Transition Towards a Green Economy in Europe: Innovation and Knowledge Integration in the Renewable Energy Sector

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Summary

EU strong commitment to climate policy and ambitious sustainability targets increased innovation rate in renewable technologies (RES)

This begs the question: how were knowledge flows affected?

- EU research/innovation system is very fragmented (SET Plan)
- Promote integration to induce more effective knowledge creation

Overall, fragmentation is believed to slow the movement towards the technological frontier

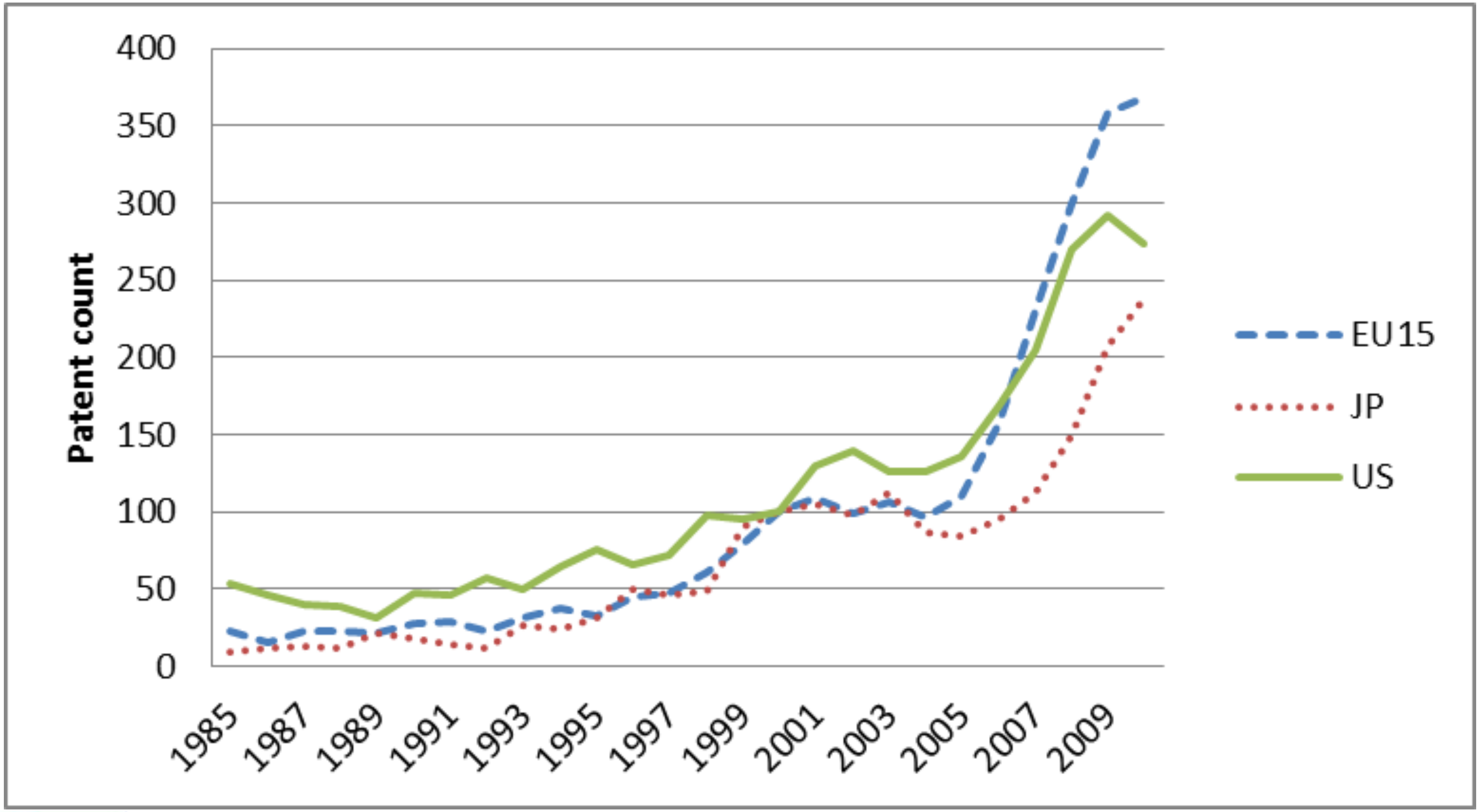
Summary

Investigate the fragmentation of the EU RES innovation system by estimating the intensity and direction of knowledge flows over the years 1985-2010 and if/how they changed

Results

- Knowledge flows across EU countries increased
- The importance of the EU as a source country for knowledge spillovers increased
- Yet, EU is still poorly integrated compared to US or JP

Motivation


400
350
300
250
200
150
100
50
0
Patent count
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
EU15
JP
US

Motivation

But much remains to be done

Fragmentation of the EU innovation system and R&D effort hinders knowledge flows (EC 1997,2010; Fisher et al. 2009; LeSage et al. 2007)

- ➔ few spillovers across member countries
- ➔ low integration
- ➔ duplication of research effort
- ➔ inability to build on experience of other countries

↓

"insufficient capacity to innovate, to launch new products and services, to market them rapidly on world markets and, finally, to react rapidly to changes in demand"

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Motivation

This is particularly troubling for Renewable Energy Technologies (RES)

"Fragmentation, multiple non-aligned research strategies and sub-critical capacities that remain a prevailing characteristic of the EU research base"

- are critical factors constraining EU firms' innovative capability and competitiveness in global markets for renewable energy technologies.
- delay (or, in the worst scenario, impede) the achievement of the ambitious EU climate targets (EC 2007; EC 2008; EC 2015b)

<u>Rationale: spillovers overall have a positive impact on innovation activity</u>

- Supported by much economic literature (De Bond et. al 1992, Popp 2002, Cassiman, B., Veugelers, R., 2006, etc.) although some raise concerns regarding rivals' free riding (Grafström 2017 and Rennings 2000)

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Contribution

We investigate the fragmentation of the EU renewable (RES) innovation system

- Estimate the intensity and direction of knowledge flows over the years 1985-2010, and their changes
- Study the performance of EU countries vis-à-vis other top innovators
- Modify the approach to distinguish between domestic and 'other EU' citations within the EU

Contribution

Focus on two periods: pre and post 2000

1997 Kyoto protocol
1997 White Paper on Renewable Energies
2005 EU-ETS

(Indirectly) test the effectiveness of actions and policy support to promote RES development

Empirical Proxies

Patent citations

=

flows of codified knowledge

+ : Valid measures of linkages between innovations

+ : Widely used to study how knowledge diffuses across geographical and technological spaces, few applications in environmental/energy technologies

- : Noisy measures (Griliches, 1990, Jaffe et al. 1998)

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Data and Descriptives

- Patent applications at the EPO between 1985 and 2010 and their citations (EP-CRIOS Database)
- Patents assigned to EU15, US and JP (country of residence of the inventor)
- RES technologies identified by IPC codes: Hydro, Solar, Wind, Biomass, Geothermal, Ocean, Waste (but also Y02)

RENEWABLE ENERGY TECHNOLOGIES						
Country	*Patents*	*Percent*	*Backward citations*	*Avg Citation/Patent*	*Citations received*	*Received Citation/Patent*
EU15	14,263	0.62	24,478	1.72	23,082	1.62
JP	4,169	0.18	6,482	1.55	8,098	1.94
US	4,730	0.2	12,130	2.56	11,910	2.56
Total	23,162	1	43,090	1.86	43,090	1.86

Data: Citation patterns pre/post 2000

EU RES support (and innovation) ↑ steadily

What about knowledge flows?

RENEWABLE TECHNOLOGIES

Period of reference		**1987-1997**				*Period of reference*		**2000-2010**			
Cited country		EU15		JP	US	***Cited country***		EU15		JP	US
		Nat	*Int*					*Nat*	*Int*		
Citing country	EU15	0.33	0.25	0.10	0.32	***Citing country***	EU15	0.32	0.44	0.10	0.14
	JP	0.27		0.29	0.44		JP	0.26		0.61	0.13
	US	0.34		0.12	0.54		US	0.41		0.17	0.42

EU15 ↑ EU15

EU15 ↓ US

US ↑ EU15

JP ↑↑ JP

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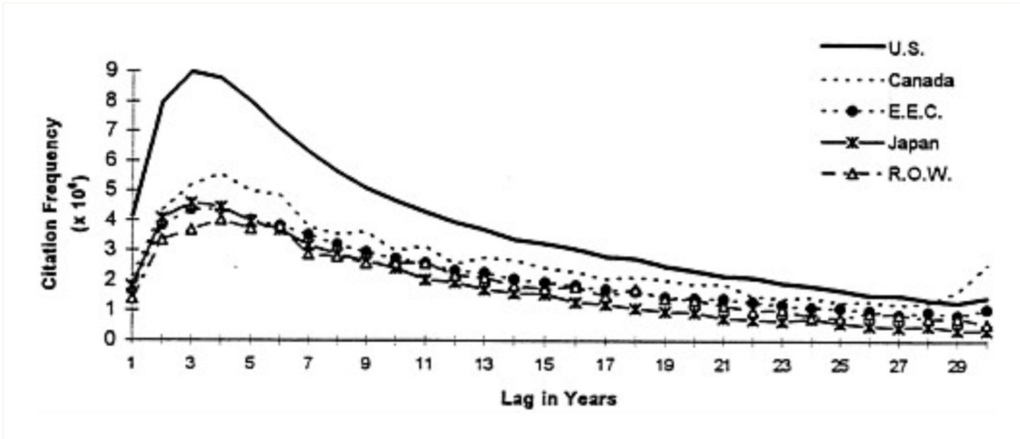
Empirical Approach

$$p_{iTjt} = C_{iTjt} / (N_{iT})(N_{jt}) =$$



$$\alpha_T \ \alpha_t \ \alpha_{ij} \ \exp[-\beta_1 (T-t)] \ (1-\exp[-\beta_2 (T-t)]) + \varepsilon_{iTjt}$$

- **Decay** and **Diffusion** of knowledge
- α → fixed effects – shift parameters

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Empirical Approach

$$p_{iTjt} = \frac{C_{iTjt}}{(N_{iT})(N_{jt})} =$$

$$\alpha_T \, \alpha_t \, \alpha_{ij} \, [1+\phi_{ij} * D_{2000}] \exp[-\beta_1 (T-t)] (1-\exp[-\beta_2 (T-t)]) + \varepsilon_{iTjt}$$

- $\boldsymbol{\alpha_{ij}}$ → relative likelihood that the average patent from i is cited by patent from j
- $\boldsymbol{\phi_{ij}}$ → increase in the likelihood of citation by patents applied for after 2000
- We look at 3 regions citing regions (US, EU15, JP)
- With the EU, we distinguish between EU_{nat} and EU_{int} citations

Main Results

	α_{ij} (1)	α_{ij} (2)
Citing/cited country pairs (αi,j) [(a)]		
US citing US	1	1
	NA	NA
EU15 citing EU15	0.384***	
	(0.013)	
EU15 citing EU15 (national)		0.582***
		(0.022)
EU15 citing EU15 (international)		0.299***
		(0.011)
EU15 citing US	0.279***	0.280***
	(0.013)	(0.013)
EU15 citing JP	0.170***	0.170***
	(0.008)	(0.008)
US citing EU15	0.315***	0.314***
	(0.013)	(0.013)
US citing JP	0.470***	0.469***
	(0.027)	(0.027)
JP citing EU15	0.140***	0.140***
	(0.007)	(0.007)
JP citing US	0.262***	0.264***
	(0.014)	(0.014)
JP citing JP	0.814***	0.817***
	(0.038)	(0.038)

EU/EU
38% <u>as likely</u>
<u>as US/US</u>

NAT
>
OTHER EU

EU/OTHER EU
=
EU/US

US/JP
>
US/EU

JP/JP
~
US/US

Main Results

$$\alpha_{ij}\,[1+\phi_{ij} * D_{2000}]$$

	(1)	(2)	(3)	[illegible]	(5)
Citing/cited country pairs (αi,j) [(a)]					
US citing US			1	1	1
			NA	NA	NA
EU15 citing EU15					
EU15 citing EU15 (national)			0.661***	0.647***	0.655***
			(0.045)	(0.043)	(0.044)
EU15 citing EU15 (international)			0.249***	0.243***	0.246***
			(0.019)	(0.018)	(0.019)
EU15 citing US			0.317***	0.281***	0.314***
			(0.025)	(0.013)	(0.025)
EU15 citing JP			0.215***	0.171***	0.213***
			(0.022)	(0.008)	(0.022)
US citing EU15			0.314***	0.261***	0.264***
			(0.013)	(0.020)	(0.020)
US citing JP			0.468***	0.469***	0.468***
			(0.027)	(0.027)	(0.027)
JP citing EU15			0.139***	0.169***	0.170***
			(0.007)	(0.015)	(0.015)
JP citing US			0.263***	0.264***	0.264***
			(0.014)	(0.014)	(0.014)
JP citing JP			0.813***	0.819***	0.816***
			(0.039)	(0.039)	(0.039)

Main Results

$$\alpha_{ij}\,[1+\phi_{ij} * D_{2000}]$$

Citing pattern differences since 2000 (ϕ_{ij}) *[(b)]*					
US citing US			0 NA	0 NA	0 NA
EU15 citing EU15 (national)			-0.145** (0.063)	-0.118* (0.065)	-0.133** (0.065)
EU15 citing EU15 (international)			0.233** (0.098)	0.272*** (0.101)	0.251** (0.101)
EU15 citing US			-0.147* (0.077)		-0.135* (0.078)
EU15 citing JP			-0.244*** (0.084)		-0.233*** (0.086)
US citing EU15				0.267** (0.104)	0.245** (0.104)
JP citing EU15				-0.207*** (0.079)	-0.220*** (0.079)
Decay (β_1) [(b)]	0.263*** (0.010)	0.264*** (0.009)	0.263*** (0.009)	0.263*** (0.009)	0.263*** (0.009)
Diffusion (β_2) [(b)]	0.001*** (0.0001)	0.001*** (0.0001)	0.001*** (0.0001)	0.001*** (0.0001)	0.001*** (0.0001)
N° of obs.	3,159	3,510	3,510	3,510	3,510

EU15 ↓ *Nat*, US, JP **wrt to US/US**

EU15 ↑ EU15

US ↑ EU15

JP ↓ EU15

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Robustness: EU14 vs Germany

	(1)	(2)	(3)	(4)	(5)
Citing/cited country pairs (αi,j) [(a)]					
US citing US	1	1	1	1	1
	NA	NA	NA	NA	NA
EU14 citing EU14	0.550***				
	(0.022)				
EU14 citing EU14 (national)		2.020***	2.479***	2.411***	2.449***
		(0.097)	(0.209)	(0.203)	(0.207)
EU14 citing EU14 (international)		0.344***	0.277***	0.269***	0.273***
		(0.015)	(0.029)	(0.028)	(0.028)
EU14 citing DE	0.268***	0.270***	0.224***	0.218***	0.221***
	(0.012)	(0.012)	(0.028)	(0.027)	(0.027)
EU14 citing US	0.339***	0.343***	0.467***	0.342***	0.462***
	(0.018)	(0.018)	(0.045)	(0.018)	(0.044)
EU14 citing JP	0.162***	0.163***	0.192***	0.163***	0.189***
	(0.009)	(0.009)	(0.027)	(0.009)	(0.027)
DE citing DE	0.432***	0.435***	0.441***	0.429***	0.435***
	(0.017)	(0.017)	(0.033)	(0.032)	(0.032)
DE citing EU14	0.304***	0.306***	0.250***	0.244***	0.247***
	(0.014)	(0.014)	(0.025)	(0.024)	(0.024)
DE citing US	0.224***	0.224***	0.195***	0.224***	0.193***
	(0.011)	(0.011)	(0.018)	(0.011)	(0.017)
DE citing JP	0.179***	0.180***	0.233***	0.179***	0.231***
	(0.009)	(0.009)	(0.027)	(0.009)	(0.027)

EU14 NATIONAL
241 percent as likely as US/US

EU14 relatively little from abroad

DE/DE
43 percent as likely as US/US

Robustness: EU14 vs Germany

Citing pattern differences since 2000 (ϕ_{ij}) [(b)]			
US citing US	0	0	0
	NA	NA	NA
EU14 citing EU14 (national)	-0.237***	-0.204***	-0.222***
	(0.072)	(0.075)	(0.074)
EU14 citing EU14 (international)	0.264*	0.318**	0.287**
	(0.138)	(0.145)	(0.142)
EU14 citing DE	0.224	0.276*	0.247
	(0.158)	(0.165)	(0.162)
EU14 citing US	-0.335***		-0.324***
	(0.072)		(0.074)
EU14 citing JP	-0.181		-0.166
	(0.124)		(0.126)
DE citing DE	-0.026	0.016	-0.008
	(0.078)	(0.082)	(0.081)
DE citing EU14	0.259*	0.309**	0.281**
	(0.134)	(0.139)	(0.138)
DE citing US	0.181		0.201*
	(0.119)		(0.122)
DE citing JP	-0.278***		-0.265***
	(0.090)		(0.092)
US citing EU14		0.343**	0.312**
		(0.148)	(0.146)
US citing DE		0.251*	0.221
		(0.138)	(0.136)

EU14 ↓
NAT and US

EU14 ~
DE and JP

DE and US
↑ EU14

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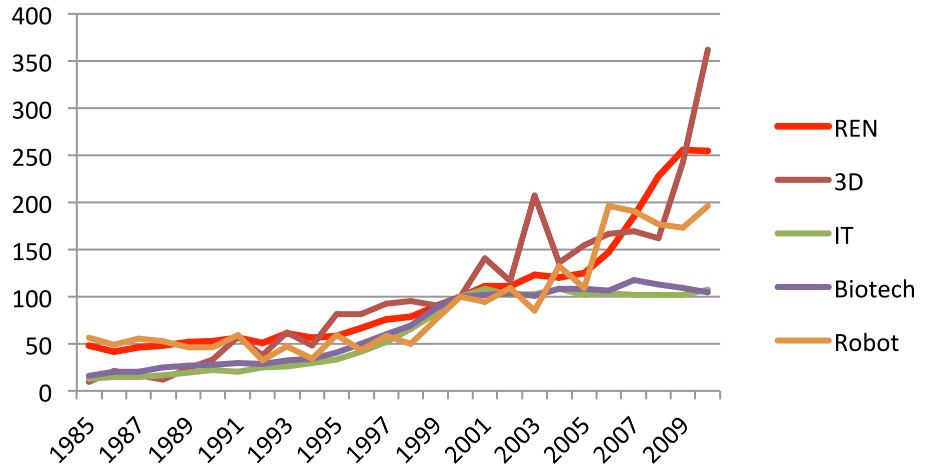
Robustness: Fossil Fuel Technologies

- Perform the analysis using **highly efficient fossil-based technologies**
- Fossil-based technologies: significantly reduce emissions per unit of energy in the short-to-medium term but do not imply a significant shift in the energy system
- Robustness meant to check if observed patterns are common to all energy technologies aimed at reducing emissions and not specific to RES
- Patterns we found in RES technologies after 2000 do not emerge here. In particular:
  - there is no evidence of any increase in cross-country/within EU15 citation intensity for fossil technologies - $\phi_{EU15,internat}$ is (negative and) not significant in all specifications.
  - there is no evidence of any increase in the likelihood that a US inventor cites a EU15 patent, which instead significantly decreases by 21 percent

Robustness: radically new techs

- Perform the analysis using **radically new technologies: 3D, IT, biotechnology, robot**
- Check if results characterize other technologies at an early stage of development and with high economic potential



- None of the patterns we found in RES technologies after 2000 emerges.

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Robustness: multi-country patents

- 8% of RES patents in our sample are “multiple-country” patents

REN TECHNOLOGIES		
	1985-1999	2000-2010
co-patenting EU15-EU15 on total EU15 patents	0.04	0.08
co-patenting EU15-US on total US patents	0.20	0.17

- Check if increasing intensity of citation across EU countries is due to increasing share of co-patenting (direct collaborations vs knowledge flows)
- Repeat the analysis for RES sample which excludes patents with multiple-country inventors
- All findings are strongly confirmed.

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Conclusions: positive message

- **EU RES inventors have increasingly built "on the shoulders of the other EU giants",** intensifying their citations to other member countries and decreasing those to domestic inventors
- Stronger integration of the EU RES knowledge
- The EU strengthened its position as source of RES knowledge for the US
- Suite of robustness checks suggest that the pattern is peculiar for RES. Likely explanation is the more stringent environmental policy of the EU

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Conclusions

EU strong commitment to RES climate policies

↑ EU RES innovation

<u>but also</u>

↔ strengthened EU15(14) linkages

and

↑ EU RES innovation relevance
for the US *(not JP)*

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Conclusions

However, EU RES innovative activity still poorly integrated compared to the US or Japan

Call for increased policy support to fully exploit the potential of increased RES innovation

Caveats to our analysis

- *Focus on innovation and knowledge flows, not on markets (China and solar panels)*
- *Evidence of policy impact is suggestive, further analysis needed*

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