THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

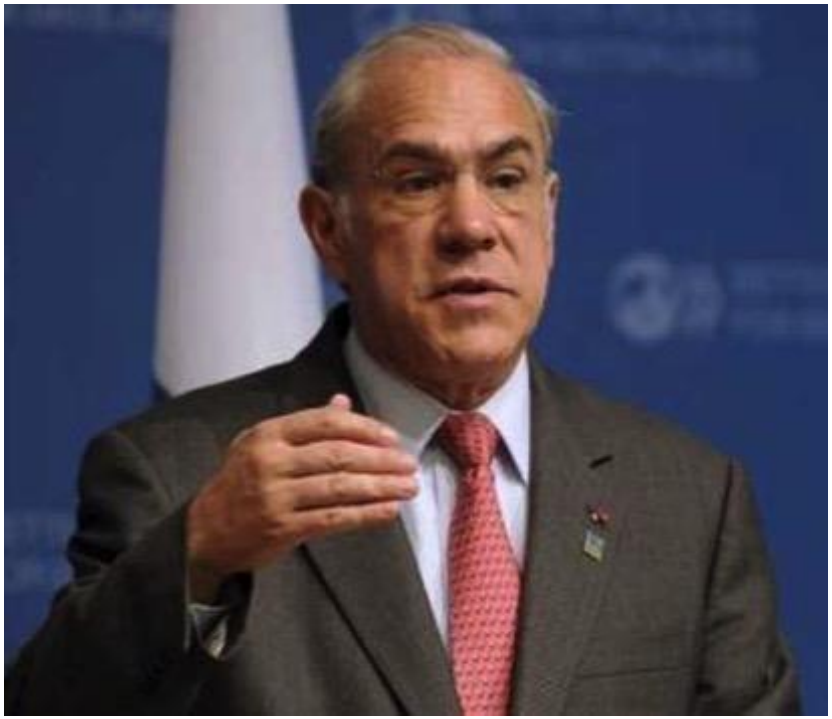
Grantham Research Institute on Climate Change and the Environment

Green policies, clean technology spillovers and growth

Antoine Dechezleprêtre
London School of Economics

Joint work with Ralf Martin & Myra Mohnen

Green policies as growth policies?



"Green policies can boost productivity, spur growth and jobs"

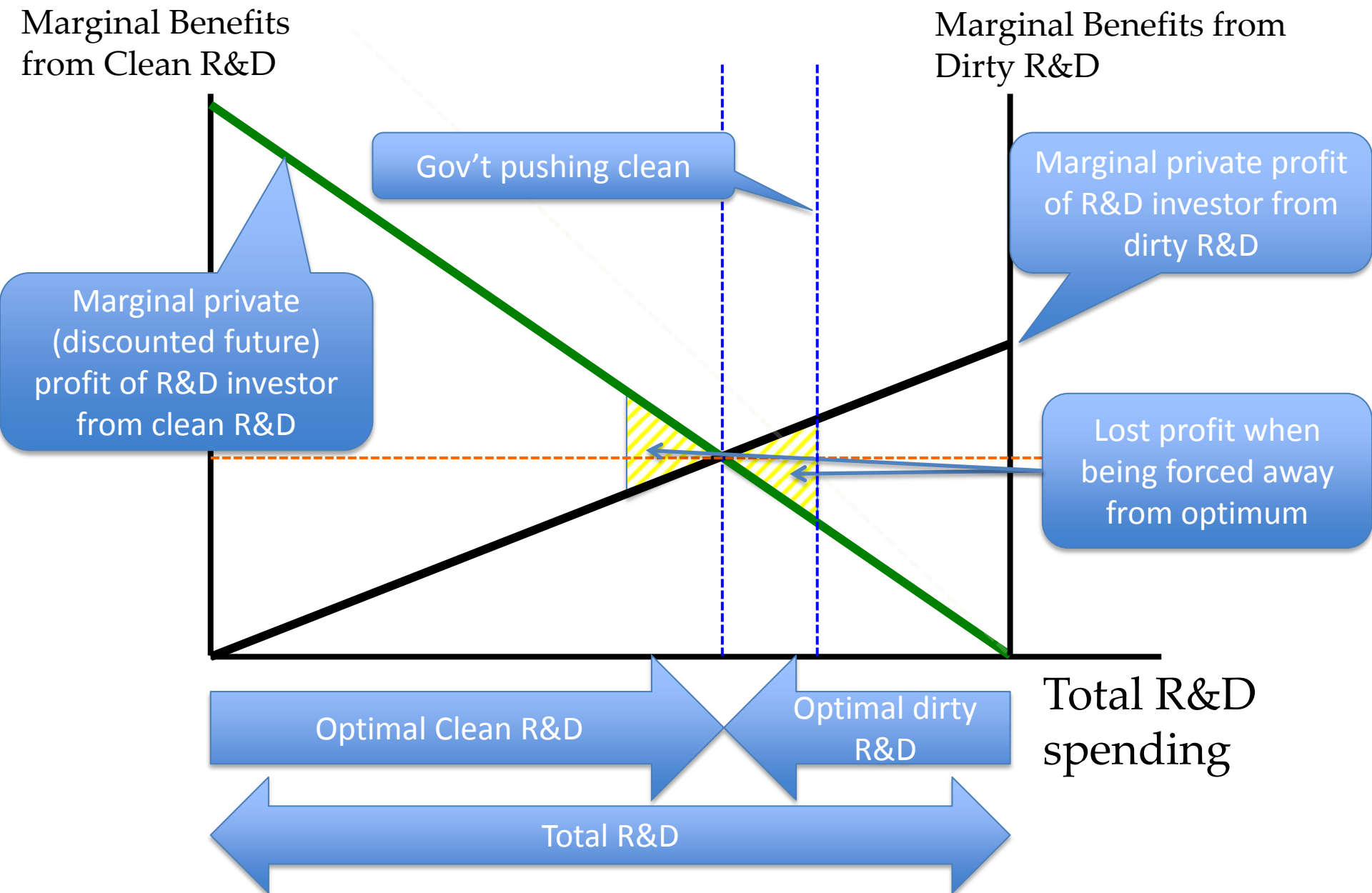
Angel Gurría, OECD Secretary-General

Climate policies and induced technical change

- Climate policies such as carbon pricing induce a switch of innovation activities away from dirty technologies and towards clean technologies
  - [Aghion, Dechezleprêtre, Hemous, Martin & van Reenen (JPE *forth.*), Noailly & Smeets (2014), Popp & Newell (2012), Hottenrott & Rexhaüser (2013)]

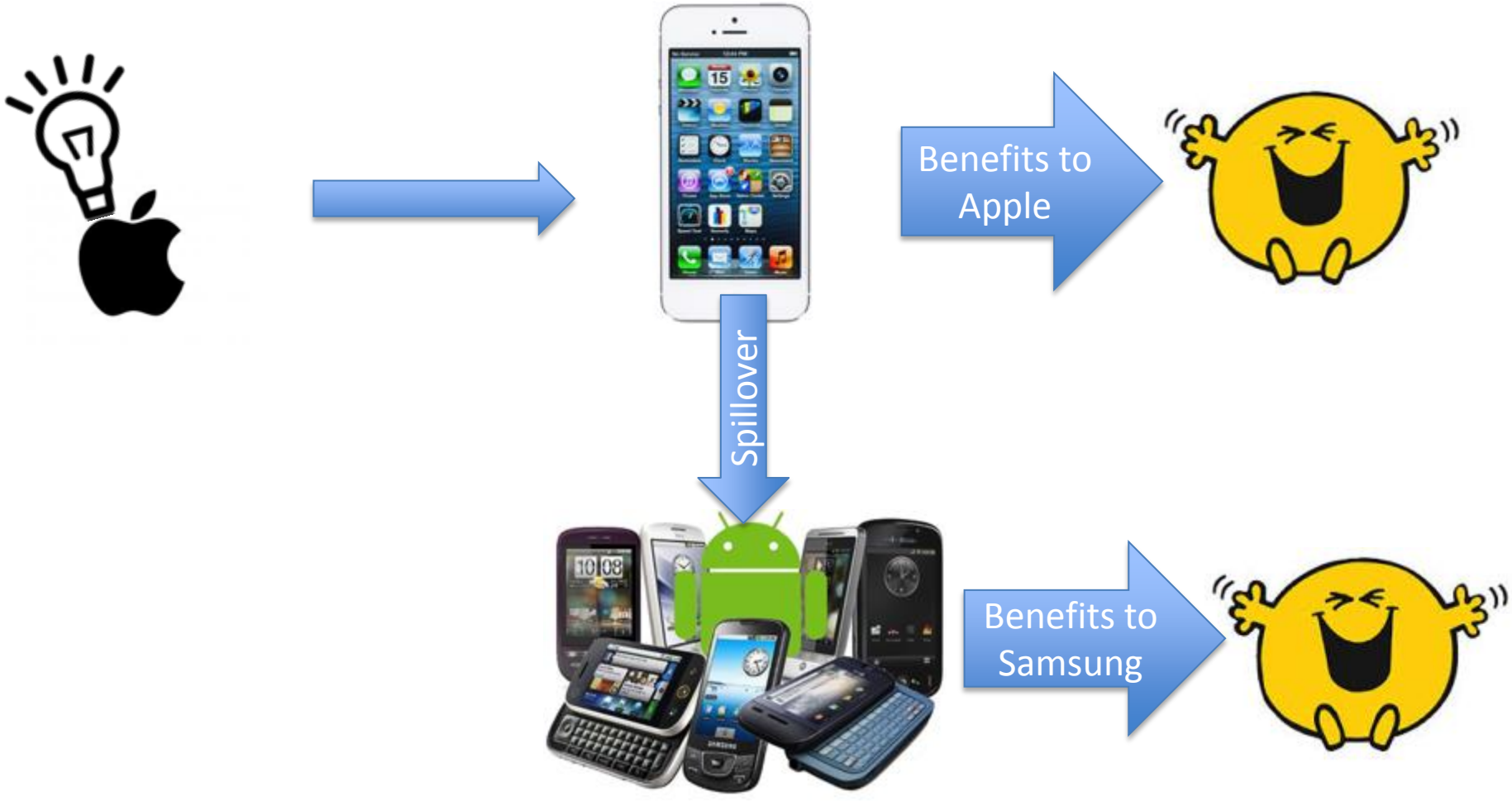
- What is the impact on innovating firms and on the economy?

Clean R&D push & private benefits

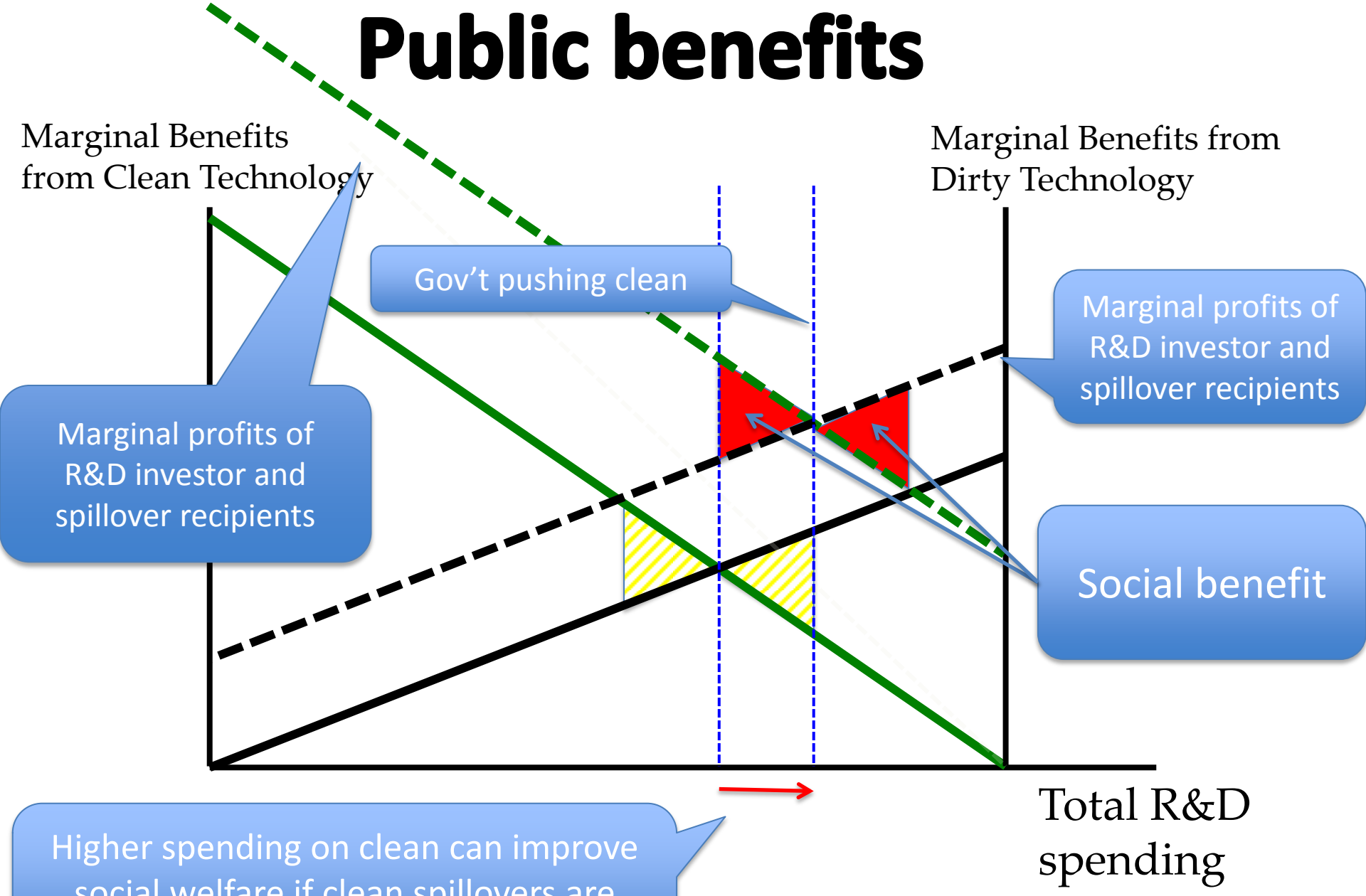


Spillovers

In addition to private benefits…



Public benefits



Double dividend?

If Clean > Dirty Spillovers

- A policy-induced redirection of innovation from dirty to clean technologies will reduce the net cost of environmental policies...
- ... and can even lead to higher economic growth
  - One of the theoretical motivations for the Porter hypothesis [Mohr (2002); Smulders & de Nooij (2003); Hart (2004, 2007); Ricci (2007)]

Research programme

- Compare relative degree of spillovers between clean and dirty technologies
  - Measure knowledge spillovers using patent citations
  - 2 sectors: transportation and electricity production
- Measure the economic value of these spillovers for potential growth impacts

Technology groups

Dirty	Group	Clean
Fossil fuel based (coal & gas)	*Electricity generation*	Renewables
Internal combustion vehicles	*Automotive*	Electric, Hybrid, Hydrogen

Measuring knowledge spillovers

- Count citations made by future patents
  - Trajtenberg (1990), Cabellero and Jaffe (1993), Jaffe and Trajtenberg (1996, 1998), Jaffe et al. (1998), Jaffe et al. (2000)

- Advantages
  - Mandatory for inventors to cite "prior art"
  - Data availability
  - Technological disaggregation

Data

- World Patent Statistical Database (PATSTAT) @ EU Patent Office
- 1.2 million inventions filed in 107 patent offices from 1950 to 2005, 3 million citations made to these inventions

Patent example

US005369324A

United States Patent [19]

Saether

[11] **Patent Number: 5,369,324**

[45] **Date of Patent: Nov. 29, 1994**

[54] **ELECTRIC MOTOR**

[75] Inventor: **Gustav Saether**, Leksvik, Norway

[73] Assignee: **Lyng Elektronikk A-S**, Vanvikan, Norway

[21] Appl. No.: **92,092**

[22] Filed: **Jul. 16, 1993**

[30] **Foreign Application Priority Data**

Jul. 17, 1992 [NO] Norway 92.2844

[51] **Int. Cl.**[5] **H02K 37/00**

[52] **U.S. Cl.** ..... **310/49 R**; 310/67 R; 310/68 B; 310/75 R; 310/156; 310/179

[58] **Field of Search** ..... 310/49 R, 67 R, 156, 310/162, 216, 75 R, 68 B, DIG. 6, 179, 180, 184, 254, 263, 42

[56] **References Cited**

U.S. PATENT DOCUMENTS

Re. 28,075	7/1974	Kavanaugh	310/49 R
3,783,313	1/1974	Mathur	310/49 R
4,075,519	2/1978	Mrcun	310/67 R
4,280,072	7/1981	Gotou et al.	
5,200,776	4/1993	Sakamoto	310/68 B

FOREIGN PATENT DOCUMENTS

300126	1/1989	European Pat. Off. .
2211030	12/1988	United Kingdom .

FOREIGN PATENT DOCUMENTS

300126 1/1989 European Pat. Off. .

2211030 12/1988 United Kingdom .

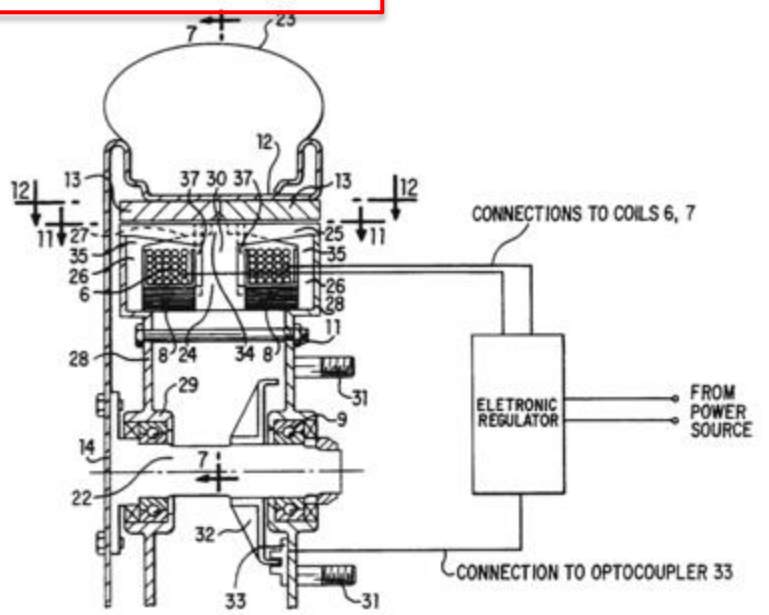
Primary Examiner—R. Skudy

Attorney, Agent, or Firm—Keck, Mahin & Cate

[57] **ABSTRACT**

An electric motor consisting of an inside stator part and a rotor part placed outside and concentrically in relation to the stator part, has a high number of permanent magnets (13) on the inside of the rotor part. The magnetic fields from these permanent magnets interact with magnetic fields between flux-conducting lamella blocks (30, 35) engaging the coil cores (8) on the stator. The lamella blocks (30, 35) are T- and Γ-shaped with top beams (25, 27) pointing in directions parallel to the axis, and the top beams (25, 27) are positioned to provide substantially circumferentially directed magnetic fields in flux gaps (36) therebetween. The magnetic fields in the flux gaps (36) between the top beams (25, 27) are reversed in successive order, and under time control from an electronic regulator.

10 Claims, 8 Drawing Sheets



Spillover from US 5369324

US005690185A

United States Patent [19]

Sengel

[11] Patent Number: 5,690,185

[45] Date of Patent: Nov. 25, 1997

[54] **SELF POWERED VARIABLE DIRECTION WHEELED TASK CHAIR**

[75] Inventor: **Michael P. Sengel**, 110 S. Lorraine Rd., Wheaton, Il. 60187-5833

[73] Assignee: **Michael P. Sengel**, Wheaton, Ill.

[21] Appl. No.: **410,685**

[22] Filed: **Mar. 27, 1995**

[51] **Int. Cl.**[6] **B60K 1/02**

[52] **U.S. Cl.** **180/65.1**; 180/65.5; 180/907; 280/304.1

[58] **Field of Search** 180/65.1, 65.5, 180/65.6, 65.8, 907, 214, 15, 21, 24.01, 24.07, 224, 255; 280/647, 648, 650, 250, 250.1, 304.1

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,839,981	1/1932	Markey	180/255
2,362,616	11/1944	Cloud	180/65.1
3,111,181	11/1963	Yatich	180/65.1
3,534,825	10/1970	Reffle	180/252
4,461,367	7/1984	Eichinger et al.	180/65.1
4,613,151	9/1986	Kielczewski	280/650
5,090,513	2/1992	Bussinger	180/907
5,183,133	2/1993	Roy	180/252
5,249,636	10/1993	Kruse	180/21
5,275,248	1/1994	Finch	180/65.6
5,322,140	6/1994	Bussinger	180/65.1
5,369,324	11/1994	Sacher	310/49 R
5,482,125	1/1996	Pagett	180/65.5

FOREIGN PATENT DOCUMENTS

0 338 689	10/1989	European Pat. Off.	180/907
43 03 342	8/1994	Germany	180/65.6
330480	6/1930	United Kingdom .	

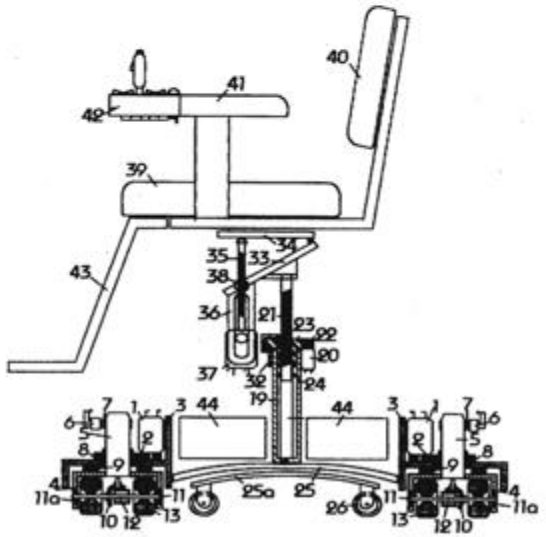
Primary Examiner—Brian L. Johnson

Assistant Examiner—Frank Vanaman

[57] **ABSTRACT**

A Self Powered Variable Direction Wheeled Task Chair, and a personal mobility device, providing additional ranges of motion in that it has an electrically powered height adjustable seat allowing the operator's seating position to range from standard table height seating to work bench or counter top seating. Additionally and more importantly, the chair, will have directional movement capabilities well beyond typical wheel chairs, or other wheel driven personal mobility devices in that it will utilize electro-mechanical directionally pivoting propulsion, capable of not only forward, backward, and pivot turning capabilities, but also sideways movement or more precisely, movement in any direction, and a rotational movement as may be required by the operator.

6 Claims, 16 Drawing Sheets



Spillovers from spillovers…

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 March 2006 (02.03.2006)

PCT

(10) International Publication Number
WO 2006/023539 A3

(51) International Patent Classification:
A61G 5/10 (2006.01)

(21) International Application Number:
PCT/US2005/029229

(22) International Filing Date: 16 August 2005 (16.08.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/601,924 16 August 2004 (16.08.2004) US
60/611,407 20 September 2004 (20.09.2004) US

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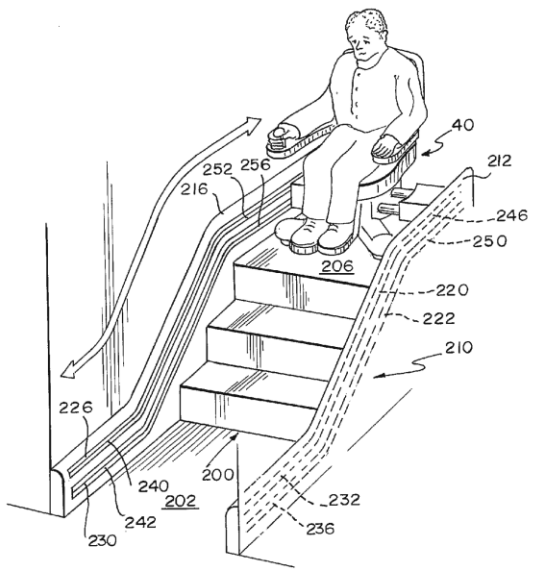
(74) Agent: **CONRAD, Richard, D.**; Barnes & Thornburg LLP, 11 South Meridian Street, Indianapolis, IN 46204 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM,

[Continued on next page]

(54) Title: HOME CARE EQUIPMENT SYSTEM

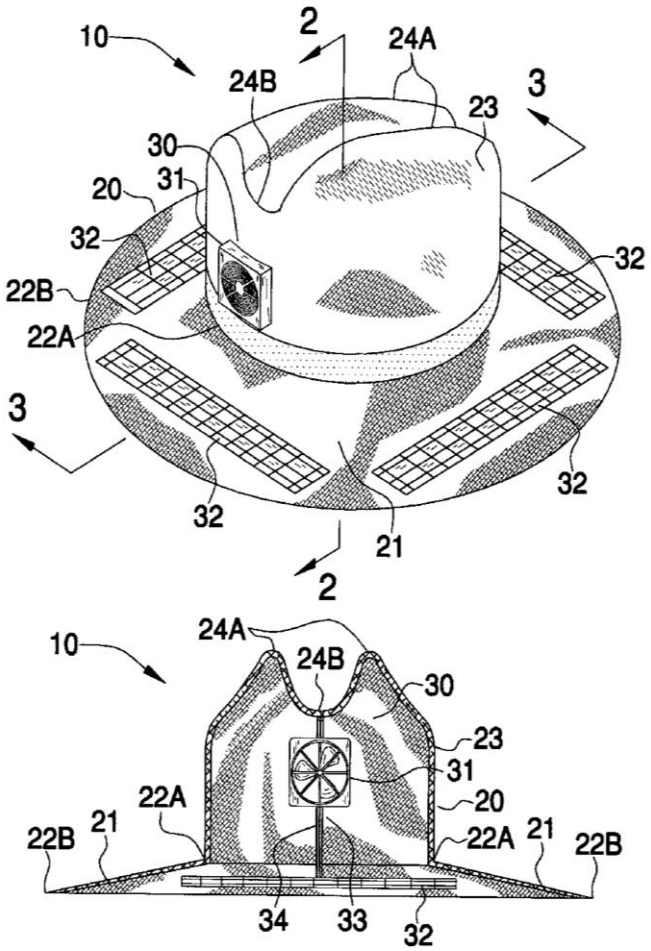


(57) Abstract: A system for assisting a person of limited mobility in moving from room to room within a home and performing essential daily activities includes a personal mobility device (40, 100, 1700, 1800, 2000) which includes transfer drivers (164) which engage a transfer system (210) to transition from a first elevation to a second elevation.

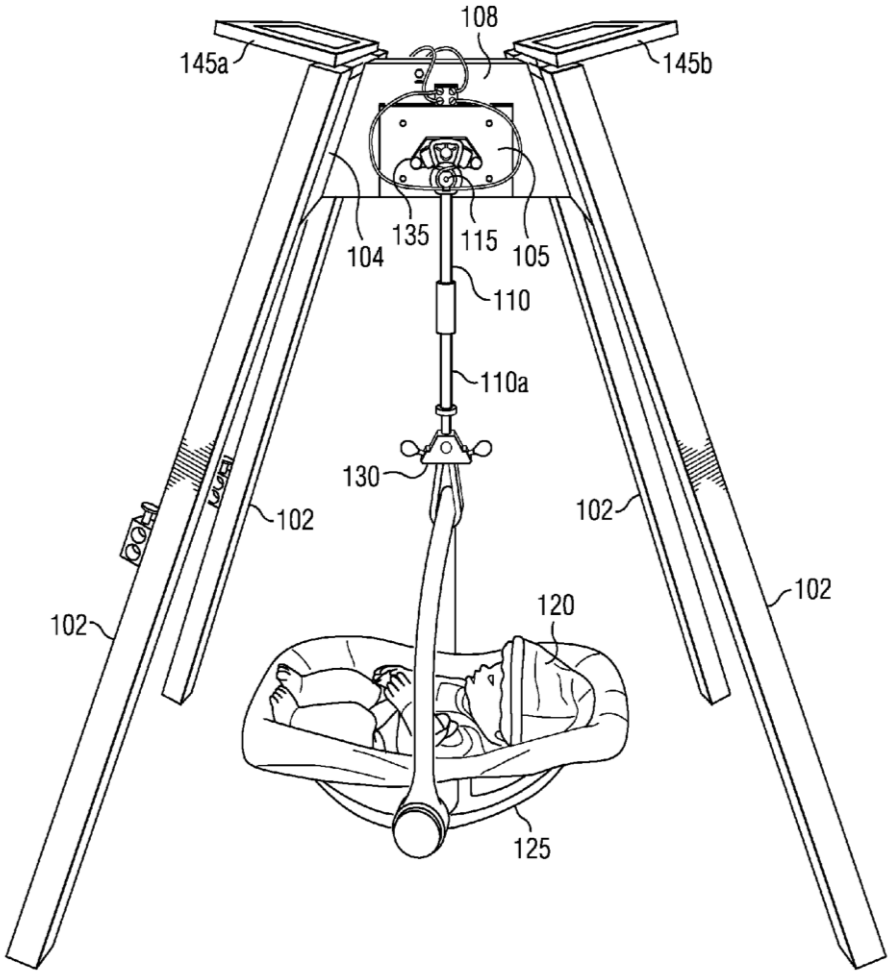
WO 2006/023539 A3

Ground-breaking spillovers from clean tech

COMBINED SOLAR POWERED FAN AND HAT ARRANGEMENT FOR MAXIMIZING AIRFLOW THROUGH THE HAT



SOLAR POWERED, SILENT, ENERGY EFFICIENT BABY ROCKER



Counting citations received by clean & dirty patents

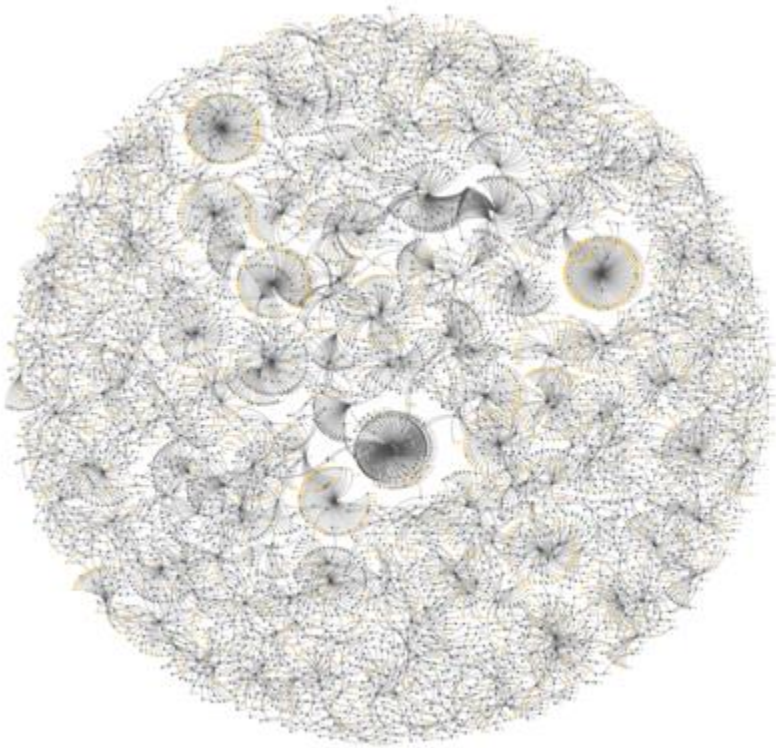
Table 2: Mean number of citations

	Clean	Dirty	Diff.
Citations received	3.399	2.295	1.104***
	(8.256)	(5.921)	[0.016]

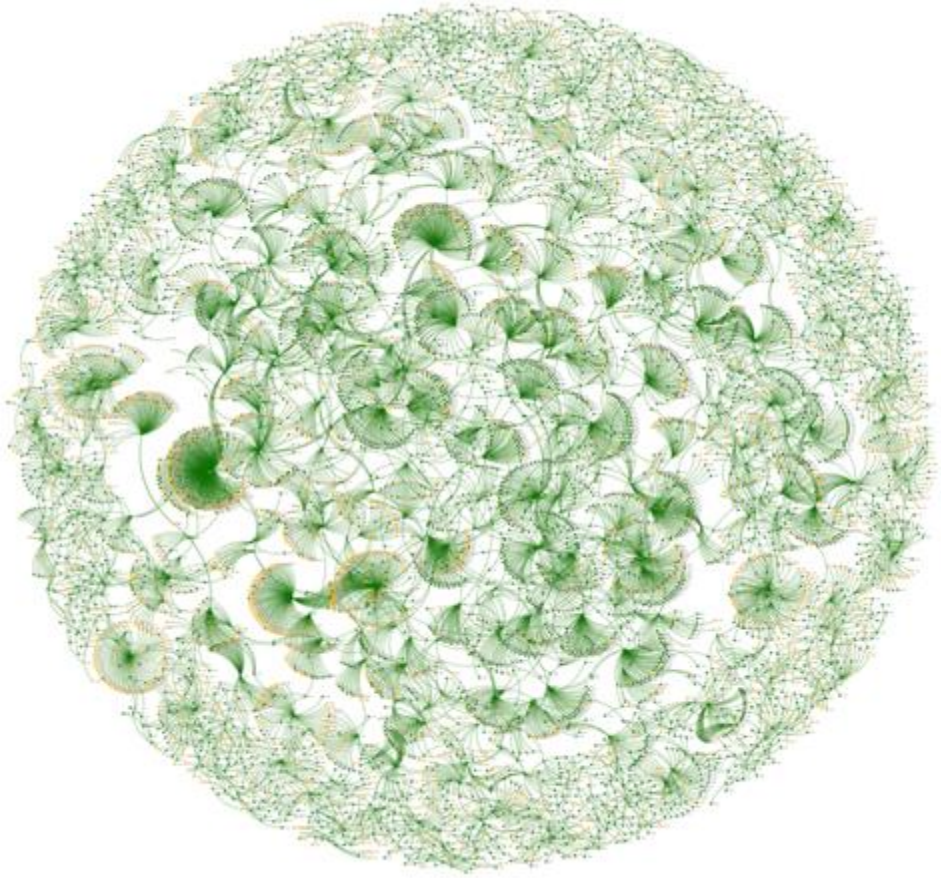
50% higher

Citations flowers

Citations to 1000 dirty....



…and 1000 clean innovations



Econometric analysis

- Potential issues:
  - Recent increase in citations (web searches)
  - Clean patents younger
  - Differences across patent offices
  - Citation pool larger for dirty

➢ **Regression approach**

$$Cites_i = \exp\left(\beta Clean_i + \gamma X_i + \epsilon_i\right)$$

Not all citations are equal

- Economic value of citations vary greatly

  - Weight citing patents on the basis of how many times they are themselves cited
    - Based on Google's "Page rank" algorithm

Results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.	Citations received			PatentRank		
Clean invention	0.398***	0.392***	0.430***	0.267***	0.264***	0.292***
	(0.015)	(0.015)	(0.014)	(0.013)	(0.014)	(0.014)
Number of patents		-0.092***	-0.057***		-0.052***	-0.031***
		(0.00	(0.007)		(0.006)	0.005)
Family size			0.073***			067***
			(0.004)			0.003)
Triadic			0.456***			241***
			(0.036)			
Granted			0.947***			*
			(0.031)			
Patent office-by-year-by-sector	yes	yes	yes	yes	yes	yes
Month fixed effect	yes	yes	yes	yes	yes	yes
Obs.	1,149,988	1,149,988	1,149,988	1,149,988	1,149,988	1,149,988

+43% spillovers

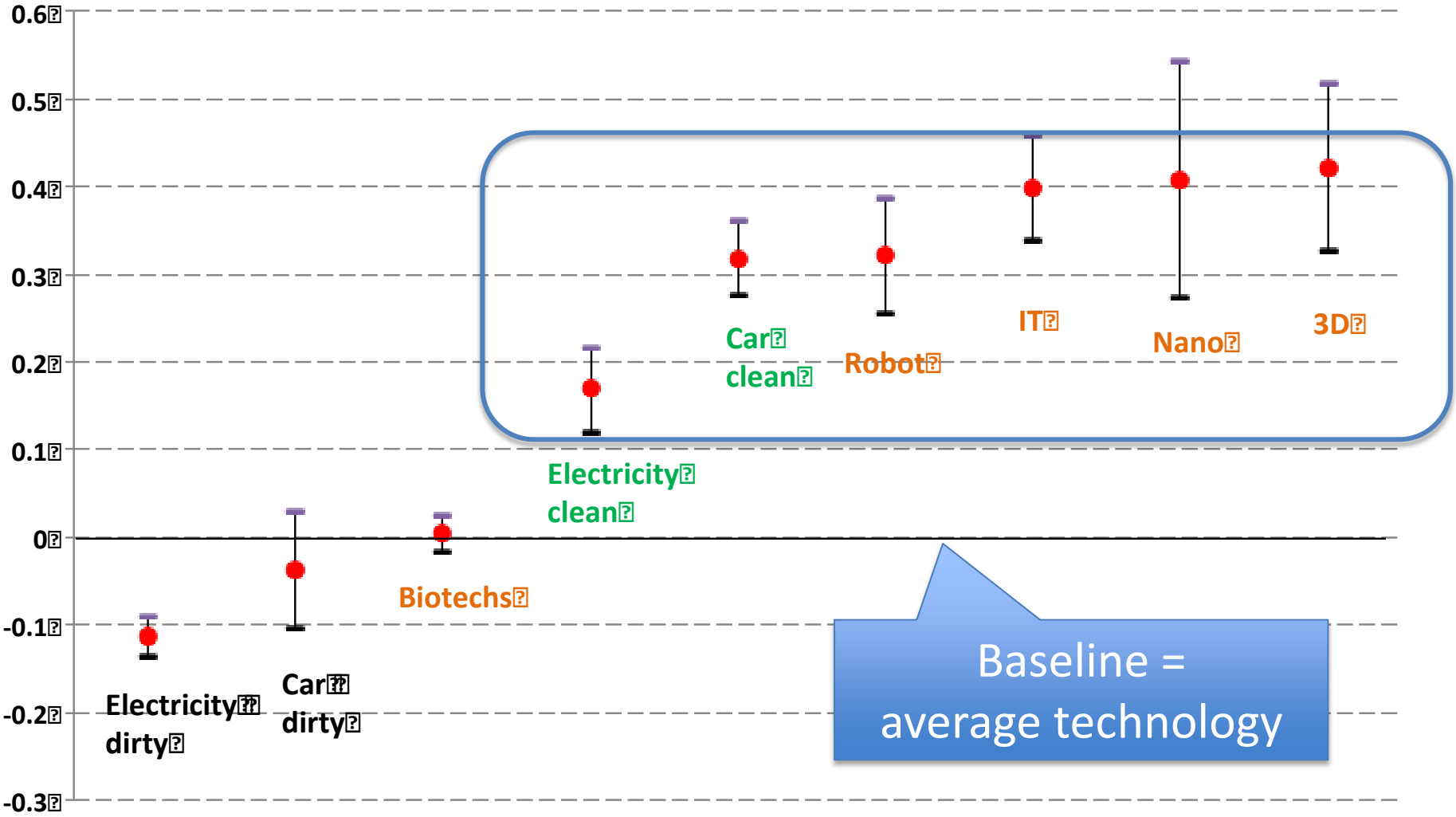
+29% spillovers

Notes: Robust standard errors in parentheses (* p<0.05, ** p<0.01, *** p<0.001). The dependent variable is the total number of citations received excluding self-citations by inventors (columns 1 to 3) and the PatentRank after 20 iterations (columns 4 to 6). All columns are estimated by fixed-effects Poisson pseudo-maximum likelihood.

Robustness

- Results robust to multiple sensitivity checks
- Results true both for energy and transportation
- Spillovers higher for clean both nationally and internationally
- Spillovers higher for clean both intra and extra sector

The drivers – comparing clean to other emerging technologies



The value of clean and dirty spillovers

- What is the economic value of spillovers to knowledge recipients?
- We estimate the impact of spillovers on the market value of firms (discounted future profits): $V_{it} = q_t(A_{it} + \beta K_{it})^{\sigma}$

Knowledge assets

Firm i's stock market value in year t

Physical assets

Knowledge assets = firm's own R&D activity + spillovers from the economy

Data

- Firm-level patent data + financial data
- 8735 firms, 2000-2011
  - Market value, assets, R&D, patents
- Citations between firms to capture knowledge spillovers

Results

	(1)	(2)	(3)	(4)	(5)
Dep. var.			ln Tobin's Q		
R&D / assets	0.438***	0.436***	0.427***	0.433***	0.428***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Patent / R&D	-0.097**	-0.070	-0.062		-0.062
	(0.044)	(0.044)	(0.045)		(0.045)
Fwd citations / patent		0.074***	0.031***		0.029***
		(0.006)	(0.010)		(0.010)
Knowledge spillovers			0.059***		
			(0.011)		
Clean spillovers				0.146***	0.125***
				(0.037)	(0.037)
Dirty spillovers				0.053	0.041
				(0.033)	(0.033)
Other spillovers				0.080***	0.056***
				(0.007)	(0.011)

Where do spillovers occur?

- Who captures these spillovers and the benefits that go with them?
- On average, 50% of knowledge spillovers in clean occur within the country of the inventor
  - The figure is smaller for small open economies (ex: UK 20%)

➢ Good news from unilateral policy perspective

Conclusion & policy implications

- Clean innovations generate significantly more spillovers than dirty technologies; the marginal value of clean spillovers is also greater
  - This comes from the relative novelty of clean technologies
  - Climate policies that induce a switch away from dirty and towards clean innovation can have economic co-benefits
  - Crowding out of dirty is key
- Spillovers are localized
  - This might lower concerns that unilateral climate policies lead to negative competitiveness effects
  - The share of benefits from innovation will be larger than benefits from avoided climate damage

Road ahead

- Quantify and simulate the effect of clean policies on economic growth
- Determine optimal amount of public R&D support to new techs (including clean)
- How to encourage innovation specifically in clean/new techs?
- How to ensure crowding out of dirty?

Back-up

Maybe things aren't so binary?

Grey (less dirty) innovations: Making fossil fuels more efficient

→ Cars: fuel injection technologies

→ Energy generation: "cleaner" coal (CHP, IGCC…)

Clean & dirty patents

- Usage of patent classification system (IPC & ECLA)
- OECD & EPO have been working on identifying clean patents
- Most recently Y02: A new classification system for climate change related technologies
  - Input from examiners and experts
  - Backward re-classification of patents

Related literature

1. Measurement and drivers of knowledge spillovers using patent citations
   - [Griliches (1992); Trajtenberg (1990); Jaffe et al (1993); Henderson, Jaffe and Trajtenberg (1996); Thompson and Fox-Kean, (2005)]
   - ➢ A few papers on energy technologies [Popp and Newell (2012); Nemet (2012); Bjorner and Mackenhauser (2013); Verdolini and Galeotti (2011), Noailly & Shestalova (2013)] but no paper on clean vs dirty technologies
2. Impact of knowledge spillovers on firms' productivity and long run growth [Romer (1990); Aghion and Howitt (1996)]
   - – Endogenous growth models with clean technologies and environmental policies [Smulders & de Nooij (2003); Hart (2004, 2007), Ricci (2007)]

Classification groups for car

Clean

B60K 1	Arrangement or mounting of electrical propulsion units
B60K 6	Arrangement or mounting of hybrid propulsion systems comprising electric motors and internal combustion
B60L 3	Electric devices on electrically-propelled vehicles for safety purposes: Monitoring operating variables, e.g. speed, deceleration, power consumption
B60L 7	Dynamic electric regenerative braking
B60L 11	Electric propulsion with power supplied within the vehicle
B60L 15	Methods, circuits, or devices for controlling the traction-motor speed of electrically-propelled vehicles
B60R 16	Electric or fluid circuits specially adapted for vehicles and not otherwise provided for
B60S 5	Supplying batteries to, or removing batteries form
B60W 10	Conjoint control of vehicles sub-units of different type or different function
B60W 20	Control systems specially adapted for hybrid vehicles
H01M	Fuel cells

Grey

F02M 39/71	Fuel injection apparatus
F02M 3/02-05	Idling devices for carburettors l preventing flow of idling fue
F02M 23	Apparatus for adding secondary air to fuel-air mixture
F02M 25	Engine-pertinent apparatus for adding non-fuel substances or small quantities of secondary fuel to combustion-air, main fuel, or fuel-air mixture
F02D 41	Electric control of supply of combustion mixture or its constituents
F02B 47/06	Methods of operating engines involving adding non-fuel substances or anti-knock agents to combustion air, fule, or fuel-air mixtures of engines, the substances including non-airborne oxygen

Dirty

F02B	Internal-combustion piston engines; combustion engines in genera
F02D	Controlling combustion engines
F02F	Cylinders, pistons, or casings for combustion engines; arragement of scalings in combustion engines
F02M	Supplying combustion engines with combustiles mixtures or constituents thereof
F02N	Starting of combustion engines
F02P	Ignition (other than compression ignition) for internal-combustion engines

Classification groups for electricity

Clean

Y02E10	Energy generation through renewable energy sources
Y02E30	Energy generation of nuclear origin
E02B9/08	Tide or wave power plants
F03B13/10-26	Submerged units incorporating electric generators or motors characterized by using wave or tide energy
F03D	Wind motors
F03G1	Devices for producing mechanical power from geothermal energy
F03G6	Devices for producing mechanical power from solar energy
F03G7/05	Ocean thermal energy conversion
F24J2	Use of solar heat, e.g. solar heat collectors
F24J3/08	Production or use of heat, not derived from combustion using geothermal heat
F26B3/28	Drying solid materials or objects by processes involving the application of heat by radiation, e.g. from the sun

Grey

Y02E50	Technologies for the production of fuel of non-fossil origin
Y02E20/10	Combined combustion
Y02E20/12	Heat utilisation in combustion or incineration of waste
Y02E20/14	Combined heat and power generation
Y02E20/16	Combined cycle power plant, or combined cycle gas turbine
Y02E20/18	Integrated gasification combined cycle
Y02E20/30	Technologies for a more efficient combustion or heat usage
Y02E20/32	Direct C02 mitigation
Y02E20/34	Indirect C02 mitigation, by acting on non C02 directly related matters of the process, more efficient use of fuels
Y02E20/36	Heat recovery other than air pre heating

Dirty

C10G1	Production of liquid hydrocarbon mixtures from oil-sha oil-sand, or non-melting solid carbonaceous or similar materials, e.g. wood, coal, oil-sand, or the like B03B
C10L1	Fuel
C10J	Production of fuel gases by carburetting air or other ga
E02B	Hydraulic engineering
F01K	Steam engine plans; steam accumulators; engine plants not otherwise provided for; engines using special working fluids or cycles
F02C	Gas-turbine plants; air intakes for jet-propulsion plants; controlling fuel supply in air-breathing jet-propulsion plants
F22	Steam generation
F23	Combustion apparatus; combustion processes
F24J	Production or use of heat not otherwise provided for
F27	Furnaces; kilns; ovens; retorts
F28	Heat exchange in general

Regression approach

$$Cites_i = \exp\left(\beta Clean_i + \gamma X_i + \epsilon_i\right)$$

Number of citations received by innovation *i*

Poisson model because of left censoring

Can interpret as percentage difference

Clean Dummy

Controls

Control variables

- Patent office **x** year **x** technology fixed effects
- Past patent stock in the same technological class (4 digit IPC)

Accounting for size of "citation pool"

- Family size
- Triadic
- Granted

Controls for private value of innovation

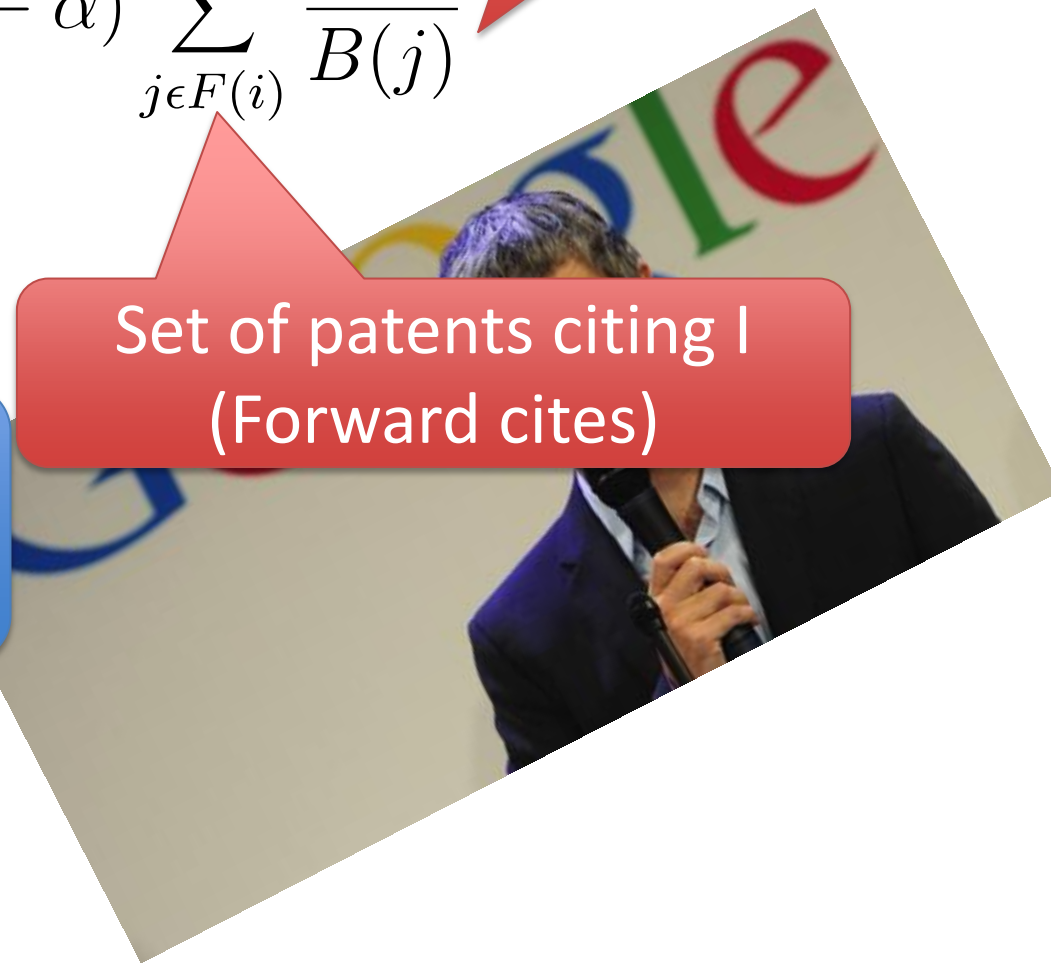
"Patent Rank"

Number of patents j cites (Backward cites)

$$r(i) = \frac{\alpha}{N} + (1-\alpha) \sum_{j \epsilon F(i)} \frac{r(j)}{B(j)}$$

Defines a system of linear equations.
Solve recursively

Set of patents citing I (Forward cites)



Results by sector

	(1)	(2)	(3)	(4)
Sector	Transport	Electricity	Transport	Electricity
Dep. var.	Citation count		PatentRank	
Clean invention	0.347***	0.488***	0.219***	0.333***
	(0.018)	(0.023)	(0.014)	(0.023)
Number of patents	-0.068	-0.047***	-0.048***	-0.019**
	8)	(0.009)	(0.006)	(0.007)
		0.067***	0.062***	0.060***
		(0.004)	(0.007)	(0.004)
		0.432***	0.279***	0.252***
	(0.056)	(0.050)	(0.045)	(0.041)
Granted	1.134***	0.725***	0.620***	0.381***
	(0.034)	(0.024)	(0.027)	(0.017)
Observations	419,959	748,918	419,959	748,918

Stronger effects in electricity

Clean, grey & dirty

	(1)	(2)	(3)	(4)
Sample	Clean vs. Grey and true Dirty	Clean vs. Grey	Grey vs. True Dirty	Clean vs. True Dirty
Dep. var.	Citations received			
Clean/Grey invention	0.430***	0.191***	0.307***	0.502***
	(0.014)	(0.016)	(0.016)	(0.015)
Number of patents	-0.057***	-0.051***	-0.114***	-0.060***
	(0.007)	(0.00	(0.005)	(0.007)
Family size	0.		72***	0.071***
	(		004)	(0.004)
Triadic	0.456***	0.481***	0.454***	0.441***
	(0.036)	(0.055)	(0.037)	(0.035)
Granted	0.947***	0.997***	0.977***	0.868***
	(0.031)	(0.035)	(0.033)	(0.027)
Observations	1,149,988	326,942	978,179	1,006,996

Clean > Grey > Dirty

Robustness

- Compare clean & dirty patents developed by same inventor / company
- Look at university/company/individuals patents
- Control for R&D subsidies
- Citations made by *applicants* only (not by *examiners*)
- Different subsamples (triadic patents, US, EPO)
- Correct for self-citations within applicant
- Adding controls (# IPC codes, # inventors, # claims, # citations made, etc)

Maybe it's a network effect?

Sample of innovations by inventors doing both dirty & clean

	(1)	(2)
Dep. var.	Citations received	
Clean invention	0.274***	0.336***
	(0.007)	(0.011)
Number of patents	-0.096***	-0.081***
	(0.004)	(0.006)
Family size	0.038***	0.094***
	(0.002)	(0.006)
Triadic	0.866***	0.644***
	(0.012)	(0.026)
Granted	1.234***	1.008***
	(0.007)	(0.011)
Inventor fixed effect	no	yes
Obs.	697,192	697,192

Maybe it's the companies?

Sample of innovations by companies doing both dirty & clean

	(1)	(2)
Dep. var.	Citations received	
Clean invention	0.400***	0.380***
	(0.000)	(0.000)
Number of patents	-0.038***	-0.067***
	(0.000)	(0.000)
Family size	0.091***	0.102***
	(0.000)	(0.000)
Triadic	0.462***	0.446***
	(0.000)	(0.000)
Granted	1.023***	1.000***
	(0.000)	(0.000)
Fixed effect	no	yes
Observations	435,584	435,584

Clean driven by subsidies already?

- Climate change has been a priority for governments for a while
- Energy efficiency and security has been an issue for even longer
- Clean innovations might already have been driven by subsidies?

Regress on R&D subsidies

- IEA collects data on clean R&D subsidies by governments for 28 countries
- Allocate spending to innovations on the basis of location of inventors

$$GovernmentSpending_i = \sum_{j \in Inventors(i)} GovernmentSpending_{c(j)}$$

Control for R&D subsidies

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All		Transport		Electricity	
Dep. var.	Citations received					
Clean invention	0.493***	0.507***	0.253**	0.253***	0.483***	0.497***
	(0.026)	(0.026)	(0.077)	(0.079)	(0.026)	(0.026)
Government spending		0.034***		-0.001		0.032***
		(0.007)		(0.033)		(0.007)
Number of patents	-0.007	-0.006	-0.070***	-0.070***	-0.006	-0.005
	(0.009)	(0.009)	(0.020)	(0.020)	(0.009)	(0.009)
Family size	0.067***	0.067***	0.054***	0.054***	0.066***	0.066***
	(0.004)	(0.004)	(0.012)	(0.012)	(0.004)	(0.004)
Triadic	0.452***	0.450***	0.474***	0.474***	0.447***	0.445***
	(0.046)	(0.046)	(0.093)	(0.094)	(0.046)	(0.047)
Granted	0.689***	0.688***	0.776***	0.776***	0.696***	0.695***
	(0.025)	(0.025)	(0.055)	(0.055)	(0.026)	(0.026)
Obs.	496,788	496,788	16,703	16,703	488,896	488,896

Universities are subsidy channel

	(1)	(2)
Dep. var.	Citations received	
Clean invention	0.421***	0.423***
	(0.014)	(0.015)
Number of patents	-0.047***	-0.050***
	(0.006)	(0.006)
Family size	0.070***	0.067***
	(0.003)	(0.003)
Triadic	0.450***	0.432***
	(0.034)	(0.034)
Granted	1.005***	0.992***
	(0.031)	(0.032)
University		0.429***
		(0.022)
Firms		0.271***
		(0.018)
Obs.	826,078	826,078

Reference category: Innovations filed by individuals

Universities / firms / individuals

	(1)	(2)	(3)
Applicant	University	Firm	Individual
Dep. var.	Citations received		
Clean invention	0.396***	0.418***	0.459***
	(0.003)	(0.016)	(0.030)
Number of patents	-0.100***	-0.041***	-0.068***
	(0.014)	(0.007)	(0.011)
Family size	0.072***	0.067***	0.377***
	(0.005)	(0.003)	(0.042)
Triadic	0.152***	0.454***	-0.870
	(0.043)	(0.035)	(0.613)
Granted	0.775***	1.022***	0.131***
	(0.047)	(0.032)	(0.036)
Obs.	36,186	706,517	75,487

Clean advantage slightly smaller for university patents

Cleanness or novelty? Clean vs CCS

	(1)	(2)
Dep. var.	Citations received	PatentRank index
Clean invention	-0.083*	0.045
	(0.034)	(0.023)
Number of patents	0.037***	0.057***
	(0.010)	(0.010)
Family size	0.065***	0.055***
	(0.006)	(0.005)
Triadic	0.477***	0.271***
	(0.062)	(0.047)
Granted	0.681***	0.338***
	(0.030)	(0.019)
Observations	106,700	106,700

Controlling for generality & originality

	(1)	(2)	(3)	(4)
Dep. var.	Citations received			
Clean invention	0.365***	0.332***	0.363***	0.332***
	(0.012)	(0.012)	(0.012)	(0.012)
Number of patents	-0.044***	0.007	-0.025***	0.006
	(0.005)	(0.006)	(0.005)	(0.005)
Family size	0.043***	0.039***	0.041***	0.039***
	(0.002)	(0.002)	(0.002)	(0.002)
Triadic	0.296***	0.264***	0.287***	0.264***
	(0.014)	(0.013)	(0.014)	(0.013)
Granted	0.673***	0.591***	0.659***	0.592***
	(0.023)	(0.021)	(0.022)	(0.021)
Generality		1.149***		1.164***
		(0.019)		(0.019)
Originality			0.371***	-0.036*
			(0.015)	(0.015)
Obs.	281,978	281,978	281,978	281,978

-5%

Further robustness

- Five-year window
- Citations made by *applicants* only (not by *examiners*)
- Extreme outcomes
- Different samples: inventions receiving at least one citation, Triadic patents, US or EPO patent office
- Correct for self-citations within same applicant
- Adding controls (# IPC codes, # inventors, # claims, # citations made, etc)

Cross-sectoral spillovers

	(1)	(2)	(3)
Dep. var.	Citations received	Intra-sectoral citations	Inter-sectoral citations
Clean invention	0.430***	0.457***	0.247***
	(0.014)	(0.015)	(0.019)
Number of patents	-0.057***	-0.053***	-0.081***
	(0.007)	(0.007)	(0.006)
Family size	0.073***	0.074***	.066***
	(0.004)	(0.004)	(0.003)
Triadic	0.456***	0.48	0.212***
	(0.036)		(0.040)
C			
Obs.	1,149,988	1,149,988	1,149,988

Good news from growth perspective

National & international spillovers

	(1)	(2)	(3)
Dep. var.	Citations received	Citations received within country	Citations received across country
Clean invention	0.430***	0.423***	0.247***
	(0.014)	(0.017)	(0.019)
Number of patents	-0.057***	-0.057***	-0.081***
	(0.007)	(0.008)	(0.006)
Family size	0.073***	0.062***	0.066***
	(0.004)	(0.00	(0.004)
Triadic	0.456***	0.36	0.212***
	(0.036)	(	(0.040)
G			
Obs.			

>

Good news from unilateral & multilateral policy perspective

The (unsurprising) deep reasons

Controlling for the age of technology

	(1)	(2)	(3)	(4)
Dep. var.	Citations received			
Clean invention	0.410***	0.381***	0.363***	0.354***
	(0.013)	(0.013)	(0.013)	(0.013)
Number of patents	-0.094***	-0.052***	-0.043***	-0.046***
	(0.004)	(0.005)	(0.005)	(0.005)
Family size	0.070***	0.067***	0.068***	0.068***
	(0.004)	(0.003)	(0.003)	(0.003)
Triadic	0.448***	0.431***	0.406***	0.397***
	(0.035)	(0.035)	(0.034)	(0.034)
Granted	0.939***	0.929***	0.917***	0.912***
	(0.031)	(0.030)	(0.030)	(0.030)
Age of tech field		-0.177***	0.194***	
		(0.009)	(0.034)	
Age of tech field^2			-0.023***	
			(0.002)	
Age of tech dummies	no	no	no	yes
Observations	1,149,237	1,149,237	1,149,237	1,149,237

-20%

Tobin's Q equation

$$\log Q_{it} = \log q_t + \log(1 + \beta_1 \frac{R\&D_{it}}{A_{it}} + \beta_2 \frac{BCIT_{it}}{PAT_{it}} + \beta_3 \frac{PAT_{it}}{R\&D_{it}} + \beta_4 \frac{FCIT_{it}}{PAT_{it}}) + \varepsilon_{it}$$

Tobin's Q = V/A

Citations made = Knowledge inflow

Decomposing knowledge spillovers

$$\beta_2 \frac{BCIT_{it}}{PAT_{it}} = \beta_{21} \frac{BCIT_{it}^{clean}}{PAT_{it}} + \beta_{22} \frac{BCIT_{it}^{dirty}}{PAT_{it}} + \beta_{23} \frac{BCIT_{it}^{other}}{PAT_{it}}$$

Knowledge inflow

Clean

Dirty

Other