firm Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Selection Control	Yes	No	No
Log-likelihood	-495.588	-297.181	-299.713
N	218	145	145

Notes. Incidence-Rate Ratios reported in brackets. Non-exponentiated coefficients reported without brackets. Robust standard errors in parentheses. Due to missing values when constructing variables of *Concern on Clean Energy*, number of observations has decreased accordingly. As a final sample testing Model 1 is different from the main analysis, we re-run Heckman 1st stage with dependent variable equals to one if a firm is included in a final sample used in Model 1. Then, we re-calculate the Inverse Mill s Ratio for Model 1. For Model 2 and 3, as not all of our sample firms answer relevant CDP questionnaire items, observation number has decreased significantly to 145. D ue to few variations in remaining observation numbers, we could not perform the Heckman 1st stage. As such, we displayed the results without controlling selection bias

* p<0.10 ** p<0.05 *** p<0.01.

Additional Analysis
: DV = Energy purchased

Negative Binomial Estimation	(1)	(2)
Dependent Variable	Energy Purchased	Energy Purchased
CO_2 Above Dummy $_{(t-1)}$	[0.982]	[0.973]
	-0.018	-0.027
	(0.080)	(0.081)
CO_2 Above Aspiration $_{(t-1)}$	[1.427]	[1.246]
	0.355*	0.220
	(0.203)	(0.145)
CO_2 Below Aspiration $_{(t-1)}$	[0.952]	[0.920]
	-0.049	-0.083
	(0.100)	(0.080)
Control Variables	Included	Included
Firm Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Selection Control	Yes	Yes
Log-likelihood	-2189.083	-2132.190
N	146	146

Notes. Incidence-Rate Ratios reported in brackets. Non-exponentiated coefficients reported without brackets. Robust stand ard errors in parentheses. We do not include the control variable of Total Backward Citations because the variable was to c ontrol a firm's overall tendency to cite prior arts rather than energy purchase. Since not all of our sample firms are include d in Refinitiv Eikon database, observation numbers have decreased significantly to 146. As control variables are different f rom the main analysis, we re-run Heckman 1st stage for each model. Then, we re-calculate the Inverse Mills Ratio for Mod el 1 and 2, respectively.

* p<0.10 ** p<0.05 *** p<0.01.

Limitations

Does not consider social aspiration (i.e., average emissions of industry)

A single industry study

Focus only on renewable energy technology

Focus only on the firm's technology-related behavior