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The Performance Effect of Environmental Innovations

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Introduction and motivation

- **Evidence:** broad empirical investigations about driving forces of green innovation
  - Induced - prices (Popp 2002, Newell et al. 1999), regulation (Jaffe and Palmer 1997, Lanoie et al. 2011)
  - Technological capabilities (Horbach 2008)
- **Missing:** broad empirical evidence whether environmental innovations are profitable or when they are profitable
- **Policy relevance:** green innovation investments would proceed without further interventions if such investments are already profitable

Conceptual background (1)

- In order to investigate the profitability of innovation – what do we know ?
- Standard result: Positive relationship between innovation and productivity (e.g. Crepon et al. 1998).
- Standard results not necessarily valid for green technologies
  - Demand side factors (Dasgupta and Stiglitz 1980)
    - willingness to pay is lower, since benefits are not fully appropriable
    - greatest benefits are likely to be public
  - New capabilities
    - require modification of resource base (e.g. Barney 1991, Penrose 1995)
    - costly to transfer knowledge (tacit) (e.g. Teece et al. 1997)

Conceptual background (2)

- Organizational changes (see Danneels 2002)
  - business processes, working routines need to be modified
  - causes resistance to change
- Financial means
  - R&D usually internally financed (Hall 1992, Himmelberg and Petersen 1994).
  - External means are difficult to get – there are information asymmetries between research and investor

- Positive returns to scale (Henderson and Cockburn 1996)
  - substantial knowledge stock
  - trained staff, new equipment, learning
  - Switch from expensive exploration of knowledge to less expensive exploitation (March 1991)

Hypotheses

- H1: the costs of developing a green knowledge stock are considerably high and they significantly decrease the performance of a firm or industry
- H2: Industries with a green knowledge stock beyond a certain limit are more likely to show positive performance effects compared to industries with a poorer knowledge stock in green technologies.

Description of Data (1)

- Patent data (collected in cooperation with Swiss Federal Institute of Intellectual Property)
- Green Patents were selected according to the OECD indicator of environmental technologies (OECD 2012):
  - General environmental management
  - Energy generation from renewable and non-fossil sources
  - Combustion technologies with mitigation potential
  - Technologies specific to climate change mitigation
  - Technologies with potential or indirect contribution to emission mitigation
  - Emission abatement and fuel efficiency in transportation
  - Energy efficiency in buildings and lighting

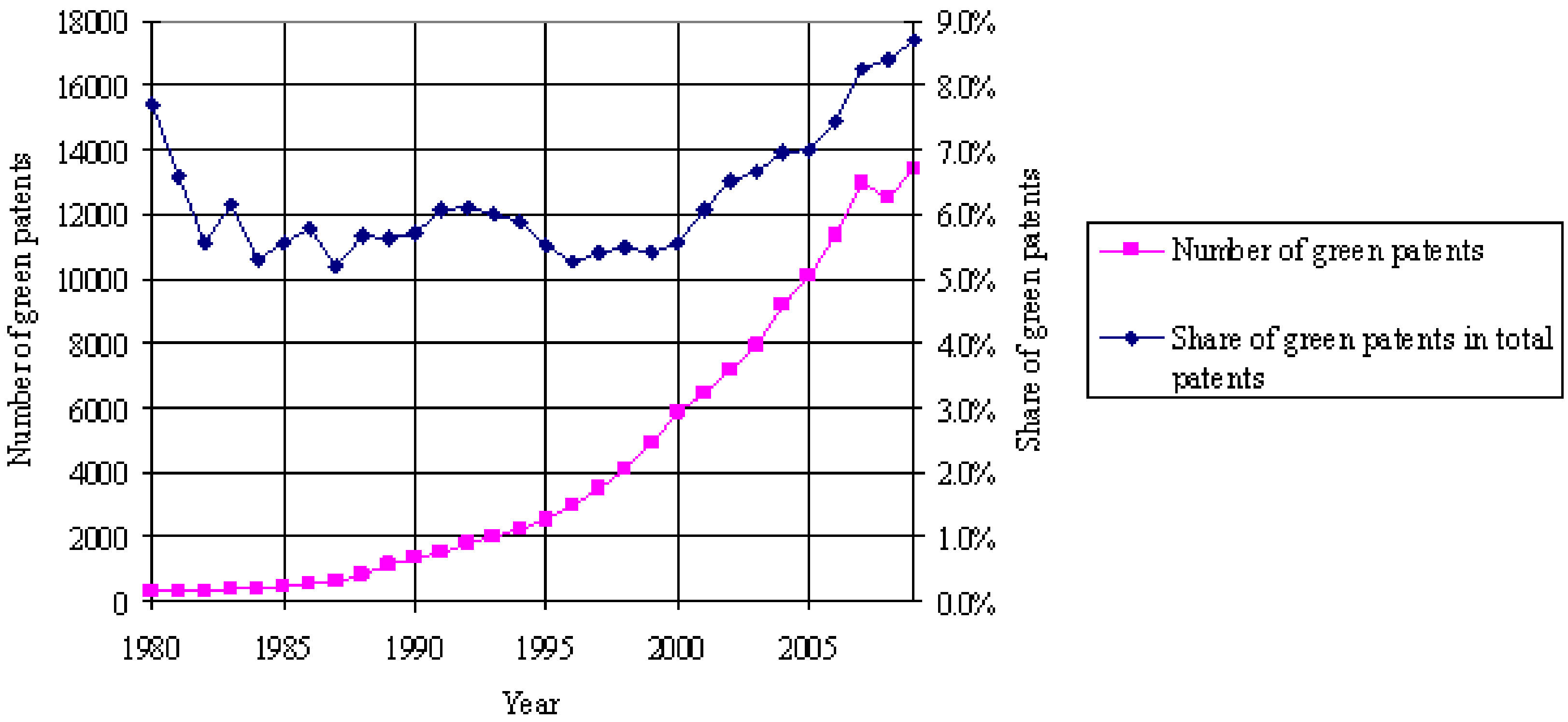
Description of Data (2)

- We used patent data for …
  - … 12 countries (Austria, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Sweden, Switzerland, UK, USA)
    - they make up for ca. 95% of all green (other) inventions worldwide
  - … 22 manufacturing industries (two/three digit level)
  - … period of 30 years (1980 – 2009) – max. of 7920 observations
- Applicant's address (not inventor) in order to assign patents to countries

Description of Data (3)

- We collected inventions (patent families) and not single patents
  - Grouping according to Derwent World Patents Index patent family definition of Thomson Reuters (peer-review procedure) - We ensure that only technologically important inventions are considered – avoiding bias due to different application attitudes
  - Only inventions are considered that have at least on patent under PCT – we focus on invention with commercial potential.
  - Inventions were aggregated on an industry level using the concordance scheme by Schmoch et al. (2003).
- Information on Productivity, labor input, and capital stock comes from the OECD STAN database

Development of green patents worldwide, 1980-2009



Number of green and other patents (inventions) by ind.

Period	1980-2009			
	Number of other patents	Number of green patents	Relative share in total green patents	Share of green patents in total patents
Industry				
Food, beverages	37'798	1'672	0.65%	4.2%
Tobacco products	2'325	69	0.03%	2.9%
Textiles	16'111	1'070	0.42%	6.2%
Wearing apparel	5'733	75	0.03%	1.3%
Leather articles	3'670	19	0.01%	0.5%
Wood products	4'584	256	0.10%	5.3%
Paper	21'463	1'400	0.54%	6.1%
Petroleum products, nuclear fuel	17'053	3'514	1.37%	17.1%
Rubber and plastics products	102'022	6'485	2.52%	6.0%
Non-metallic mineral products	81'906	8'965	3.48%	9.9%
Basic metals	42'426	6'892	2.68%	14.0%
Fabricated metal products	61'777	8'073	3.14%	11.6%
Machinery	421'085	61'667	23.96%	12.8%
Office machinery and computers	271'075	5'276	2.05%	1.9%
Electrical machinery and apparatus	96'389	28'502	11.08%	22.8%
Radio, television and communication equipment	416'041	23'731	9.22%	5.4%
Medical, precision and optical instruments	464'886	14'898	5.79%	3.1%
Motor vehicles	90'872	29'911	11.62%	24.8%
Other transport equipment	25'742	2'495	0.97%	8.8%
Furniture, consumer goods	47'174	561	0.22%	1.2%
Chemicals (excluding pharmaceuticals)	301'064	46'427	18.04%	13.4%
Pharmaceuticals	322'450	5'382	2.09%	1.6%

Number of green and other patents (inventions) by country

Period	1980-2009			
	Number of other patents	Number of green patents	Relative share in total green patents	Share of green patents in total patents
Country				
Austria	30'593	3'311	1.29%	9.8%
Switzerland	93'498	5'720	2.22%	5.8%
Germany	414'160	49'795	19.35%	10.7%
Denmark	30'970	3'825	1.49%	11.0%
Finland	43'313	3'004	1.17%	6.5%
France	167'953	14'723	5.72%	8.1%
United Kingdom	194'920	14'829	5.76%	7.1%
Italy	58'198	4'314	1.68%	6.9%
Japan	490'415	59'595	23.16%	10.8%
Netherlands	116'486	9'306	3.62%	7.4%
Sweden	93'741	6'397	2.49%	6.4%
United States	1'119'399	82'521	32.07%	6.9%

Definition of Variables

Variable	Definition/measurement	Source
Dependent variable q	Value added, volumes (current price value)	OECD STAN
Independent variable		
L	Number of persons engaged (total employment)	OECD STAN
K	Gross fixed capital formation, volumes (current price value)	OECD STAN
Other_patents	Number of patents that are not classified as green	own calculations
Green_patents	Number of green patents	own calculations
Other_stock	Stock of patents that are not classified as green	own calculations
Green_stock	Stock of green patents	own calculations

Empirical test of hypotheses (1)

- Econometric framework
  - Cobb-Douglas (in log)

$$\ln(q)_{ijt} = \ln(A)_{ijt} + \alpha \ln(L)_{ijt} + \beta \ln(K)_{ijt}.$$

  - Perpetual inventory method (δ to be equal to 15%)

$$Green\_stock_{ijt} = (1-\delta)Green\_stock_{ijt-1} + Green\_patents_{ijt},$$

  - Augmented specification (fixed effects estimator, heterosc. robust std.err.)

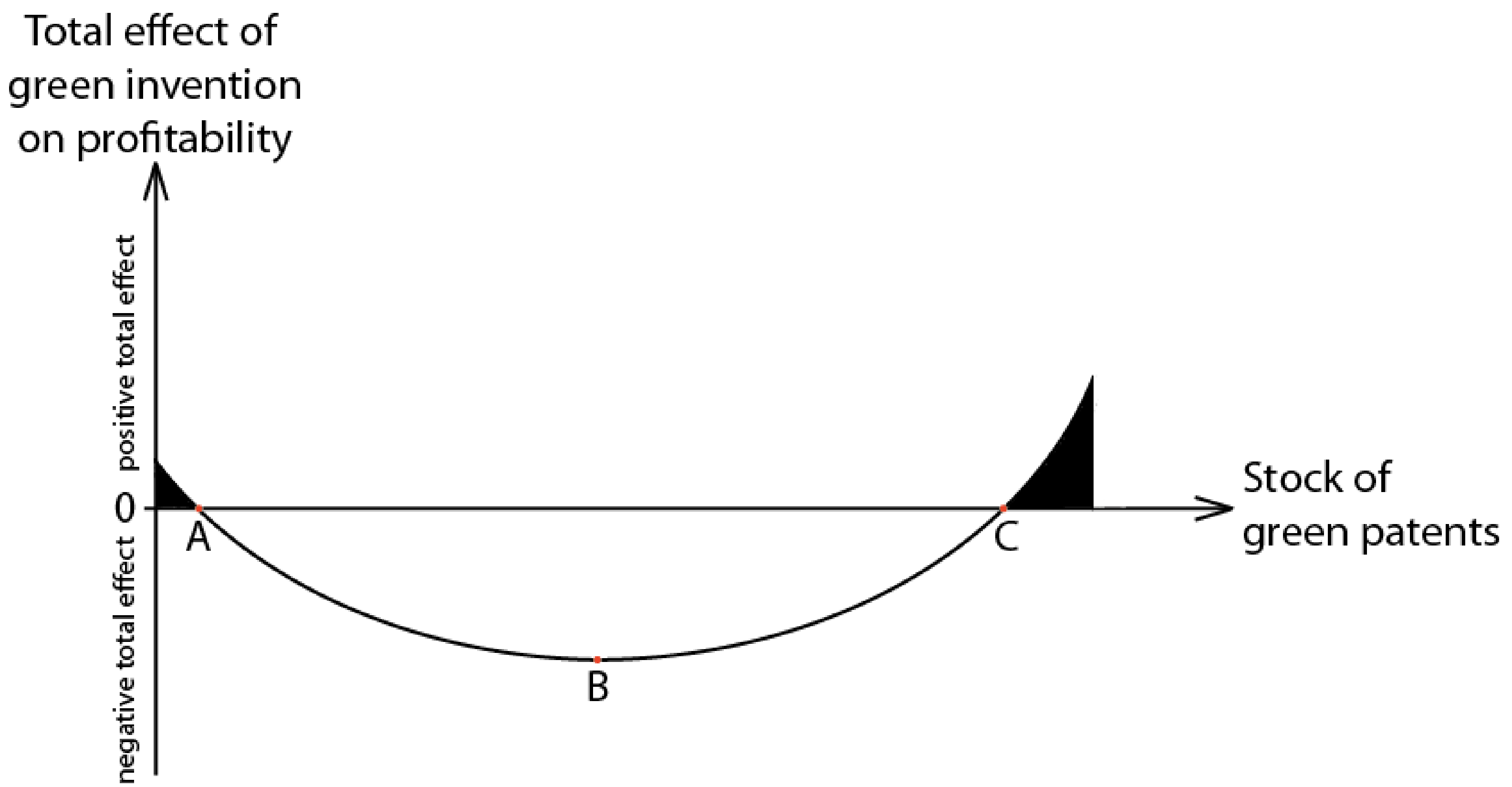
$$\ln(q)_{ijt} = \ln(A)_{ijt} + \alpha \ln(L)_{ijt} + \beta \ln(K)_{ijt} + \delta_1 Green\_stock\_d_{ijt-1} + \delta_2 Green\_stock_{ijt-1}$$
$$+ \delta_3 Green\_stock^2_{ijt-1} + \lambda_1 Other\_stock_{ijt-1} + \lambda_2 Other\_stock^2_{ijt-1} + \mu Year_{ijt} + \eta_{ij} + \varepsilon_{ijt},$$

RESULTS

Results: estimation of the profitability (value added)

	$\ln(q)_{ijt}$			
	(1)	(2)	(3)	(4)
Period	1981-2009	1981-2001	1981-2009	1981-2009
Estimation method	Fixed-effects regression	Fixed-effects regression	Fixed-effects regression	Random-effects GLS
$Constant_{ijt}$	9.6274***	10.337***	12.011***	11.388***
	(2.0202)	(1.823)	(1.594)	(1.1122)
$\ln(L)_{ijt}$	.89323***	.93892***	.9177***	.94631***
	(.16859)	(.1388)	(.1442)	(.11356)
$\ln(K)_{ijt}$	.11018	.04791		
	(.07014)	(.05102)		
$Other\_stock_{ijt-1}$	.0002**	.00023*	.00016**	.00015**
	(9.7e-05)	(.00012)	(6.5e-05)	(6.3e-05)
$Other\_stock^2_{ijt-1}$	-5.1e-09**	-1.1e-08*	-3.6e-09**	-3.4e-09**
	(2.5e-09)	(5.9e-09)	(1.5e-09)	(1.5e-09)
$Green\_stock\_d_{ijt-1}$	.08698	.11222**	.09013	.09136
	(.05791)	(.05507)	(.06584)	(.06616)
$Green\_stock_{ijt-1}$	-.00122**	-.00183*	-.00099**	-.00094**
	(.00058)	(.00093)	(.00041)	(.00039)
$Green\_stock^2_{ijt-1}$	2.0e-07**	5.6e-07*	1.4e-07**	1.4e-07**
	(1.0e-07)	(3.2e-07)	(6.3e-08)	(6.1e-08)
Year fixed effects	yes	yes	yes	yes
Country specific industry fixed effects	yes	yes	yes	no
Industry fixed effects	no	no	no	yes
Country fixed effects	no	no	no	yes
N	2936	1969	4527	4527

Stylized main result: U-shaped relationship



Tests of robustness:

- Different time segments:
  - 1983-2009; 1989-2009; 1994-2009; 1999-2009
- Controlling for country specific year-fixed effects
- Outliers (top 1% equals 1.6% of observations)
- Alternative time lags
  - 2 years and 5 years
- Alternative depreciation rates
  - 10%; 30%; 100% (patent flows)

Conclusions

- Given the dominantly negative marginal effects of green inventions the willingness to invest in green technologies (without further promotion) is supposed to be low.
- Since costs are substantial a free-riding problem may occur. A single country (small) has probably no incentives to adjust the political framework to further push green inventions – ‘free ride’ on technologies developed abroad. Multilateral coordination is required.
- If green technology markets evolve, there will be investment incentives if “first-mover” advantages are considerable. Without first-mover advantages companies are unlikely to pick up profitable opportunities without regulatory push (see Porter and Van der Linde 1995). Whether there are first-mover advantages must be left for further research.

Tests of Robustness

Results: Analysis of different time segments

	$ln(q)_{ijt}$			
	(1)	(2)	(3)	(4)
Period	1983-2009	1989-2009	1994-2009	1999-2009
Estimation method	Fixed-effects regression	Fixed-effects regression	Fixed-effects regression	Fixed-effects regression
$Constant_{ijt}$	10.12***	11.083***	12.4***	13.69***
	(2.0414)	(2.0964)	(1.9348)	(2.9622)
$ln(L)_{ijt}$	.86564***	.79342***	.74074***	.66803**
	(.17596)	(.18623)	(.18152)	(.33648)
$ln(K)_{ijt}$	.10725	.11037*	.086**	.06117
	(.06579)	(.05814)	(.04202)	(.06401)
$Other\_stock_{ijt-1}$	.0002**	.0002**	.0002**	.00017**
	(9.6e-05)	(9.5e-05)	(8.5e-05)	(7.0e-05)
$Other\_stock^2_{ijt-1}$	-5.0e-09**	-4.9e-09**	-4.4e-09**	-3.2e-09**
	(2.4e-09)	(2.4e-09)	(2.0e-09)	(1.5e-09)
$Green\_stock\_d_{ijt-1}$	.04792	-.04616	-.0948	-.05042
	(.06068)	(.08359)	(.0896)	(.09283)
$Green\_stock_{ijt-1}$	-.00123**	-.00122**	-.00111**	-.00085**
	(.00057)	(.00056)	(.0005)	(.00043)
$Green\_stock^2_{ijt-1}$	2.0e-07**	2.0e-07**	1.7e-07**	1.1e-07*
	(9.9e-08)	(9.5e-08)	(8.0e-08)	(6.1e-08)
Year fixed effects	yes	yes	yes	yes
Country specific industry fixed effects	yes	yes	yes	yes
N	2756	2446	2018	1401

Controlling for country specific time effects and outliers

	$ln(q)_{ijt}$	
	(1)	(4)
Estimation method	Fixed-effects regression	Fixed-effects regression
Robustness test	Controlling for country specific time effects	Checking for outliers
$Constant_{ijt}$	10.451***	9.6908***
	(1.8756)	(2.0157)
$ln(L)_{ijt}$	.75307***	.88369***
	(.16342)	(.16899)
$ln(K)_{ijt}$	.1651**	.11178
	(.07967)	(.07077)
$Other\_stock_{ijt-1}$	.00026***	.00021*
	(9.2e-05)	(.00011)
$Other\_stock^2_{ijt-1}$	-6.5e-09***	-6.0e-09
	(2.4e-09)	(3.6e-09)
$Green\_stock\_d_{ijt-1}$	.13224**	.09437*
	(.0552)	(.05638)
$Green\_stock_{ijt-1}$	-.00129**	-.00118**
	(.00055)	(.00058)
$Green\_stock^2_{ijt-1}$	2.3e-07**	1.9e-07*
	(9.9e-08)	(9.9e-08)
Year fixed effects	no	yes
Country specific year fixed effects	yes	no
Country specific industry fixed effects	yes	yes
N	2936	2889

Alternative lags (2 and 5 years)

	$\ln(q)_{ijt}$	
	(2)	(3)
Estimation method	Fixed-effects regression	Fixed-effects regression
Robustness test	Alternative lags	
$Constant_{ijt}$	9.7434***	9.9895***
	(2.0354)	(2.1372)
$\ln(L)_{ijt}$	.89216***	.87691***
	(.172)	(.18082)
$\ln(K)_{ijt}$	.10537	.10857*
	(.06788)	(.06132)
$Other\_stock_{ijt-2}$	.00021**	
	(1.0e-04)	
$Other\_stock^2_{ijt-2}$	-5.7e-09**	
	(2.7e-09)	
$Green\_stock\_d_{ijt-2}$	.10757**	
	(.05366)	
$Green\_stock_{ijt-2}$	-.00131**	
	(.00061)	
$Green\_stock^2_{ijt-2}$	2.3e-07**	
	(1.1e-07)	
$Other\_stock_{ijt-5}$		.00025**
		(.00012)
$Other\_stock^2_{ijt-5}$		-8.4e-09**
		(3.9e-09)
$Green\_stock\_d_{ijt-5}$		.14644***
		(.04703)
$Green\_stock_{ijt-5}$		-.00162**
		(.00074)
$Green\_stock^2_{ijt-5}$		3.7e-07**
		(1.7e-07)
Year fixed effects	yes	yes
Country specific year fixed effects	no	no
Country specific industry fixed effects	yes	yes
N	2876	2696

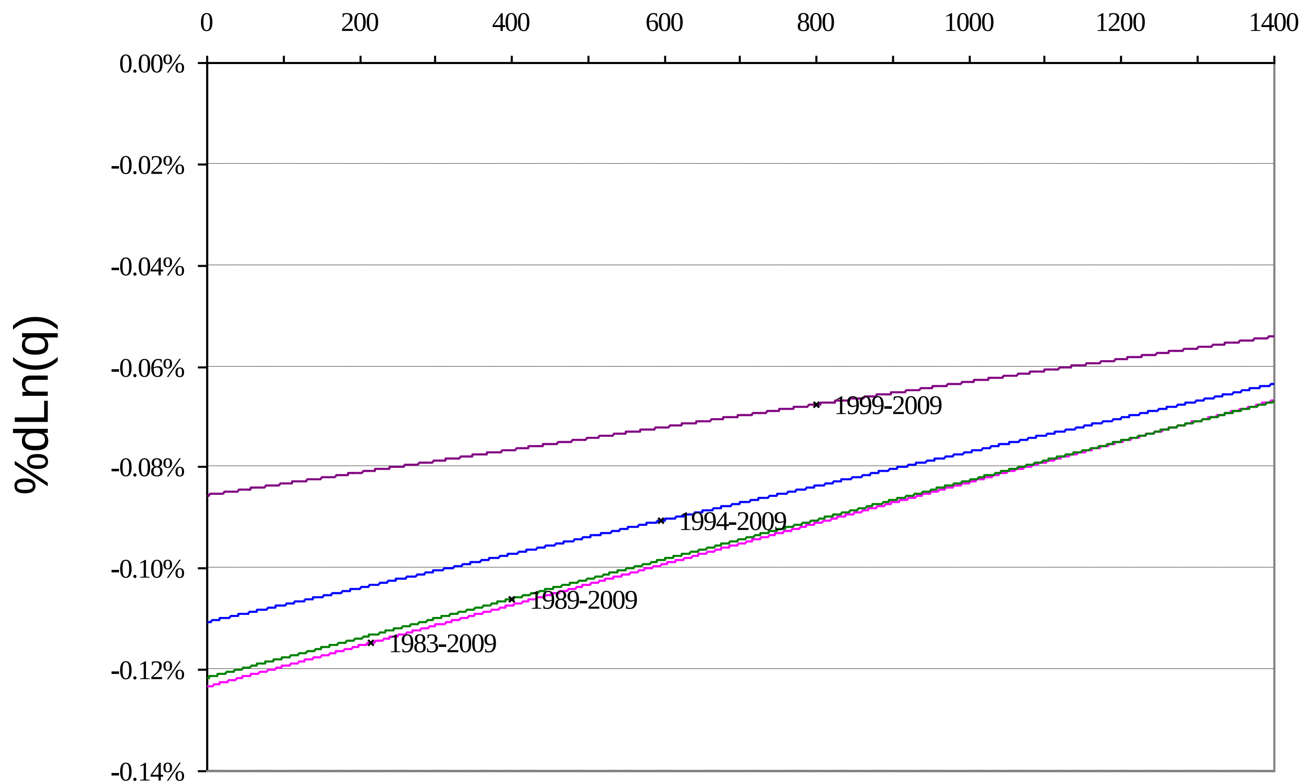
Alternative depreciation rate

	$\ln(q)_{ijt}$	
	(1)	(2)
Depreciation rate	10%	30%
Estimation method	Fixed-effects regression	Fixed-effects regression
Constant_{ijt}	9.5957***	9.6752***
	(2.0325)	(2.0068)
$\ln(L)_{ijt}$	.89572***	.88988***
	(.16948)	(.16782)
$\ln(K)_{ijt}$	.11045	.10955
	(.07024)	(.06994)
$\text{Other\_stock}_{ijt-1}$	.00016**	.0003**
	(7.9e-05)	(.00015)
$\text{Other\_stock}^2_{ijt-1}$	-3.4e-09**	-1.3e-08**
	(1.6e-09)	(6.2e-09)
$\text{Green\_stock\_d}_{ijt-1}$	.08512	.08991
	(.05791)	(.05796)
$\text{Green\_stock}_{ijt-1}$	-.00103**	-.00181**
	(.00049)	(.00088)
$\text{Green\_stock}^2_{ijt-1}$	1.4e-07**	4.8e-07*
	(6.9e-08)	(2.4e-07)
Year fixed effects	yes	yes
Country specific industry fixed effects	yes	yes
N	2936	2936
Groups	146	146
R^2 within	0.48	0.48
Rho	0.91	0.91

Estimate of the production function based on patent flows

	$ln(q)_{ijt}$
	(1)
Estimation method	Fixed-effects regression
$Constant_{ijt}$	9.8559***
	(2.0533)
$ln(L)_{ijt}$	.88***
	(.17097)
$ln(K)_{ijt}$	.10564
	(.06995)
$Other\_patents_{ijt-1}$	.00071*
	(.00039)
$Other\_patents^2_{ijt-1}$	-8.0e-08*
	(4.3e-08)
$Green\_patents\_d_{ijt-1}$	.10338***
	(.03751)
$Green\_patents_{ijt-1}$	-.00381*
	(.002)
$Green\_patents^2_{ijt-1}$	2.7e-06*
	(1.5e-06)
Year fixed effects	yes
Country specific industry fixed effects	yes
N	2936
Groups	146
R^2 within	0.48
Rho	0.91

Marginal effect of additional *Green_stock* for different time windows (ΔGreen_stock=1)



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THANK YOU VERY MUCH FOR YOUR ATTENTION

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APPENDIX

Correlation matrix (based on model (1) of Table 3; 2936 observations)

	$\ln(q)_{ijt}$	$\ln(L)_{ijt}$	$\ln(K)_{ijt}$	$Other\_stock_{ijt-1}$	$Other\_stock^2_{ijt-1}$	$Green\_stock\_d_{ijt-1}$	$Green\_stock_{ijt-1}$
$\ln(L)_{ijt}$	0.83						
$\ln(K)_{ijt}$	0.95	0.79					
$Other\_stock_{ijt-1}$	0.38	0.36	0.33				
$Other\_stock^2_{ijt-1}$	0.17	0.17	0.16	0.86			
$Green\_stock\_d_{ijt-1}$	0.43	0.32	0.44	0.15	0.05		
$Green\_stock_{ijt-1}$	0.36	0.35	0.33	0.90	0.81	0.12	
$Green\_stock^2_{ijt-1}$	0.18	0.18	0.17	0.81	0.95	0.05	0.88

Descriptive statistics (based on model (1) of Table 3; 2936 observations)

Variable	Mean	Std. Dev.	Min	Max
Dependent variable				
$\ln(q)_{ijt}$	21.98	1.82	15.20	25.75
Independent variable				
$\ln(L)_{ijt}$	10.75	1.76	5.72	14.46
$\ln(K)_{ijt}$	19.97	1.93	4.61	23.89
$Other\_stock_{ijt-1}$	1'189.14	3'550.93	0	54'430.81
$Green\_stock\_d_{ijt-1}$	0.83	0.37	0	1
$Green\_stock_{ijt-1}$	152.28	550.89	0	8'492.57

Empirical test of hypotheses (2)

- Operationalization of hypotheses:
  - H1: since we do not have a measure for the costs of diversifying into green technologies, we deduce from a negative relationship between *green_stock* and productivity that costs are considerably greater than the benefits from investing in green research.
  - H2: if there are positive scale effects we would expect a positive relationship between *green_stock* and productivity
  - H1 and H2 would point at a non-linear relationship between *green_stock* and productivity if *green_stock* is significant negative and $green\_stock^2$ is significant positive. This way we can identify the sufficient degree of specialization in terms of positive productivity effects.