THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Grantham Research Institute on Climate Change and the Environment

Climate change policy, innovation and growth

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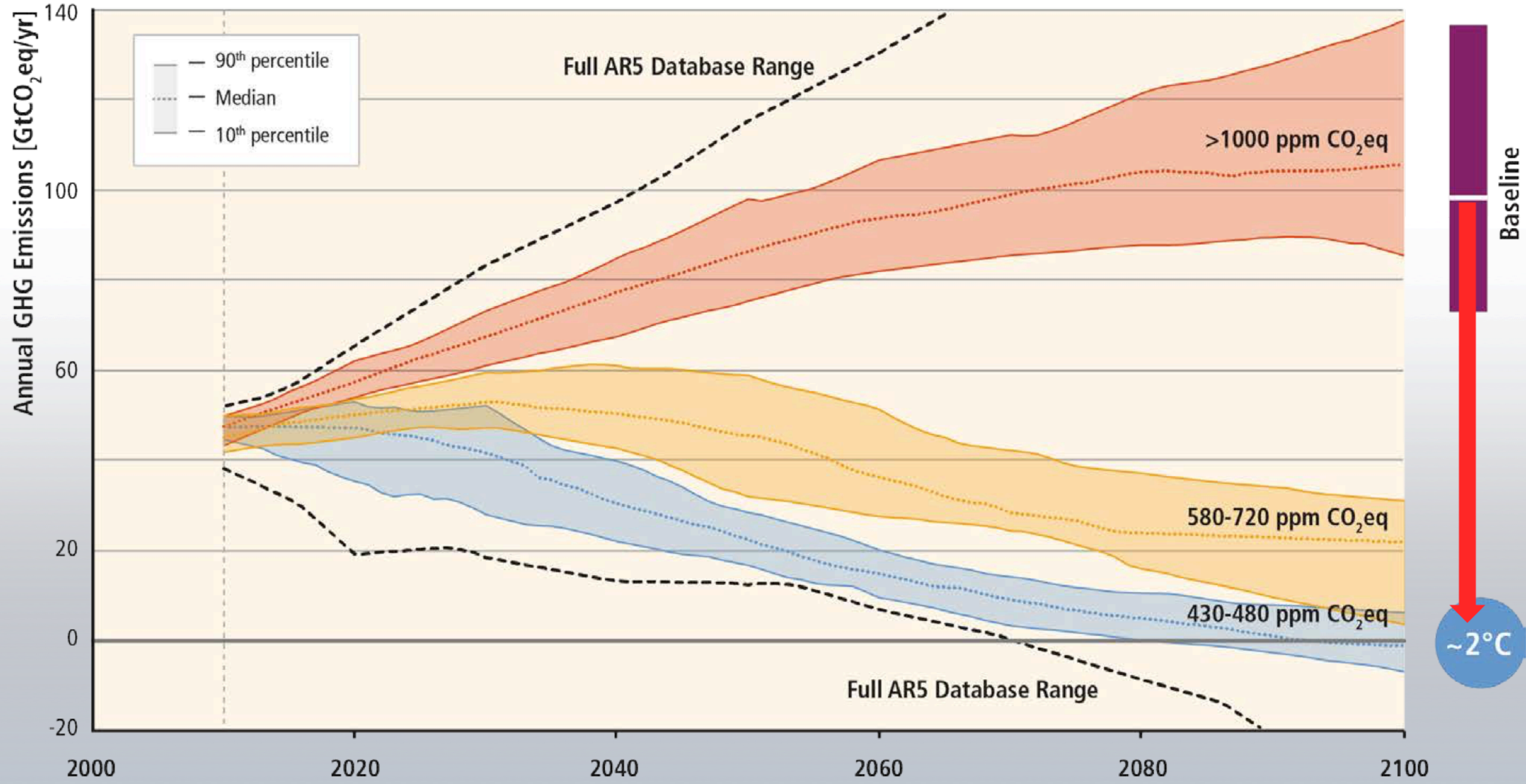
Séminaire PSL de recherches en économie de l'énergie – Paris – 16 Mars 2016

Assessing the impact of climate change policies on innovation:

Why is it important?

Global emissions scenarios



Source: IPCC 2014

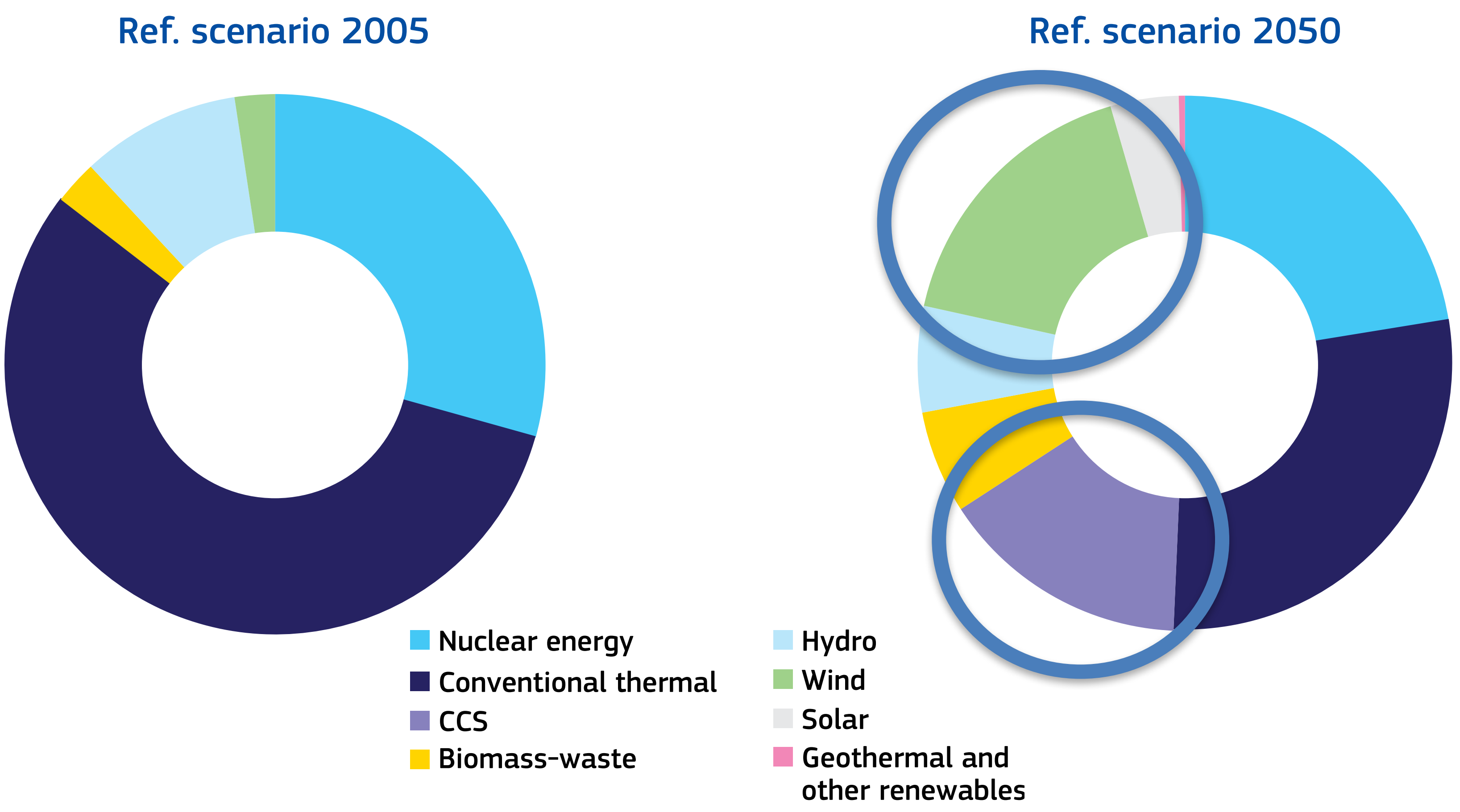
Europe’s commitments

- EU leaders have committed to cut greenhouse gas emissions by 40% by 2030, compared with 1990 levels
- Next steps: 60% by 2040; 80% by 2050

The challenge

- Stabilizing global emissions in 2050 requires 60% reduction in carbon intensity of GDP (Assuming 2.5% annual GDP growth)
- To achieve long term decarbonization we need a large change in the mix of technology we use
  - (or dramatic social and cultural changes)

Europe's Energy Roadmap 2050



Innovation is key

- Climate change mitigation requires massive investments in innovation
  1. Developing new breakthrough technologies (hydrogen)
  2. Reducing the cost of existing technologies (wind, solar)
  3. Making the transition possible with enabling technologies (smart grids, storage)

➢ Ability of climate change policies to encourage innovation is critical

Innovation as a co-benefit from green policies?

- Innovation = one of the benefits of policies, along health improvements etc, to be evaluated against the policy's costs
- Major concerns around competitiveness effects of environmental policies
- Porter hypothesis
  - Environmental regulations might lead private firms and the economy as a whole to become more competitive *by providing incentives for environmentally-friendly innovation that would not have happened in the absence of policy*

The impact of climate change policies on innovation: Recent econometric evidence

- Philippe Aghion, Antoine Dechezleprêtre, David Hemous, Ralf Martin, and John Van Reenen. "**Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry**" (*Journal of Political Economy*, 2016)

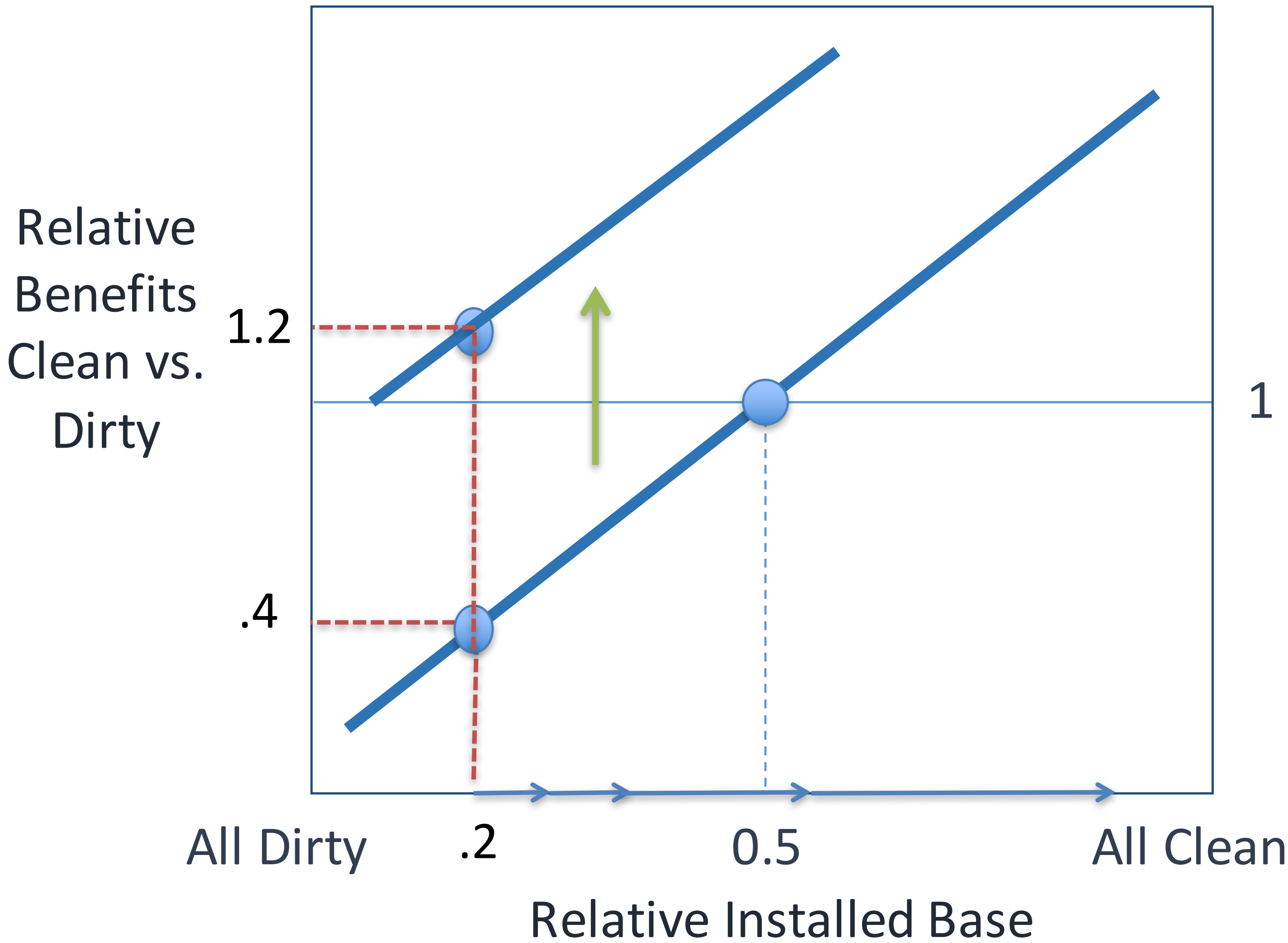
Research question 1

- Do firms respond to policies by changing the direction of innovation ("induced" innovation)?
- When firms face higher price on emissions relative to other costs of production, this provides an incentive to reduce the emissions intensity of output
- Hicks (1932): part of this investment will be directed toward developing and commercializing new emissions-reducing technologies

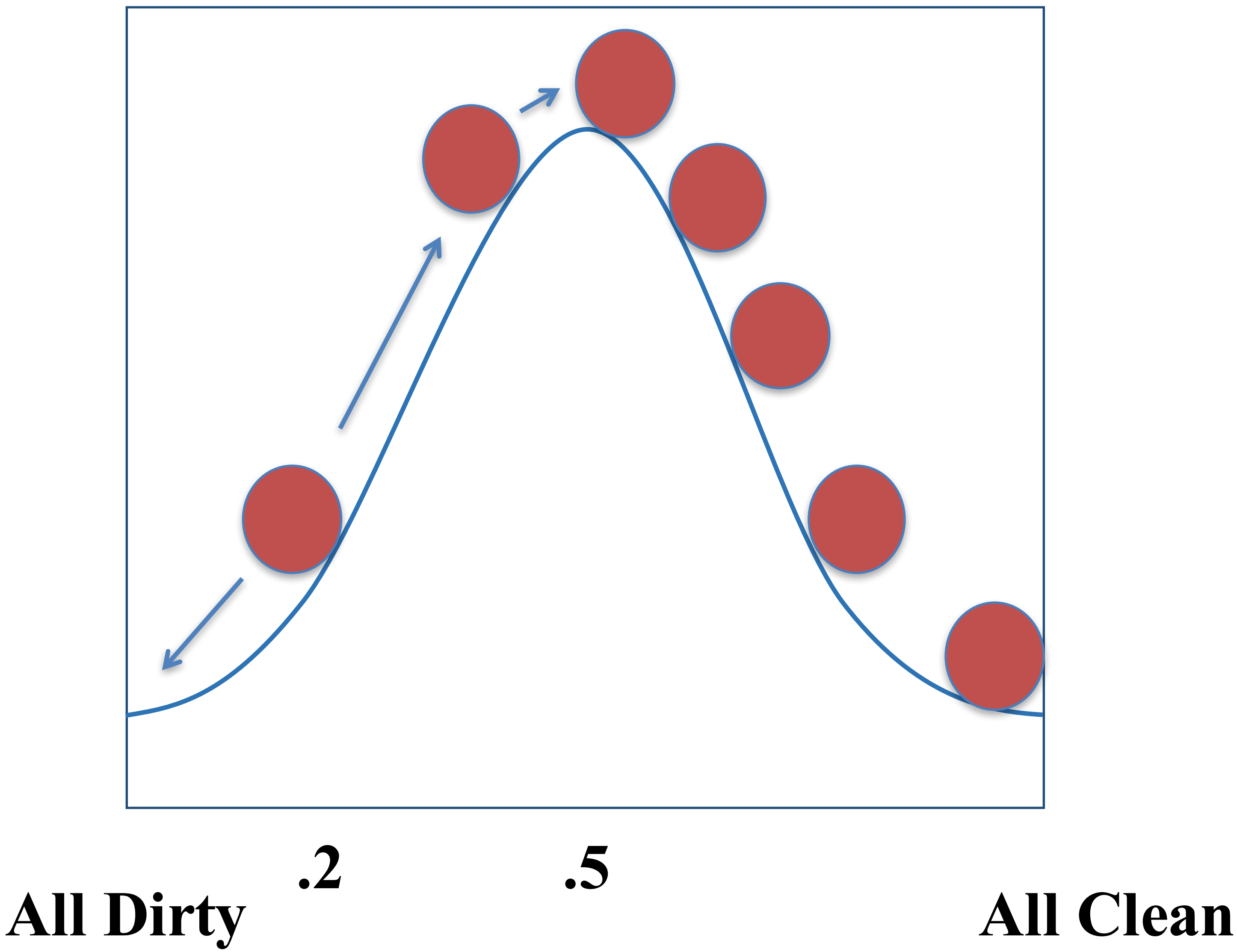
Research question 2

- How important is lock-in/path dependence in types of “clean” or “dirty” technologies?
- Some recent papers assume path-dependence in the direction of innovation (e.g. Acemoglu et al, 2012 AER)
- A crucial aspect in terms of policy consequences: this is consistent with a “tipping point” view of the world
  - Final resting point is complete dominance of one technology by another
- If this is true, clean policies only need to be temporary

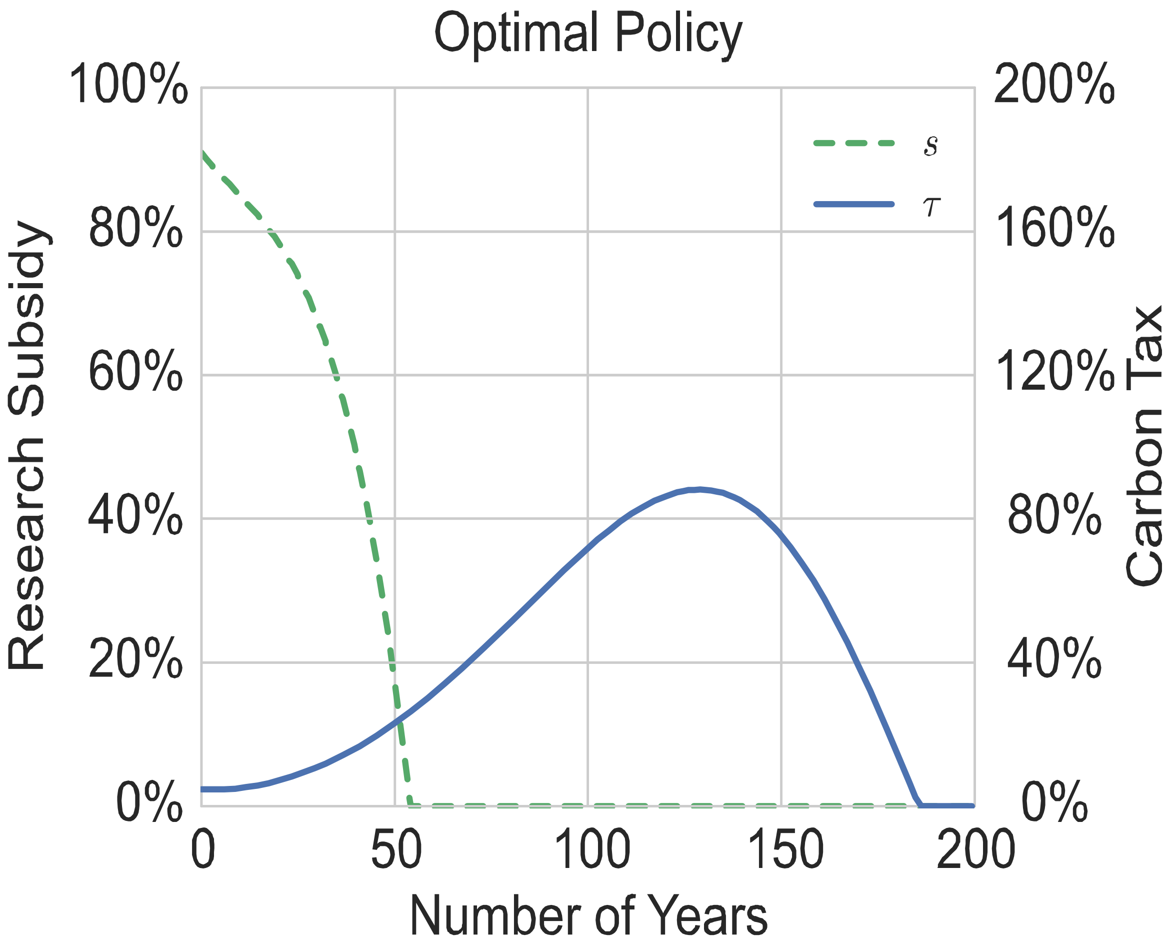
Economics of Tipping Points



The government's problem



Temporary policies: An example



Source: Acemoglu, Akcigit, Hanley & Kerr. "Transition to Clean Technology" (JPE)

This paper

- **Look at both induced innovation hypothesis and path-dependence**
- **Econometric case study: auto industry**
  - Contributor to greenhouse gases
  - Distinction between dirty (internal combustion engine) & clean (e.g. electric vehicles) innovations/patents by OECD

Simple model: basic idea

- Firms can invest in 2 types of R&D (clean or dirty)
- Previous firm/economy specialization in either clean or dirty influences direction of innovation
  - Path-dependence
- If expected market size to grow for cars using more clean technologies (e.g. electric/hybrid) then more incentive to invest in clean (relative to dirty)
- Higher fuel prices (a proxy for carbon price) increase demand for clean cars
  - Induces greater "clean" R&D and patenting

Explaining innovation

Clean Innovations (patents) for company *i* at time *t*

$$CLEAN_{it} = \exp(\alpha^C \ln P_{it-1} + \beta_1^C \ln SPILL^C_{it-1} + \beta_2^C \ln SPILL^D_{it-1} +$$
$$\gamma_1^C \ln KCLEAN_{it-1} + \gamma_2^C \ln KDIRTY_{it-1} + \delta^C X_{it-1} + \eta_i^C + T_t^C + u_{it}^C)$$

Fuel price (*P*): Test $\alpha^C > 0$

Clean spillovers (stock): $\beta_1^C > 0$ if "path dependent"

Dirty spillovers: Ambiguous, but Expect $\beta_1^C > \beta_2^C$

Own firm past clean innovations Stock: $\gamma_1^C > 0$ if "path dependent"

Own firm past dirty innovations stock, expect $\gamma_1^C > \gamma_2^C$

Other controls – GDP, fixed effects, time dummies, etc.

Innovation Equations – Cont.

Dirty Innovations (patents) for assignee *i* at time *t*

$$DIRTY_{it} = \exp(\alpha^D \ln P_{it-1} + \beta_1^D \ln SPILL_{it-1}^C + \beta_2^D \ln SPILL_{it-1}^D +$$
$$\gamma_1^D \ln KCLEAN_{it-1} + \gamma_2^D \ln KDIRTY_{it-1} + \delta^D X_{it-1} + \eta_i^D + T_t^D + u_{it}^D)$$

DATA

- World Patent Statistical Database (PATSTAT) at European Patent Office (EPO)
  - All patents filed in 80 patent offices in world (focus from 1965)
- Extracted all patents pertaining to "clean" and "dirty" technologies in the automotive industry (follows OECD definition)
- Tracked applicants and extracted all their patents. Created unique firm identifier
  - 4.5m patents filed 1965-2005

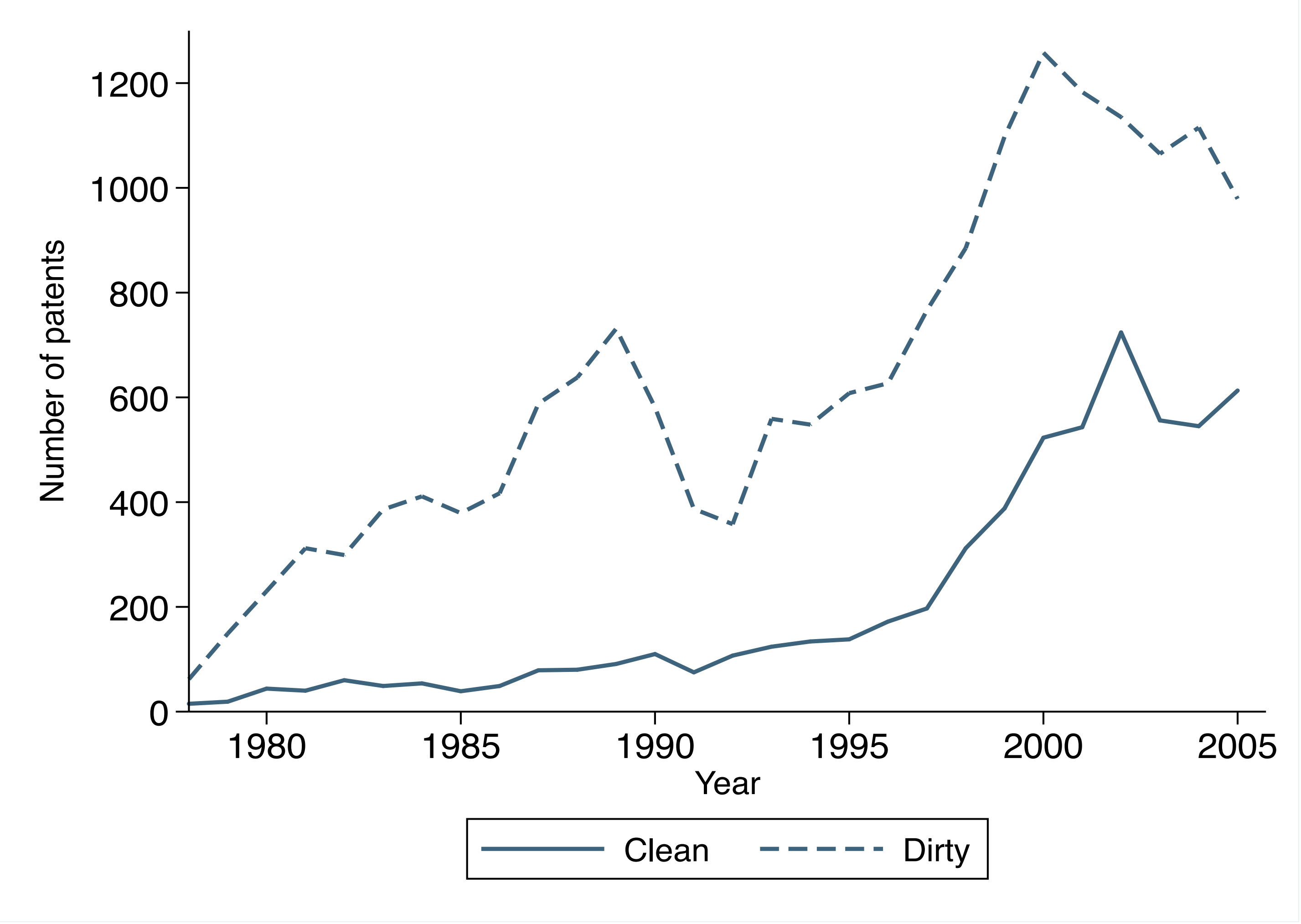
International Patent Classification codes

Electric vehicles	
Electric propulsion with power supplied within the vehicle	B60L 11
Electric devices on electrically-propelled vehicles for safety purposes; Monitoring operating variables, e.g. speed, deceleration, power consumption	B60L 3
Methods, circuits, or devices for controlling the traction- motor speed of electrically-propelled vehicles	B60L 15
Arrangement or mounting of electrical propulsion units	B60K 1
Conjoint control of vehicle sub-units of different type or different function / including control of electric propulsion units, e.g. motors or generators / including control of energy storage means / for electrical energy, e.g. batteries or capacitors	B60W 10/08, 24, 26
Hybrid vehicles	
Arrangement or mounting of plural diverse prime-movers for mutual or common propulsion, e.g. hybrid propulsion systems comprising electric motors and internal combustion engines	B60K 6
Control systems specially adapted for hybrid vehicles, i.e. vehicles having two or more prime movers of more than one type, e.g. electrical and internal combustion motors, all used for propulsion of the vehicle	B60W 20
Regenerative braking	
Dynamic electric regenerative braking	B60L 7/1
Braking by supplying regenerated power to the prime mover of vehicles comprising engine -driven generators	B60L 7/20
Fuel cells	
Conjoint control of vehicle sub-units of different type or different function; including control of fuel cells	B60W 10/28
Electric propulsion with power supplied within the vehicle - using power supplied from primary cells, secondary cells, or fuel cells	B60L 11/18
Fuel cells; Manufacture thereof	H01M 8
Combustion engines	
Combustion engines	F02 (excl. C/G/ K)

“Clean” (Electric vehicles, Hybrid vehicles, Fuel cells)

“Dirty” (Combustion engines)

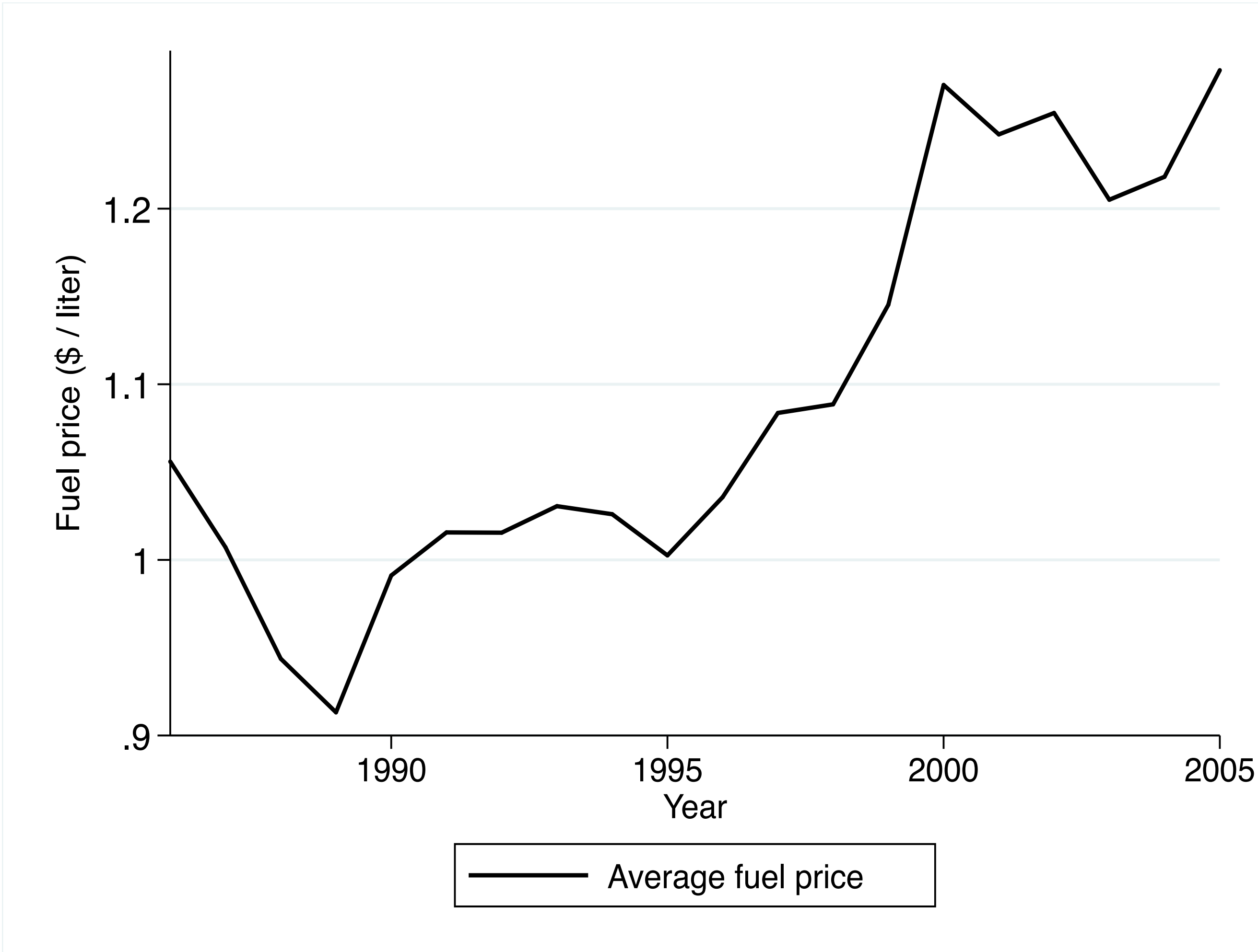
AGGREGATE NUMBER OF TRIADIC CLEAN AND DIRTY PATENTS PER YEAR



POLICY VARIABLES: FUEL PRICES & TAXES

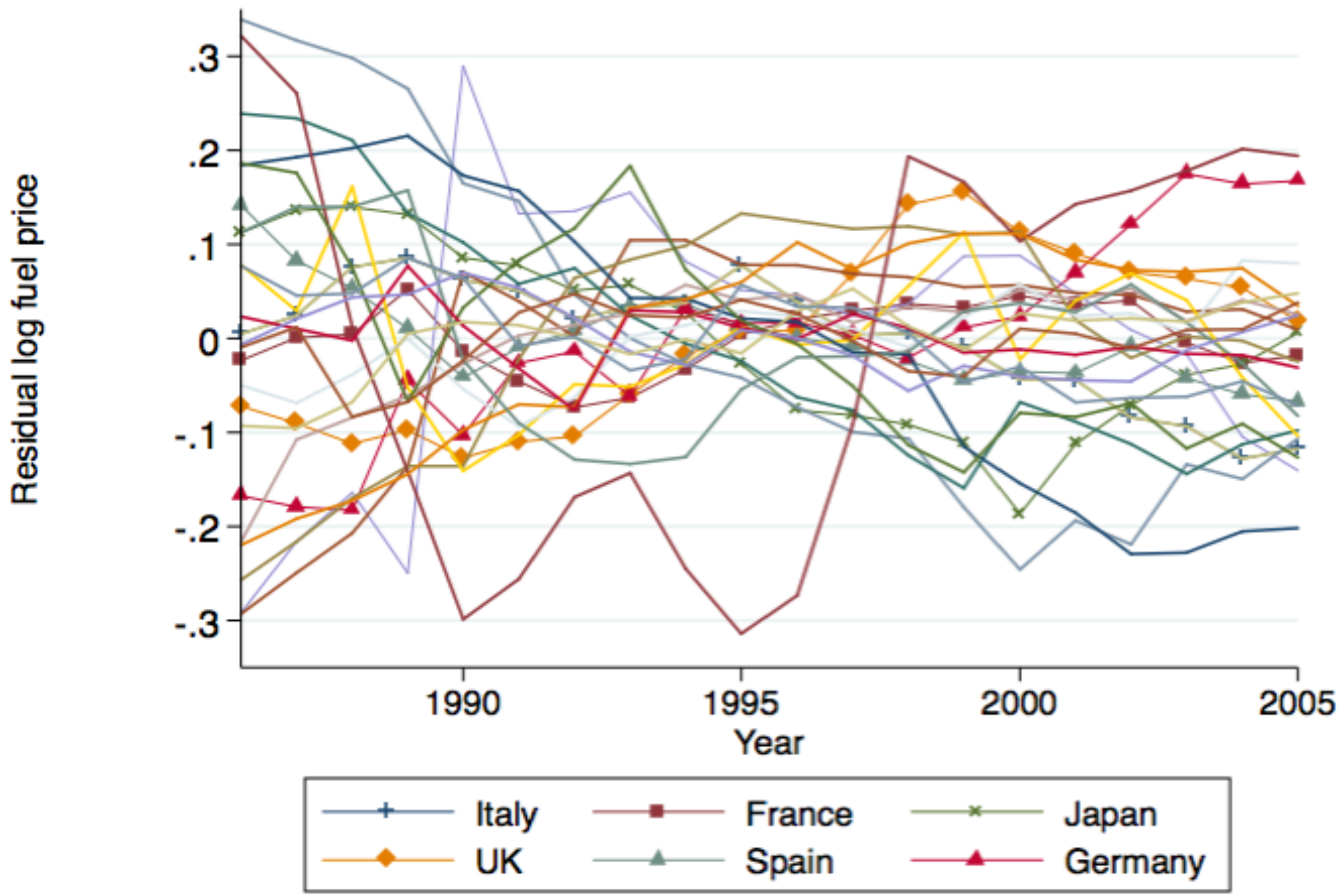
- Fuel prices vary over countries and time (e.g. because of different tax regimes)
- International Energy Agency EA (fuel prices & taxes)

EVOLUTION OF AVERAGE (TAX INCLUSIVE) FUEL PRICES OVER TIME



Source: International Energy Agency, 25 countries unweighted average

Residuals from a regression of fuel prices on country and year dummies



Source: International Energy Agency, 25 countries

POLICY VARIABLES: FUEL PRICES (FP) & TAXES

- Firms are affected differentially by fuel prices as (expected) market shares different across countries
  - Autos differentiated products: affected by national tastes
  - Government policies discriminate (e.g. tariffs & subsidies)
- Weight country prices & taxes by firm's expected future market shares in different countries
  - Use information on where patents filed (use in pre-sample period & keep these weights fixed)
  - Compare with firm *i* sales by country *c*

$$\ln FP_{it} = \sum_{c} w_{ic}^{P} \ln FP_{ct}$$

Reasonable correlation between geographical market shares based on auto sales vs. Patent filings for major vendors (correlation = 0.95)

		Car Sales shares	Patent Weights
Toyota	**2003-2005**		
	Japan	0.43	0.42
	North America	0.40	0.34
	Europe	0.17	0.23
VW	**2002-2005**		
	Germany	0.35	0.57
	UK	0.13	0.08
	Spain	0.11	0.03
	Italy	0.09	0.05
	France	0.09	0.09
	US	0.13	0.15
	Mexico	0.05	0.00
	Canada	0.04	0.00
	Japan	0.02	0.02
Ford	**1992-2002**		
	US	0.66	0.61
	Canada	0.04	0.01
	Mexico	0.02	0.00
	UK	0.09	0.08
	Germany	0.07	0.15
	Italy	0.03	0.03
	Spain	0.02	0.02
	France	0.02	0.04
	Australia	0.02	0.00
	Japan	0.01	0.05
Peugeot	**2001-2005**		
	Western Europe	0.82	0.83
	Americas	0.04	0.13
	Asia-Pacific	0.13	0.04
Honda	**2004-2005**		
	Japan	0.28	0.31
	North America	0.62	0.48
	Europe	0.10	0.20

Reasonable correlation (0.95) between geographical market shares based on auto sales vs. Patent filings: e.g. Ford

1992-2002	Car Sales shares	Patent Weights
US	0.66	0.61
Canada	0.04	0.01
Mexico	0.02	0.00
UK	0.09	0.08
Germany	0.07	0.15
Italy	0.03	0.03
Spain	0.02	0.02
France	0.02	0.04
Australia	0.02	0.00
Japan	0.01	0.05

Source: Annual Company Accounts and PATSTAT

OWN & SPILLOVER INNOVATION STOCKS

OWN LAGGED INNOVATION STOCKS (K)

- Standard Griliches perpetual inventory formula (baseline $\delta = 0.2$, robust to alternative levels of depreciation,)
- z = {CLEAN, DIRTY}

$$K_{zit} = PAT_{zit} + (1-\delta)K_{zit-1}$$

SPILLOVERS (SPILL)

- Country's clean (dirty) innovation stock is aggregate of clean (dirty) patents of inventors located in the country
- Firm's exposure to spillovers is average of country with weights based on where firm's inventors located

$$\ln SPILL_{zit} = \sum_{c} w_{ic}^{S} SPILL_{zct}$$

MAIN RESULTS

	Clean	Dirty
Fuel Price	0.992**	-0.539***
ln(FP)	(0.411)	(0.177)
Clean Spillover	0.399***	-0.160***
$SPILL_C$	(0.085)	(0.049)
Dirty Spillover	-0.331***	0.231***
$SPILL_D$	(0.076)	(0.054)
Own Stock Clean	0.505***	0.212**
K_C	(0.111)	(0.107)
Own Stock Dirty	0.246***	0.638***
K_D	(0.054)	(0.080)
#Observations	68,240	68,240
#Units (Firms and individuals)	3,412	3,412

Notes: Estimation by Conditional fixed effects (CFX), all regressions include GDP, GDP per capita & time dummies. SEs clustered by firm.

Disaggregating dirty patents into fuel efficiency (grey) and purely dirty

	(1)	(2)	(3)
Dependent Variable	Clean Patents	Grey Patents	Purely Dirty Patents
Fuel Price	0.848*	0.282	-0.832***
	(0.461)	(0.398)	(0.214)
R&D subsidies	0.031	0.081**	-0.02
	(0.047)	(0.034)	(0.030)
Clean Spillover	0.333**	-0.171*	-0.014
	(0.165)	(0.098)	(0.094)
Grey Spillover	0.215	0.173	0.235**
	(0.228)	(0.112)	(0.102)
Purely Dirty Spillover	-0.509	0.045	-0.208
	(0.377)	(0.136)	(0.161)
Own Stock Clean	0.379***	-0.005	0.047
	(0.090)	(0.035)	(0.035)
Own Stock Grey	0.185*	0.418***	-0.141***
	(0.106)	(0.035)	(0.025)
Own Stock Purely Dirty	-0.011	0.192***	0.544***
	(0.066)	(0.038)	(0.026)
Observations	68240	68240	68240
Firms	3412	3412	3412

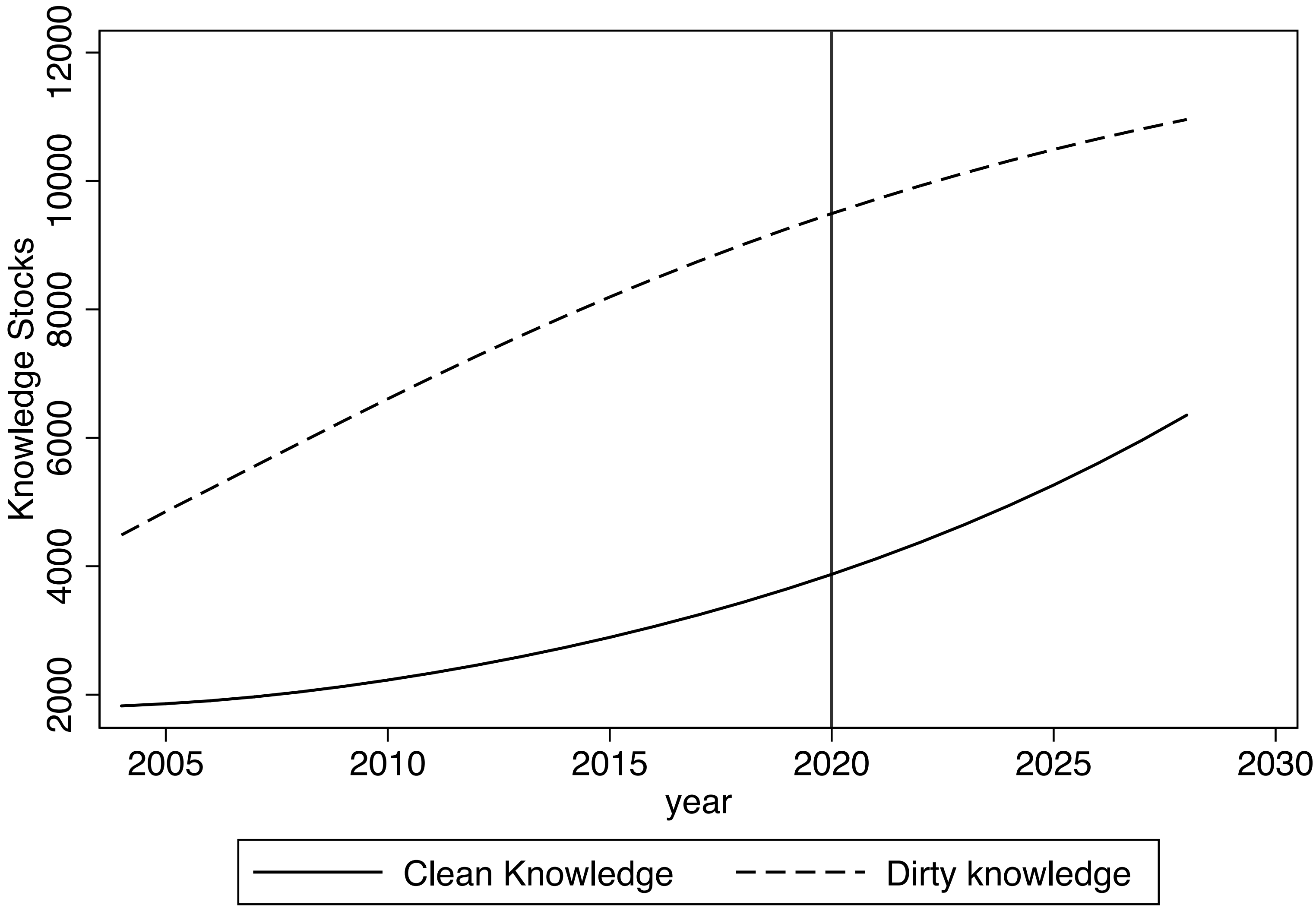
ROBUSTNESS TESTS

- Use fuel tax instead of fuel prices
- Alternative estimators (HHG, BGVR, OLS)
- Other policy variables – R&D, Emissions, electricity price
- Condition on firms with some positive pre-1985 patents
- Construct fuel price using only the largest countries
- Estimate 1991-2005 (instead of 1985-2005) & use weights 1965-1990 (instead of 1965-1985)
- Use biadic patents (or all patents) instead of triadic
- Drop individuals & just estimate on firms
- Cite-weighting patents
- Allow longer dynamics reaction, different depreciation rates, etc.

SIMULATIONS

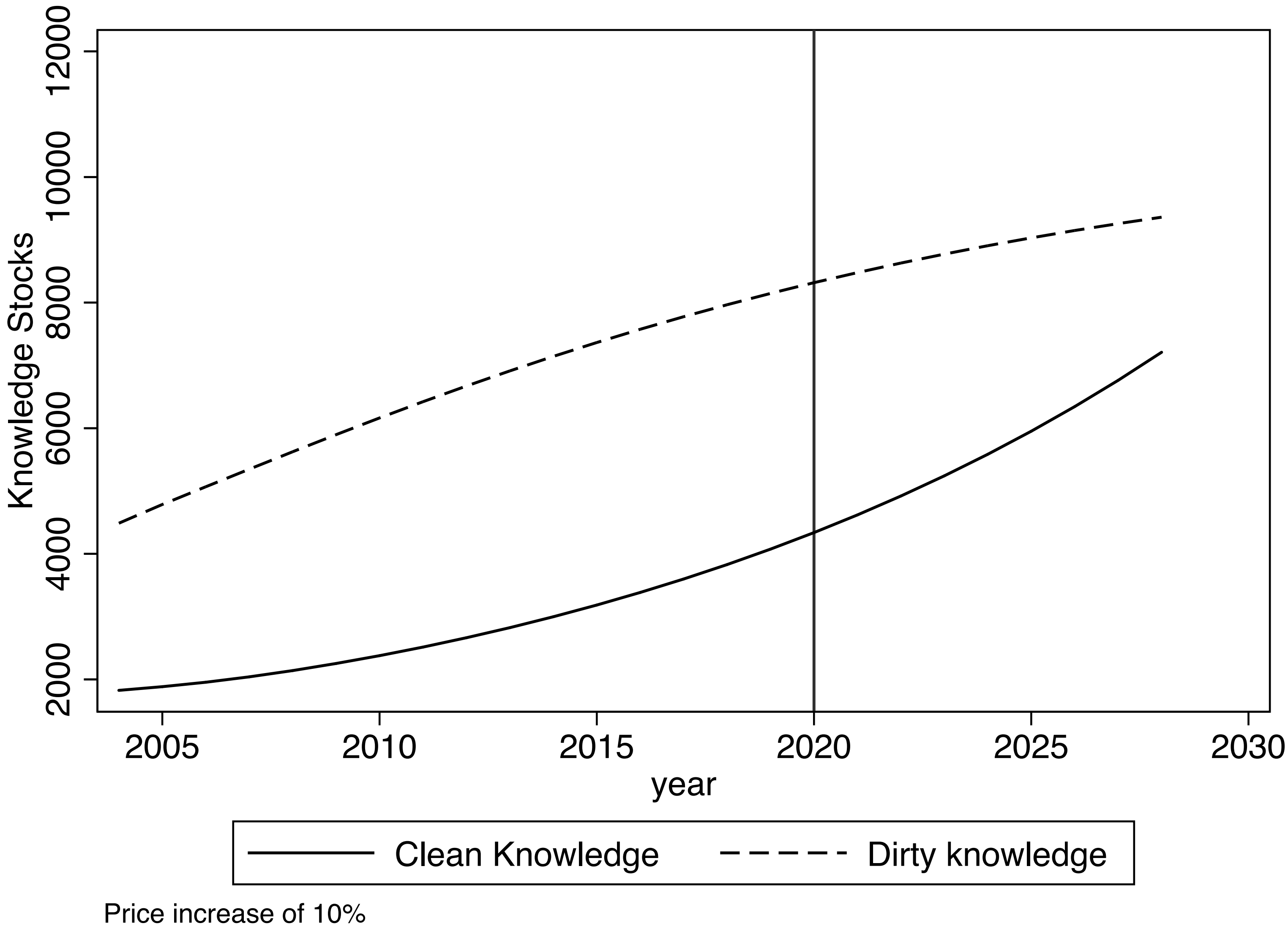
- Take estimated model & aggregate to global level taking dynamics into account (spillovers & lagged dependent variables)
- Simulate the effect of changes in fuel tax compared to baseline case (where we fix prices & GDP as “today”, 2005)
- At what point (if ever) does the stock of clean innovation exceed stock of dirty innovation
- Just illustrative scenarios – sense of difficulty & importance of path dependence

BASELINE: NO FUEL PRICE INCREASE

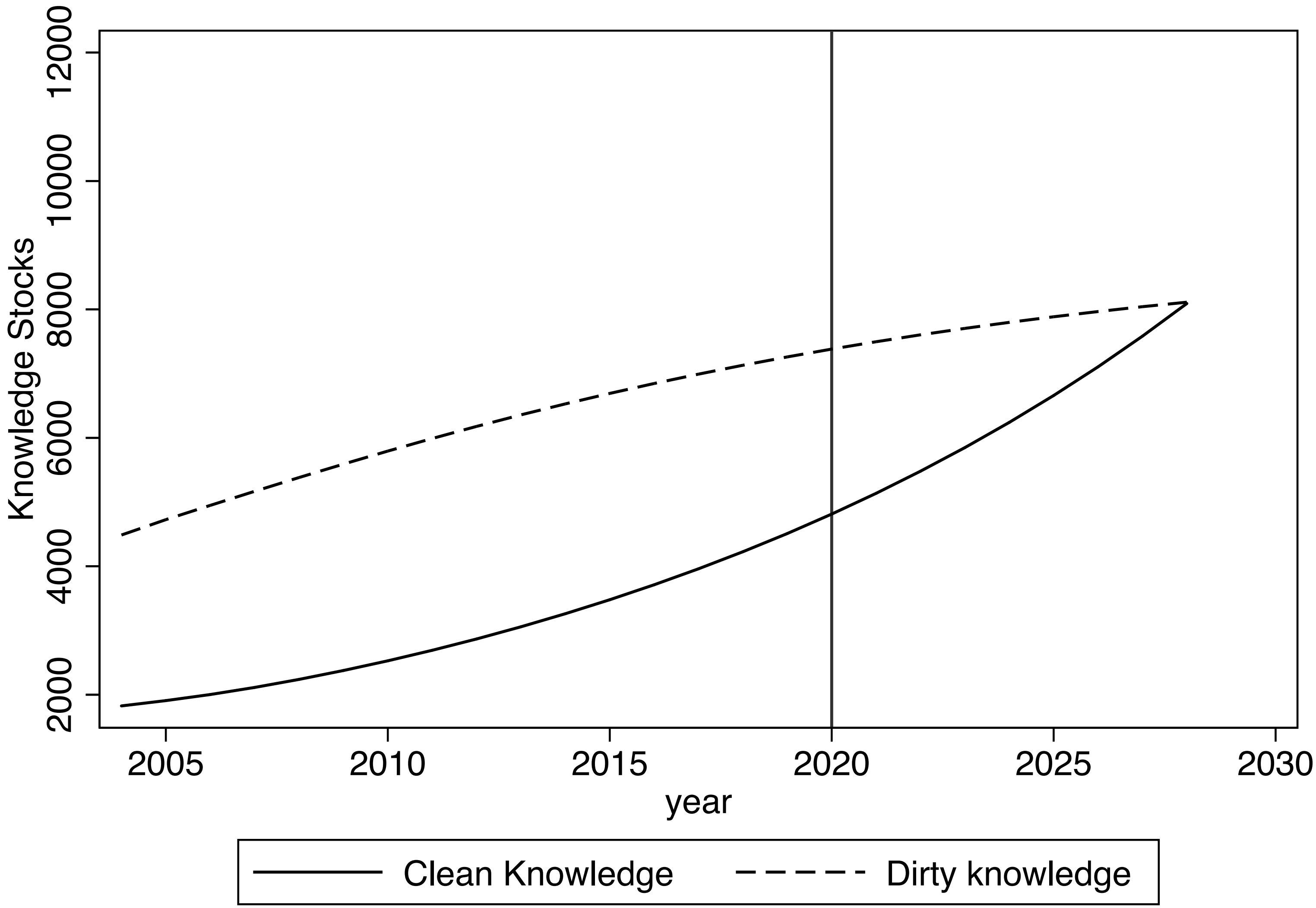


Price increase of 0%

ALTERNATIVE: 10% INCREASE IN THE FUEL PRICE

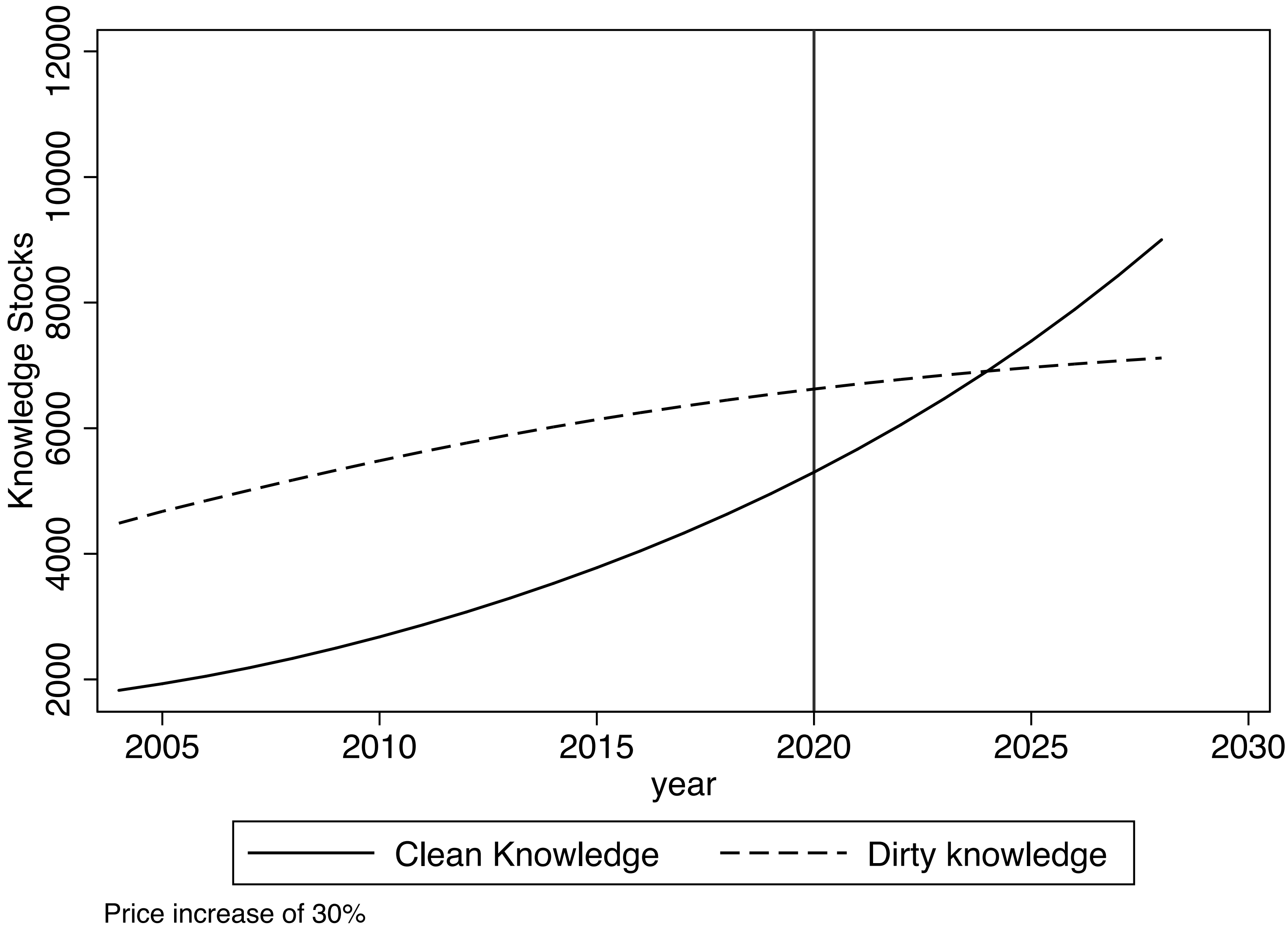


ALTERNATIVE: 20% INCREASE IN THE FUEL PRICE

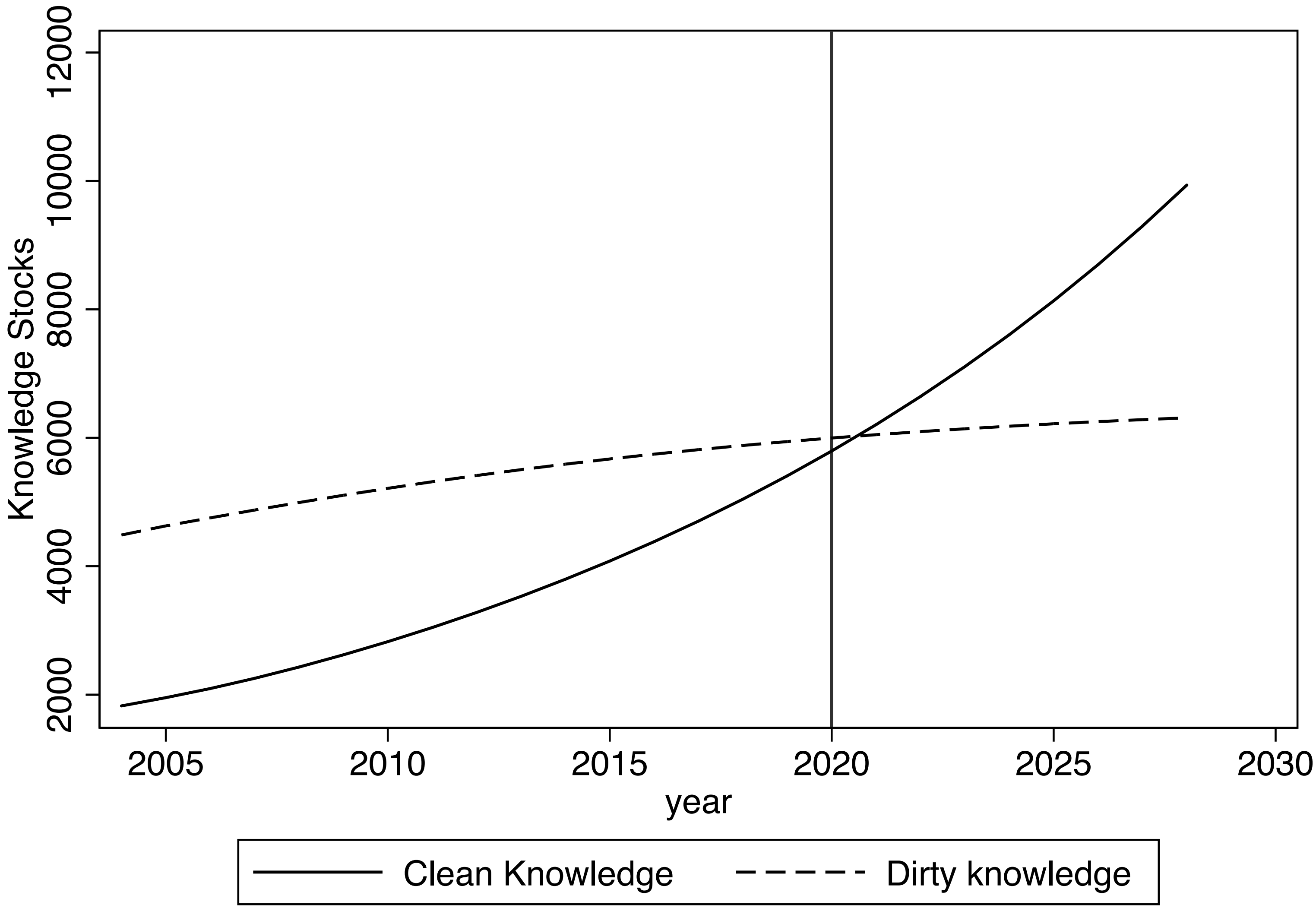


Price increase of 20%

ALTERNATIVE: 30% INCREASE IN THE FUEL PRICE

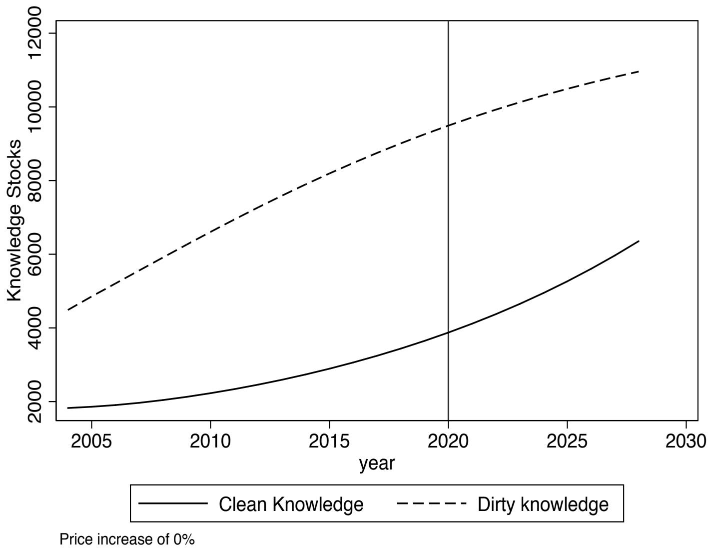


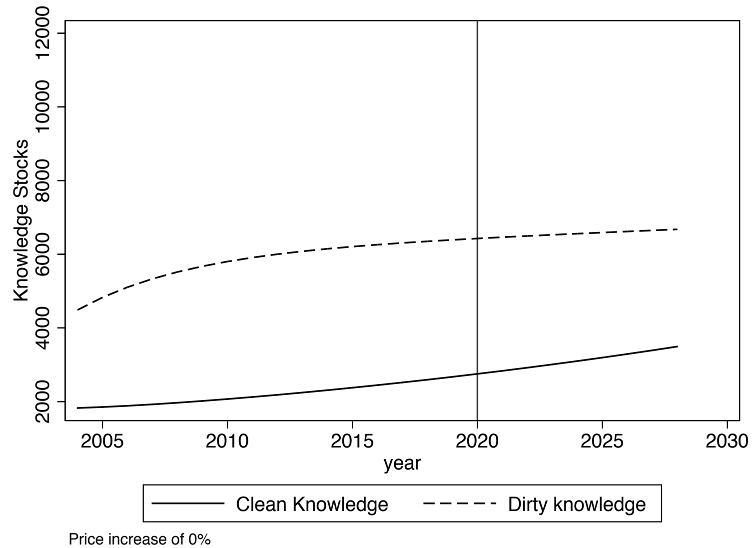
ALTERNATIVE: 40% INCREASE IN THE FUEL PRICE



Price increase of 40%

SWITCHING OFF SPILLOVER EFFECTS IN THE NO PRICE INCREASE SCENARIO – KNOWLEDGE STOCKS GROW MORE SLOWLY

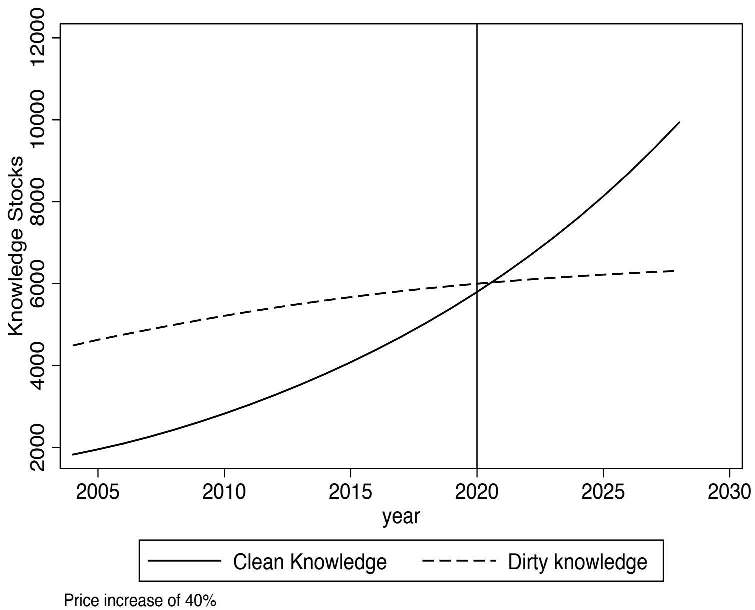




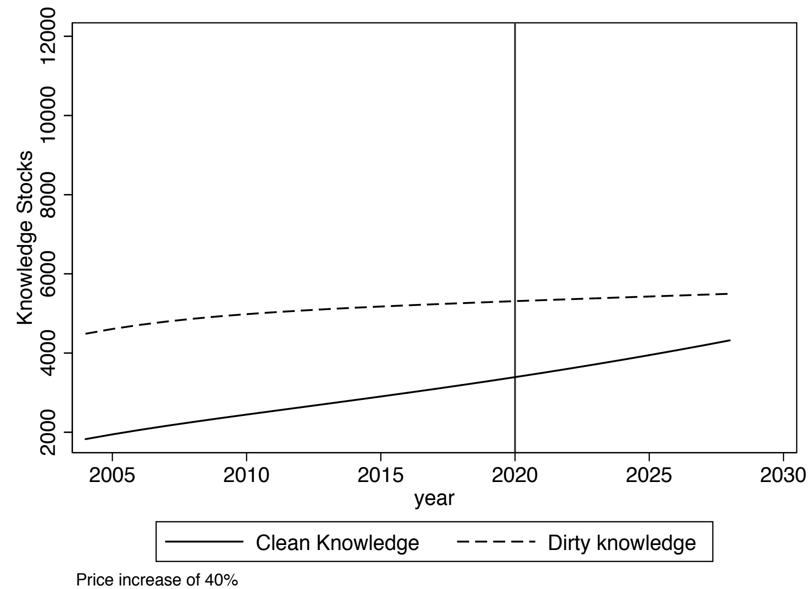
Baseline (with spillovers)

Alternative (No spillovers)

SWITCHING OFF SPILLOVER EFFECTS IN THE 40% PRICE INCREASE SCENARIO – CLEAN DOESN'T OVERTAKE DIRTY NOW



Baseline (40% price Increase with spillovers)



Alternative (40% price Increase without spillovers)

CONCLUSIONS

- Economics works! – Technical change can be directed towards "clean" innovation through price mechanism
- Path dependence important: firm-level & spillovers
  - Bad news that clean stocks may never catch up with dirty without further policy intervention
  - Good news is that early action now can become self-sustaining later due
- Simulations suggest that FP rises of ~40% cause clean to overtake dirty

The economic consequences of switching to clean innovation

Green policies as growth policies?

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

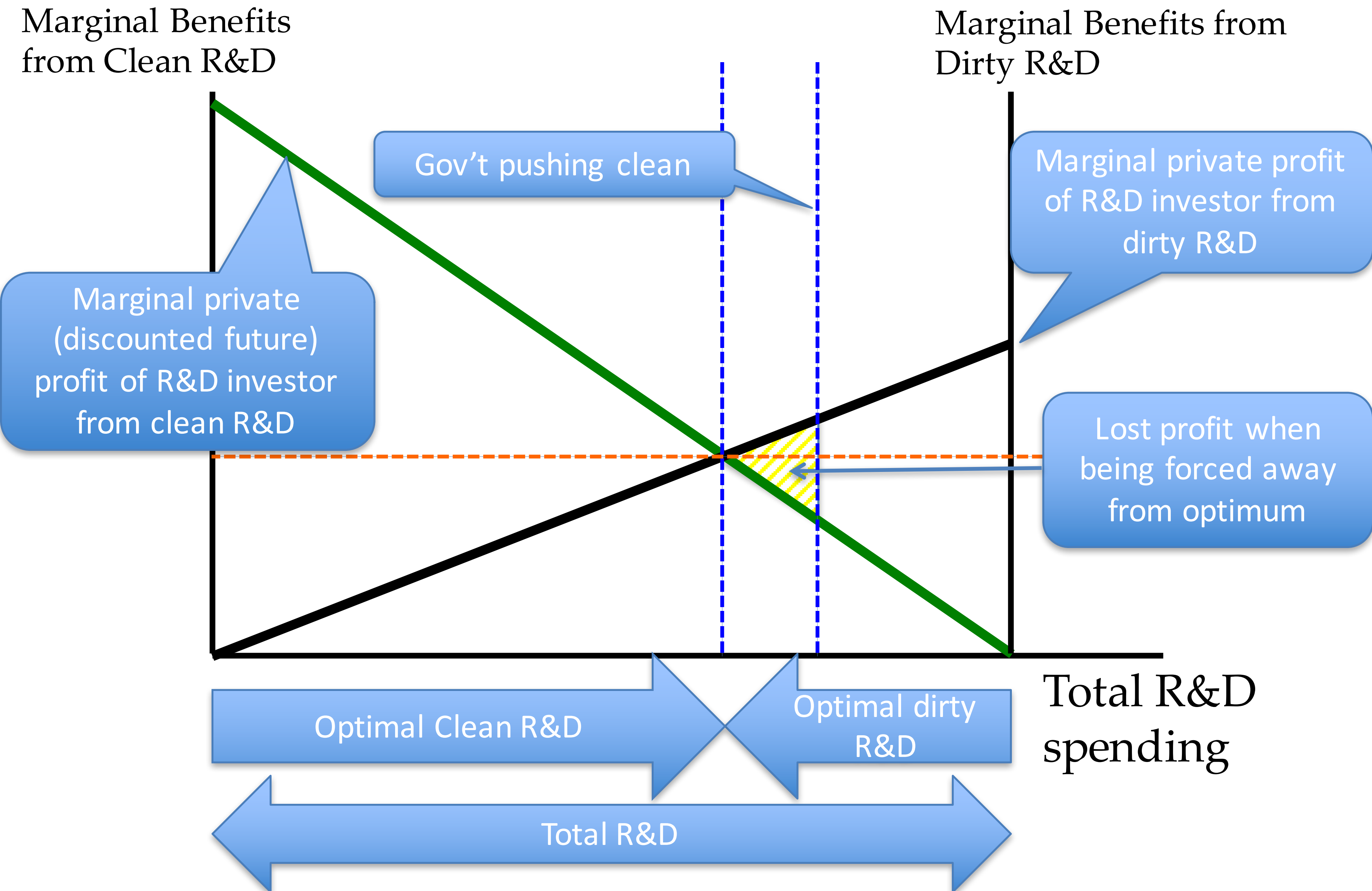
Angel Gurría, OECD Secretary-General

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 (2016), Noailly & Smeets (2014), Popp & Newell (2012), Hottenrott & Rexhaüser (2013)]

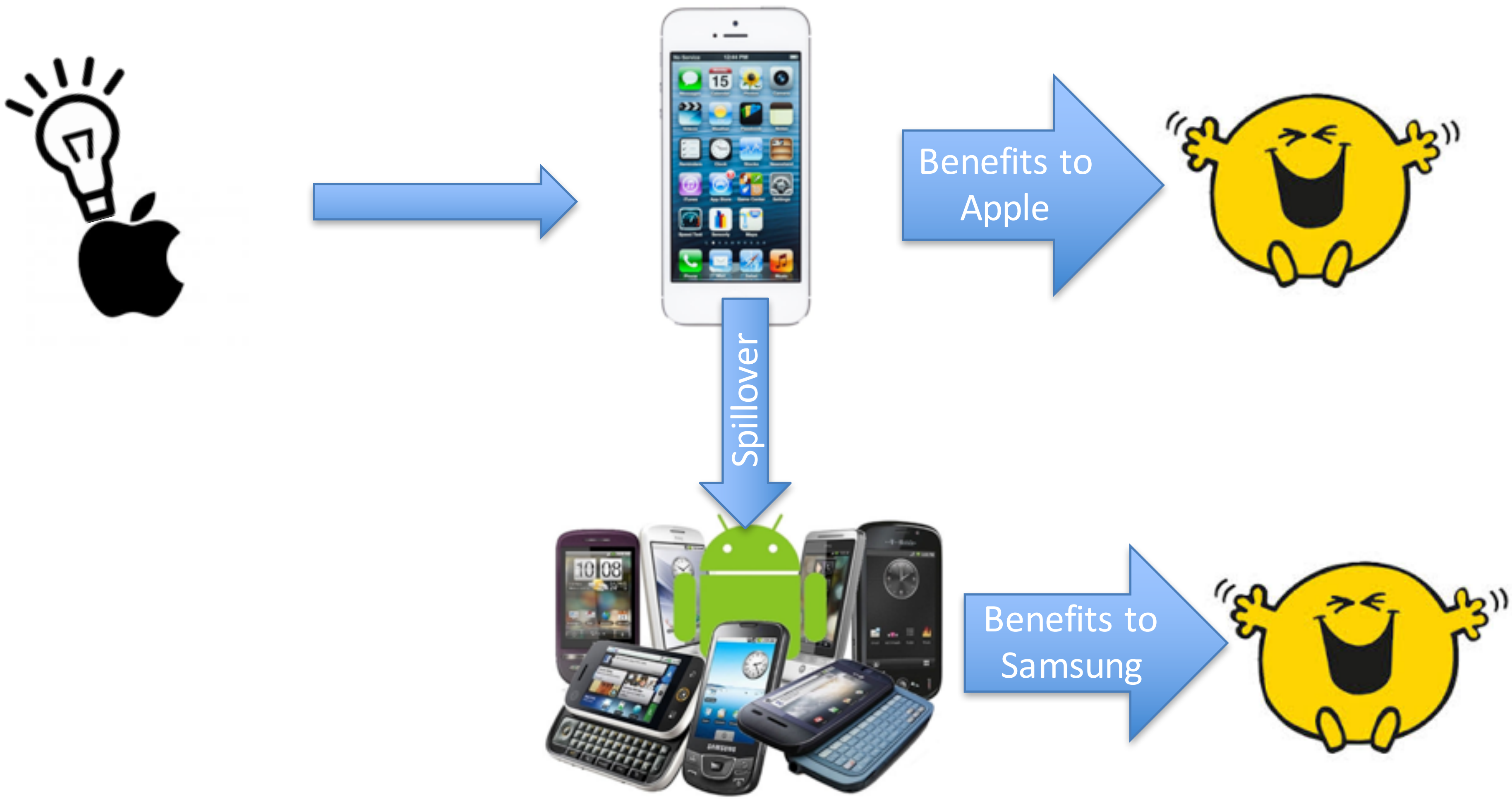
- What is the impact on the economy?

Clean R&D push & private benefits

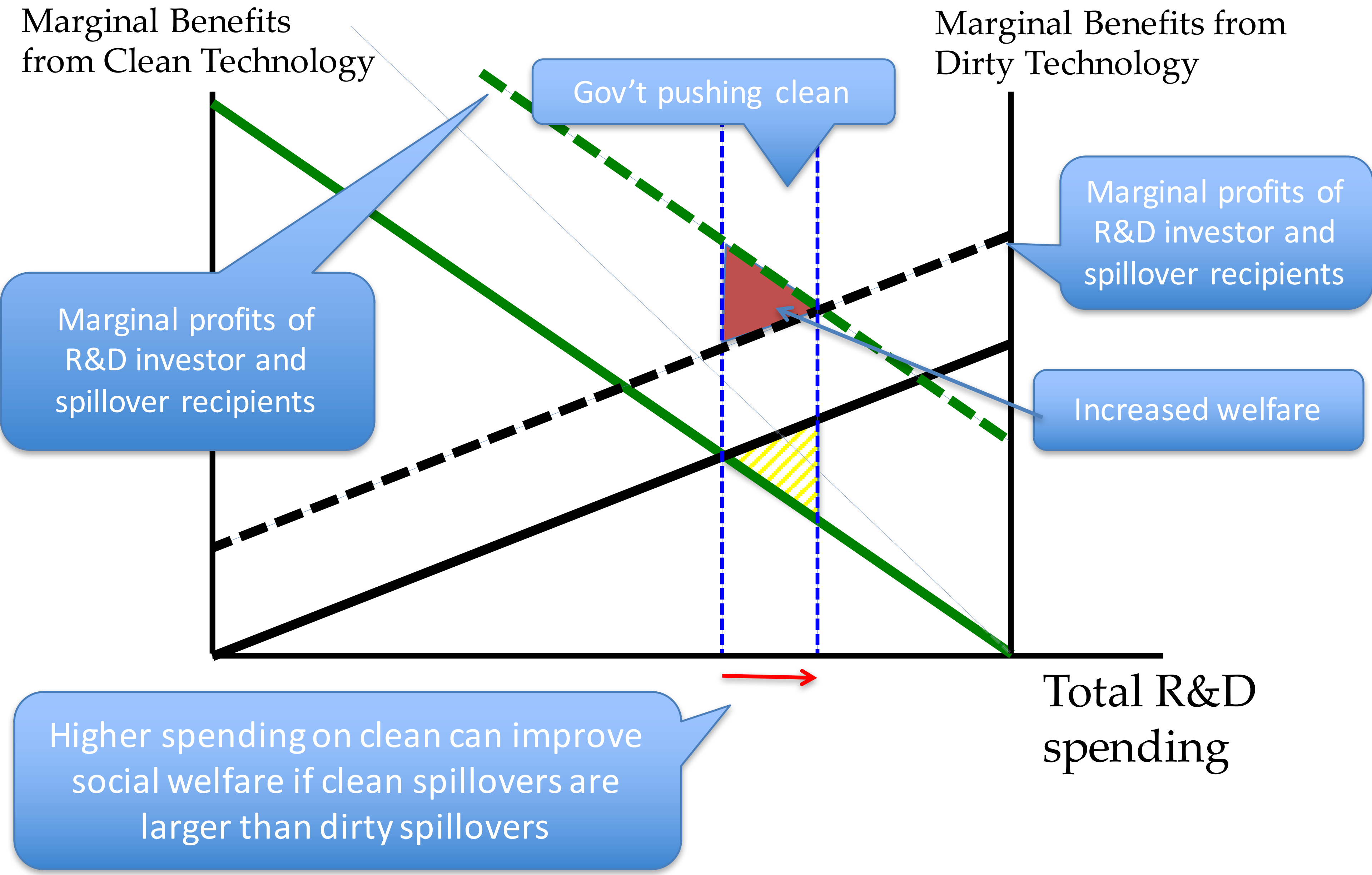


Spillovers

In addition to private benefits…



Adding in 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)]

The paper

- Antoine Dechezleprêtre, Ralf Martin & Myra Mohnen. “**Knowledge spillovers from clean and dirty technologies**” (*Working paper*, 2014)

- 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

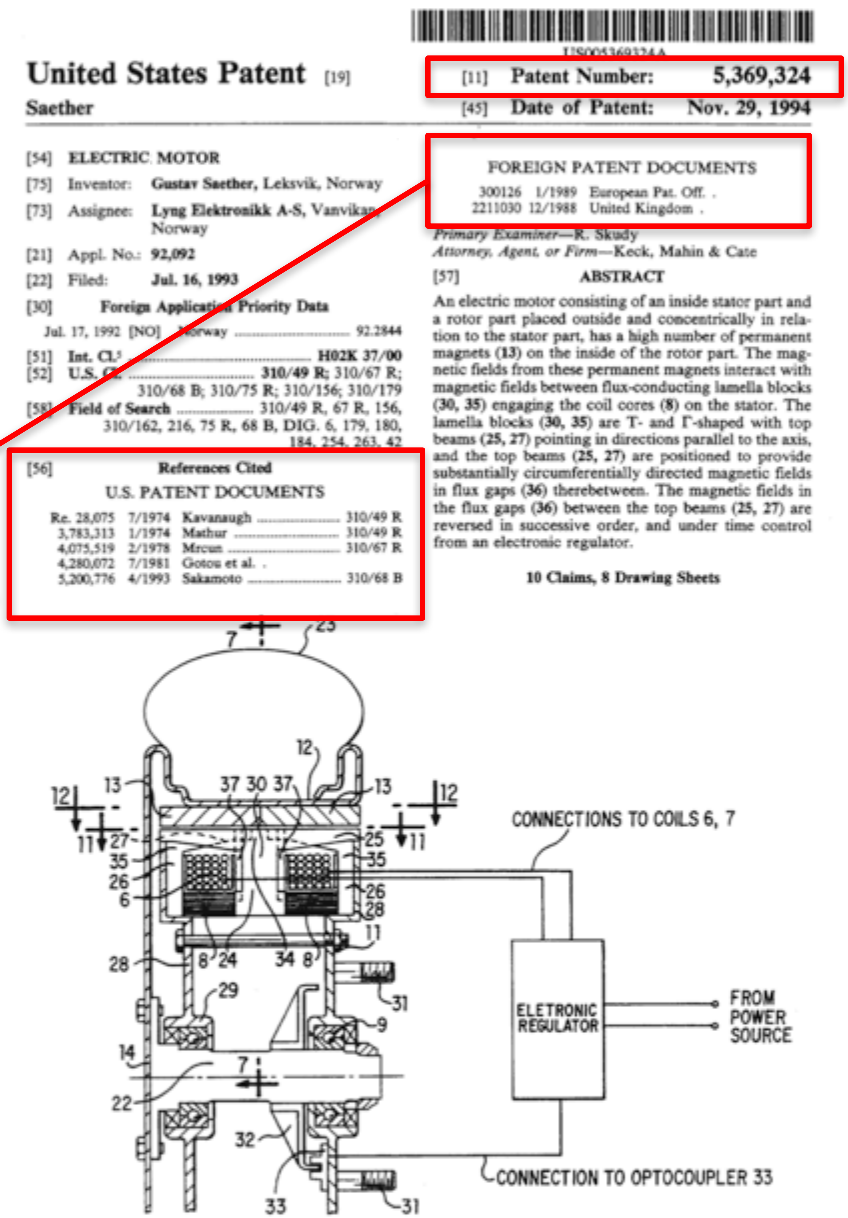
[56] **References Cited**

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 .



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

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

Primary Examiner—R. Skudy

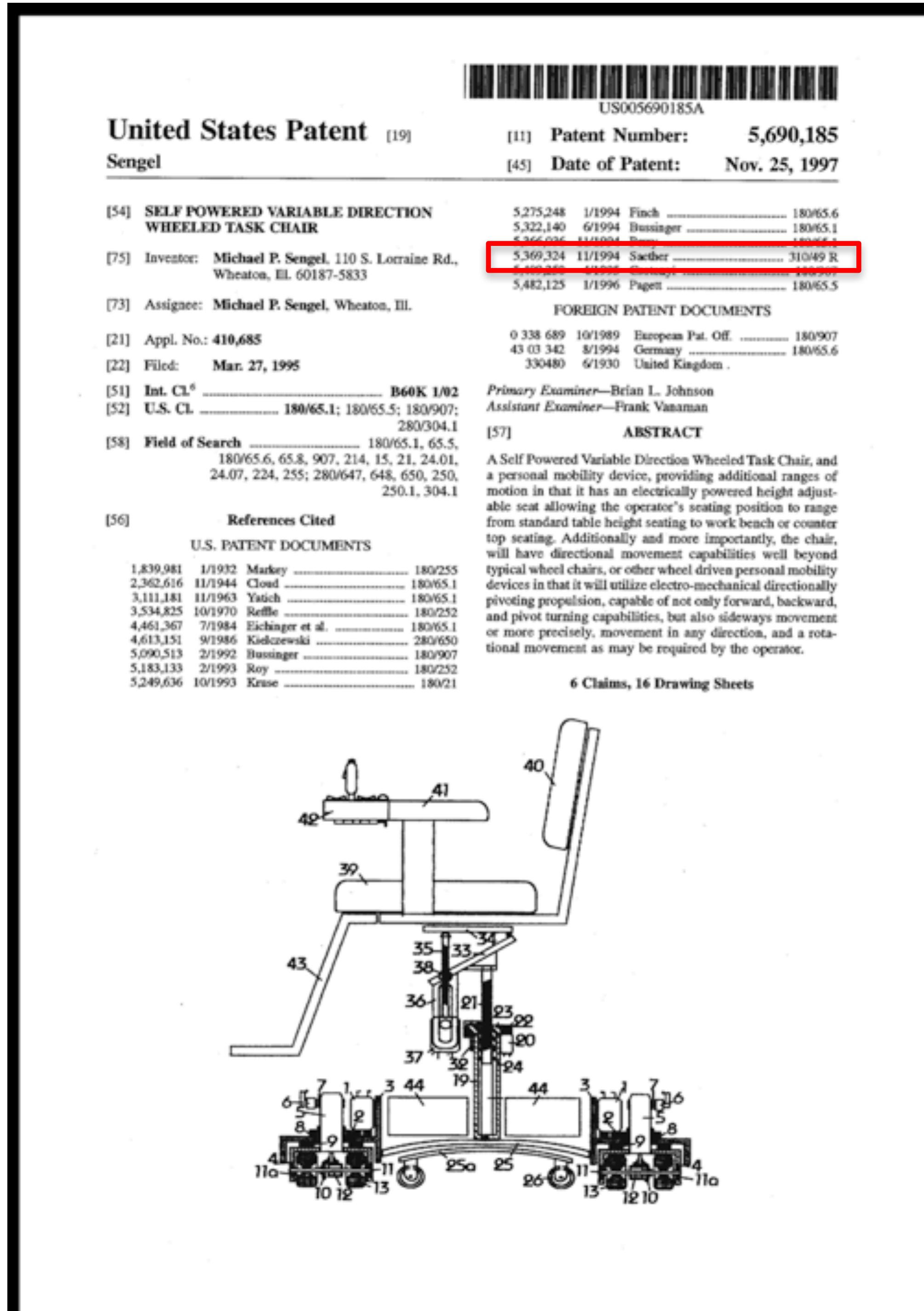
Attorney, Agent, or Firm—Keck, Mahin & Cate

[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, Ill. 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

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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…

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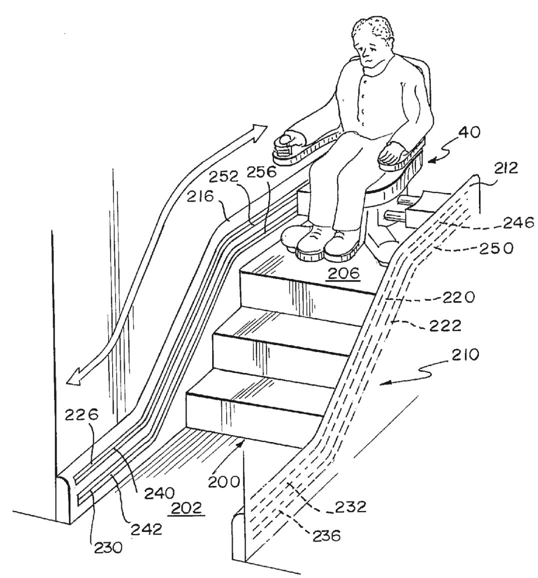
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM,

[Continued on next page]

(54) Title: HOME CARE EQUIPMENT SYSTEM

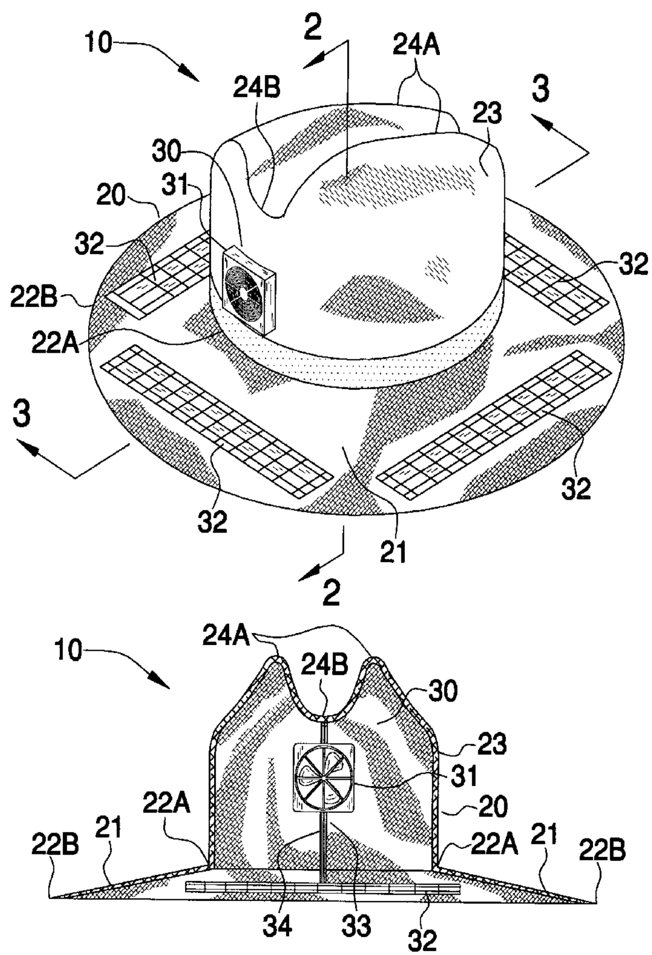


(57) Abstract: A system for assisting a person of limited mobility in moving from room to room within a home and performing essential daily activities includes a personal mobility device (40, 100, 1700, 1800, 2000) which includes transfer drivers (164) which engage a transfer system (210) to transition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

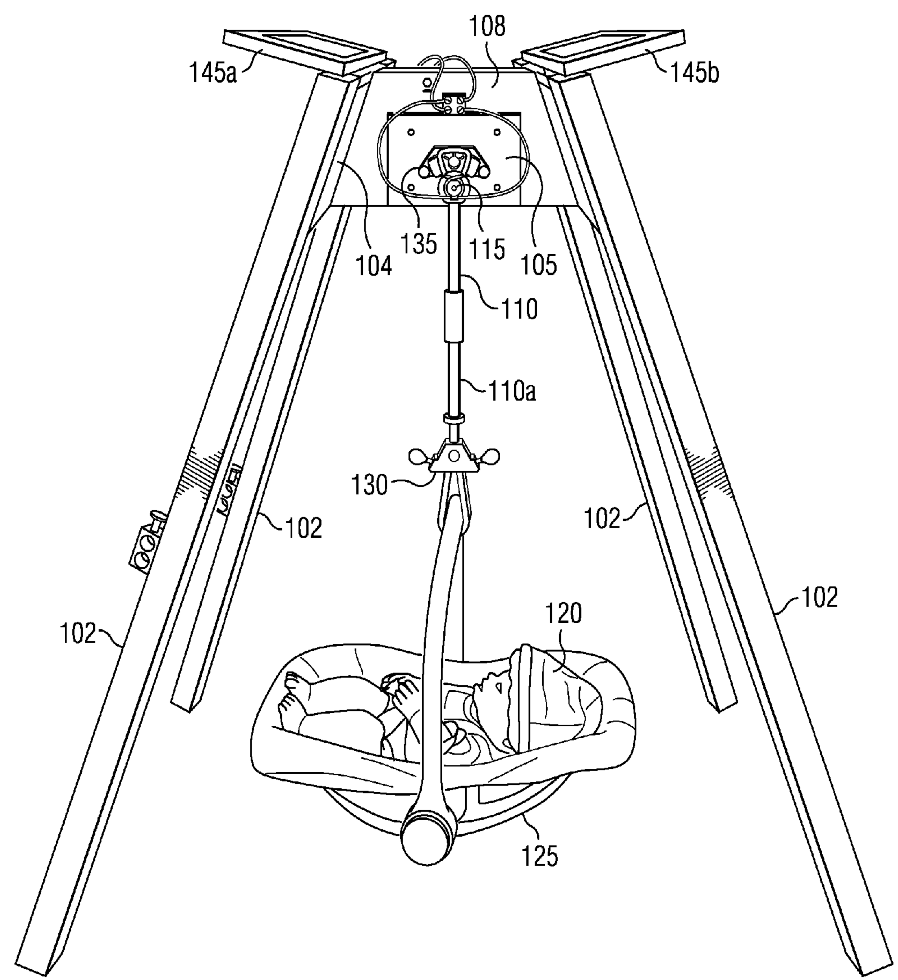
WO 2006/023539 A3

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

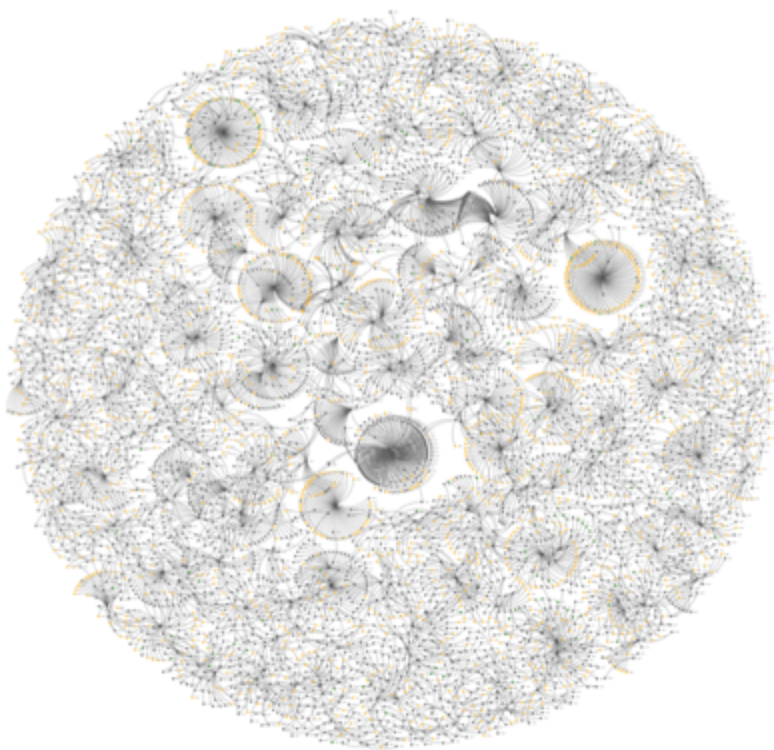
Table 2: Mean number of citations

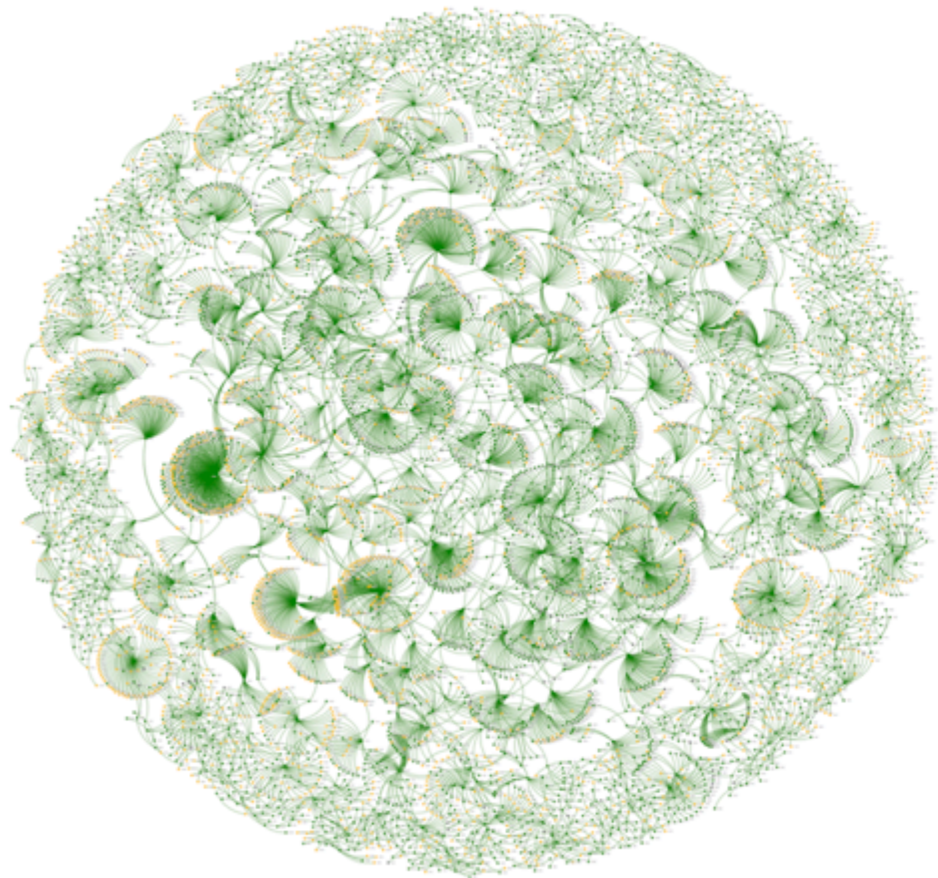
	Clean	Dirty	Diff.
Citations received	3.399	2.295	1.104***
	(8.256)	(5.921)	[0.016]

50% higher

Patent 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)	([illegible].014)
Number of patents		-0.092***	-0.057***		-0.052***	-[illegible]031***
		(0.00[illegible]	(0.007)		(0.006)	[illegible].005)
Family size			0.073***			[illegible]067***
			(0.004)			[illegible].003)
Triadic			0.456***			[illegible]41***
			(0.036)			
Granted			0.947***			[illegible]*
			(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

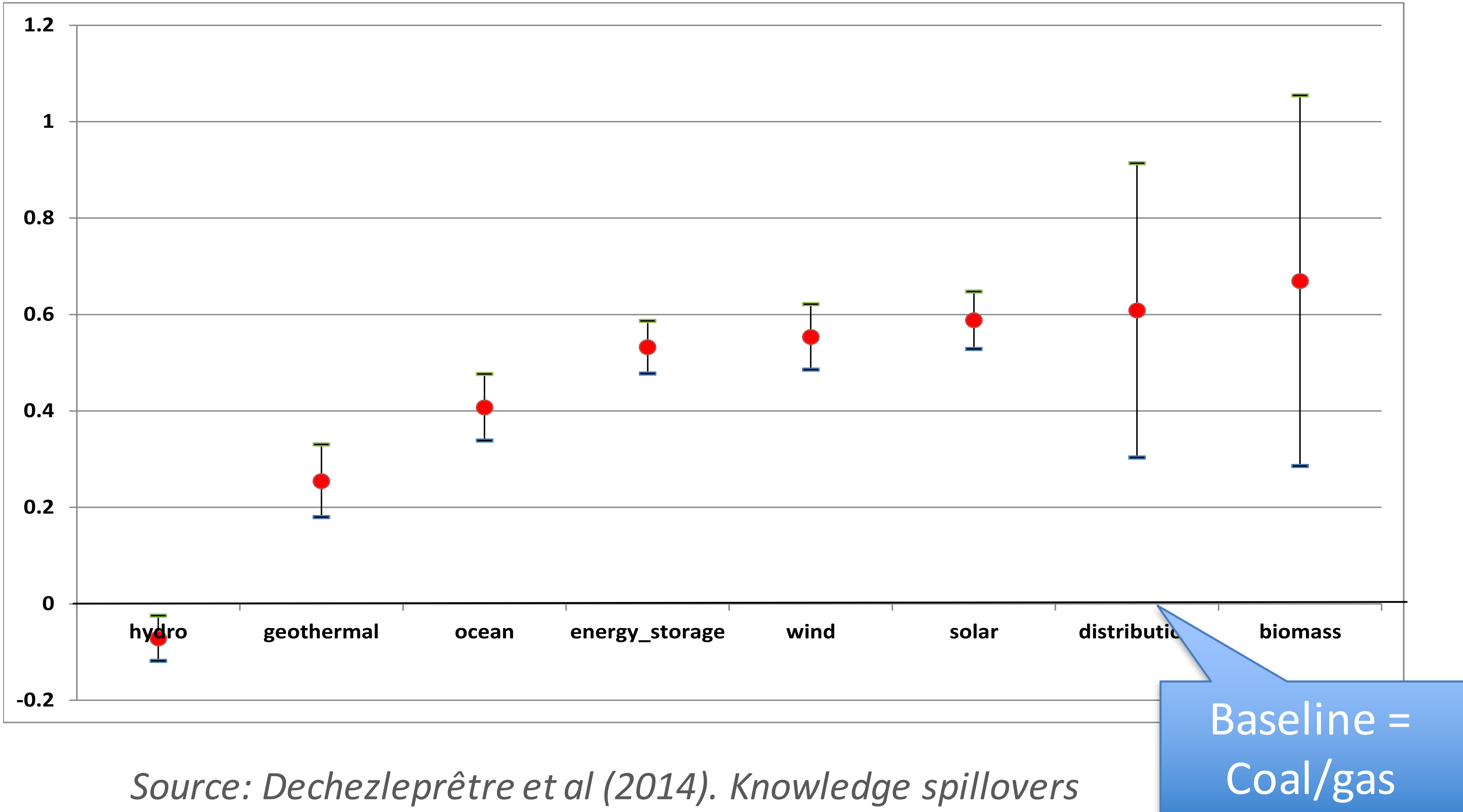
Notes: Robust standard errors in parentheses (* p<0.05, ** p<0.01, *** p<0.001). The dependent variable is the total number of citations received excluding self-citations by inventors (columns 1 to 3) and the PatentRank after 20 iterations (columns 4 to 6). All columns are estimated by fixed-effects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

Regressions 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	[illegible]	-0.047***	-0.048***	-0.019**
	[illegible]	(0.009)	(0.006)	(0.007)
[illegible]	[illegible]	0.067***	0.062***	0.060***
	[illegible]	(0.004)	(0.007)	(0.004)
[illegible]	[illegible]	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

Spillovers higher in all clean technologies



Source: Dechezleprêtre et al (2014). Knowledge spillovers from clean and dirty technologies

Clean, grey & dirty

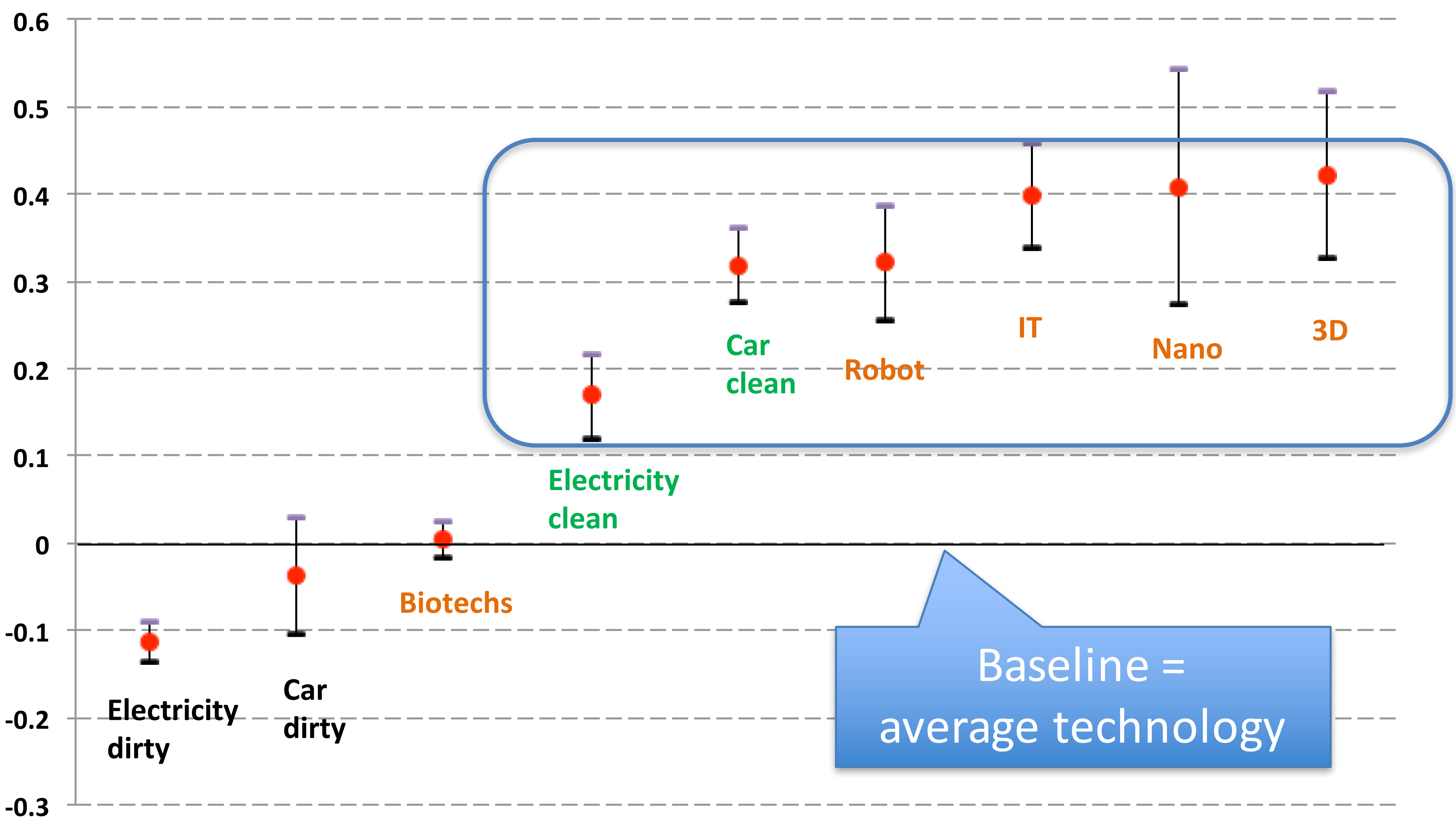
	(1)	(2)	(3)	(4)
Sample	Clean vs. Grey and true Dirty	Clean vs. Grey	Grey vs. True Dirty	Clean vs. True Dirty
Dep. var.		Citations received		
Clean/Grey invention	0.430***	0.191***	0.307***	0.502***
	(0.014)	(0.016)	(0.016)	(0.015)
Number of patents	-0.057***	-0.051***	-0.114***	-0.060***
	(0.007)	(0.00	(0.005)	(0.007)
Family size	[illegible]	[illegible]	[illegible]	0.071***
	[illegible]	[illegible]	[illegible]	(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)

The drivers – comparing clean to other emerging technologies



The monetary value of spillovers

Griliches' (1981) market valuation equation:

$$V_{it} = q_t(A_{it} + \beta K_{it})^{\sigma}$$

Knowledge assets

Firm i's stock market value in year t

Physical assets

Knowledge assets:

$$K_{it} = f_1 \times R\&D_{it} + f_2 \times BCIT_{it} + f_3 \times \frac{PAT_{it}}{R\&D_{it}} + f_4 \times \frac{FCIT_{it}}{PAT_{it}}$$

Accumulated R&D spendings

Knowledge inflows (spillovers)

Cumulated idiosyncratic productivity shocks (Hall et al. 2005)

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

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

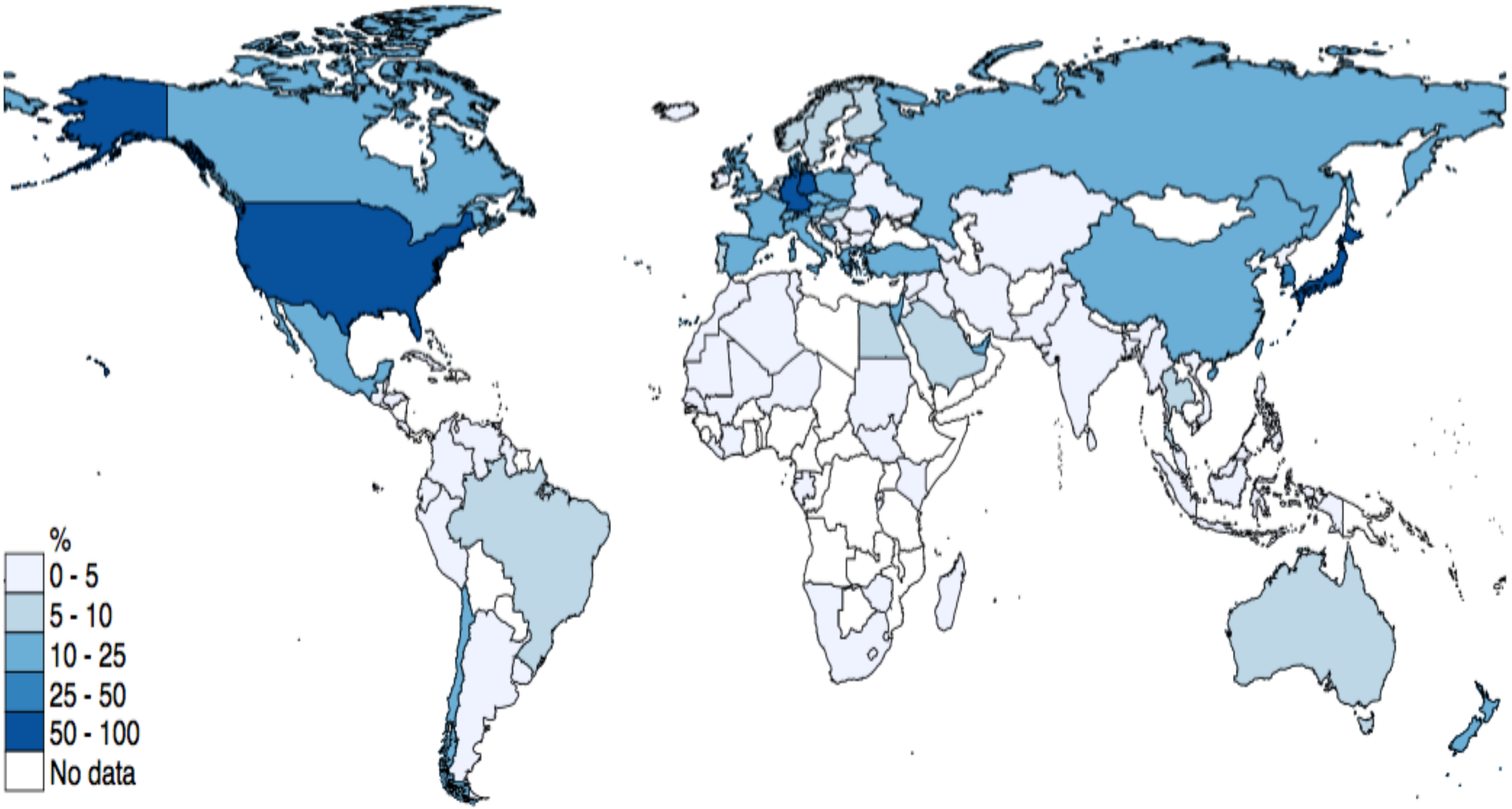
	(1)	(2)	(3)	(4)	(5)
Dep. var.			ln Tobin's Q		
R&D / assets	0.438***	0.436***	0.427***	0.433***	0.428***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Patent / R&D	-0.097**	-0.070	-0.062		-0.062
	(0.044)	(0.044)	(0.045)		(0.045)
Fwd citations / patent		0.074***	0.031***		0.029***
		(0.006)	(0.010)		(0.010)
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

Where do spillovers occur?



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

Thanks

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