What drives innovation in nuclear power technologies?
An empirical study based on patent counts.

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Innovation in nuclear power technologies

- Do we have innovation in nuclear power technologies?
  - Economic performance: design standardization, reliability, lifetime, etc.
  - Safety performance: risks (e.g., automatic scrams) and potential damages (e.g., containment walls, core catcher)

- Is it meaningful to measure nuclear innovation with patents?
  - Long tradition of patenting in the nuclear sector;
  - Innovation in nuclear essentially originates from private firms (80 %)

- Why does it matter to look at its determinants?
  - Complex industry with specific features (negative shocks in policy , safety regulation) ;
  - Good case study to analyse the impact of safety regulation in general (monitoring versus corrective actions) on innovation
  - Critics about public energy R&D allocation towards nuclear power;

Literature review

- Literature on innovation in green/energy technologies
  - Jaffe and Palmer (1997), Brunnermeirer and Cohen (2003)
    - PACE and green innovation in the US
  - Carrion-Flores and Innes (2010)
    - Environmental targets, compliance and environmental innovation
  - Nemet (2008)
    - Uncertainty about policies in favor of wind & standardization of designs
  - Dechezleprêtre & Glachant (2012)
    - Influence of foreign policies on innovation in wind technologies

Analytical framework

- **Technology push**
  - Public R&D expenditures in nuclear power (excluding Fast Neutron Reactors)
- **Demand pull**
  - NPPs construction start in innovating country and abroad
- **Nuclear power industry specificities**
  - Delay between patent application and actual use of the technology (c.f., Lor, 2008);
  - The role of nuclear safety regulation (monitoring versus corrective action);
  - Negative policy shocks (NPPs construction cancellation) following nuclear accidents

Model and data source

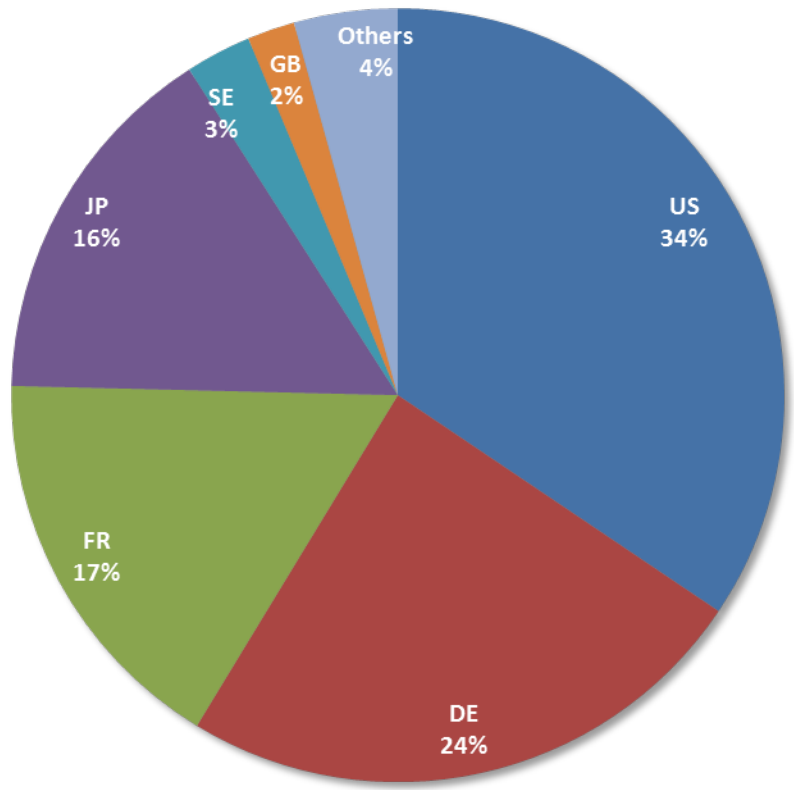
- Unbalanced Poisson panel model with country fixed effects and time fixed effects
  - Period: 1974 à 2008
  - 12 OECD countries
  - 367 observations (unbalanced panel)

- **Patstat:** International patent database developed by the EPO
  - New classification specific to nuclear fission (Y02E30*)

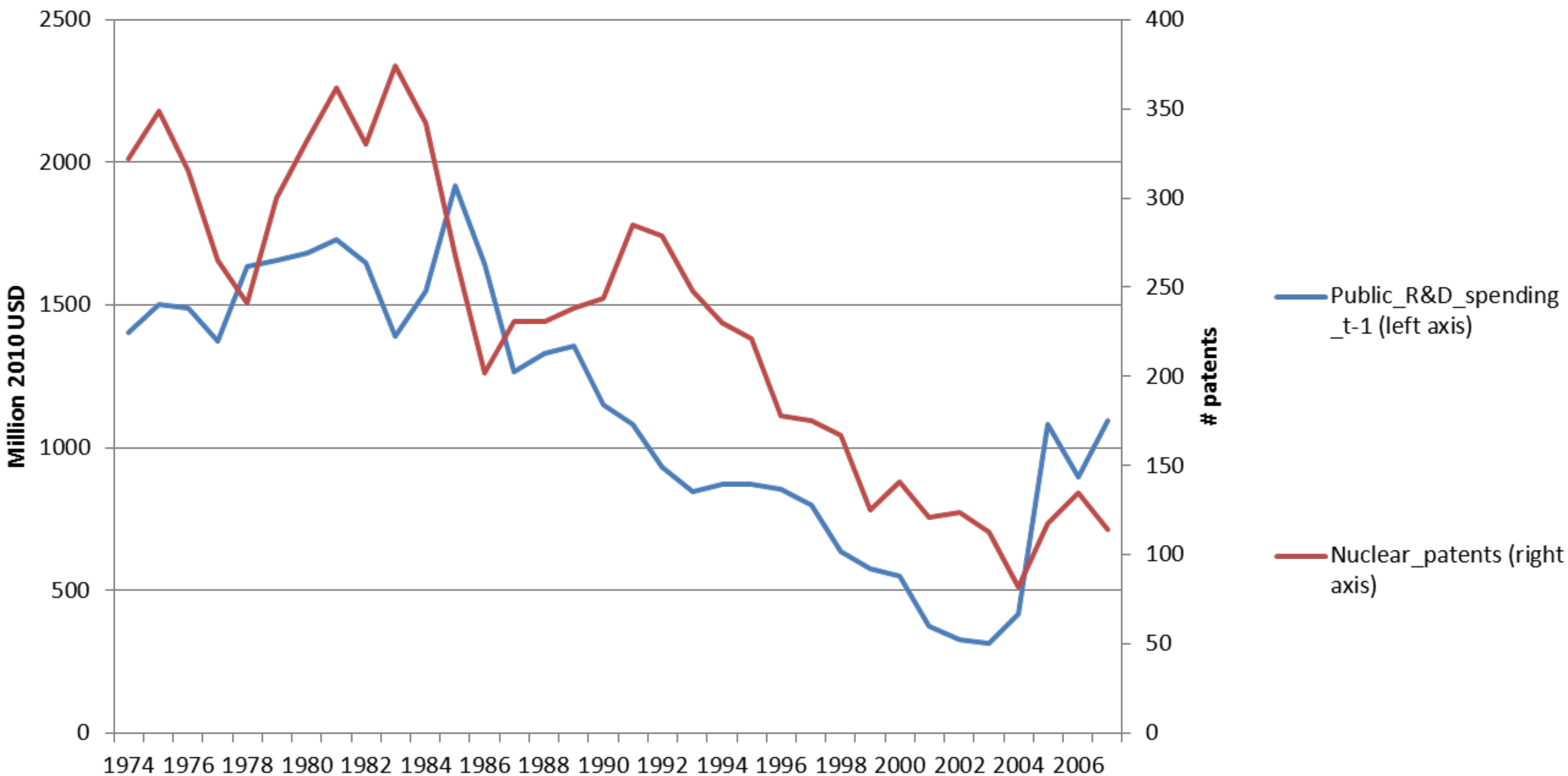
- **PRIS** : IAEA database about NPPs in the world since 1970
  - NPPs characteristics (size, construction date, vendor, etc.);
  - NPPs performance including outages and their causes

- **IEA** database about public R&D expenditures in the energy sector
  - Disaggregated data such that it is possible to only look at NPPs specific expenditures (e.g., exclude back-end of the nuclear fuel cycle)

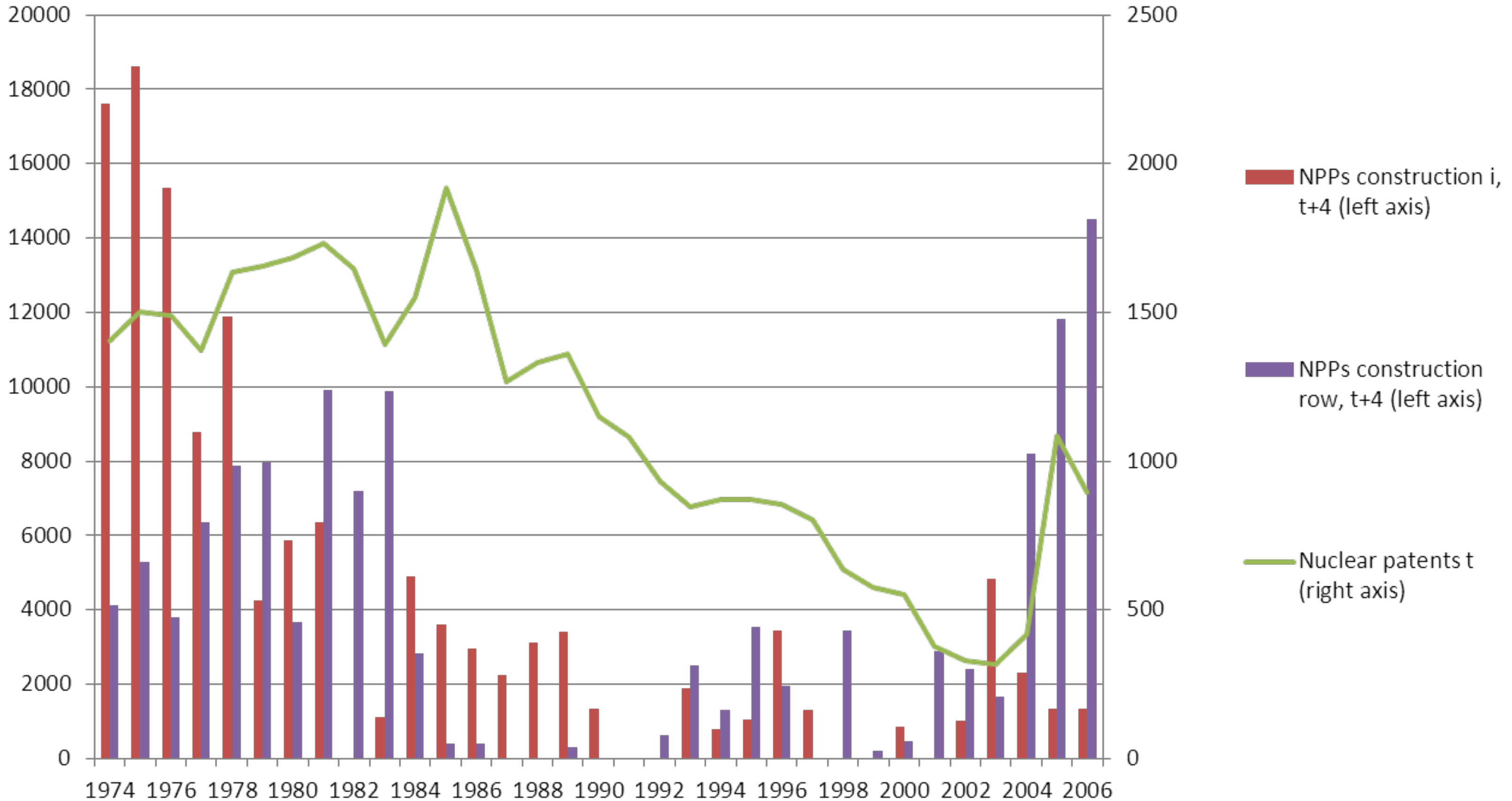
Nuclear power priority patents allocation among countries between 1974 and 2008 (total = 8145)



Public R&D expenditures and patent application in nuclear power technologies



NPPs construction start and patent application



Empirical strategy

- Dependent variables
  - Model 1: ∑ Priorities $_{i,\, t}$
  - Model 2: ∑ citation weighted priorities $_{i,\, t}$

- Independent variables
  - **Monitoring**: Outages due to inspections $_{i,\, t}$ (# outages $_{i,\, t}$ / # NPPs $_{i,\, t}$)
  - **Corrective actions:** Outages due to regulatory decisions $_{i,\, t}$ (# outages $_{i,\, t}$ / # NPPs $_{i,\, t}$)
  - **Negative policy shocks**: NPPs cancelled $_{i,\, t}$ (in MW)
  - **Technology push:** Public R&D spending $_{i,\, t-1}$
  - NPPs construction at **home** $_{i\,,\, t+4}$ (in MW)
  - NPPs construction **abroad** $_{-i,\, t+4}$ (in MW)
  - Discounted knowledge stock $_{i,\, t}$

Econometric results

Model	(1)	(2)
Dependent variable	*$Patent_{i,t}$*	*$Weighted\_patent_{i,t}$*
$log\_monitoring_{i,t}$	**0.463** **	**0.253** *
	(0.182)	(0.153)
$log\_corrective\_actions_{i,t}$	**-0.612** ***	**-0.341**
	(0.149)	(0.240)
$log\_cancelled_{i,t}$	**-0.056** ***	**-0.042** *
	(0.019)	(0.023)
$log\_RD_{i,t}$	0.072 **	0.125 ***
	(0,030)	(0,025)
$log\_Cap_{i,t+4}$	0.059 ***	0.078 ***
	(0.012)	(0.014)
$log\_Cap_{row,t+4}$	0.122 ***	0.143 ***
	(0.023)	(0.004)
$log\_know_{i,t}$	0.423 **	-
	(0.207)	
$log\_weighted\_know_{i,t}$	-	0.274 **
		(0.134)
Observation	309	309
Control for GDP	Yes	Yes
Country FE + Time FE	Yes	Yes

Note : ***, ** and * indicate that results are significant at respectively 1%, 5% and 10% confidence level. Robust-clustered standard errors are reported in bracket.

Results (1 / 2)

- **Monitoring** (inspections) has a positive impact on innovation
  - First half of the Porter hypothesis

- **Corrective actions** (regulatory outages) have a negative impact on innovation
  - These events may occur because a country nuclear industry is in a difficult economic situation leading both to safety problems and less capacity to innovate
  - Increase in nuclear safety regulation margin ?
  - Eviction effect? Human and financial resources go towards solving the safety problem so that NPPs can start again;

- **Negative policy shocks** (NPPs cancellation) have a negative impact on innovation
  - Signal about future NPPs construction;
  - Theses NPPs cancelations took place in the US after TMI and in Germany after Chernobyl (in Ukraine). Hence, they can be viewed as the indirect effects of these two major accidents

Results (2 / 2)

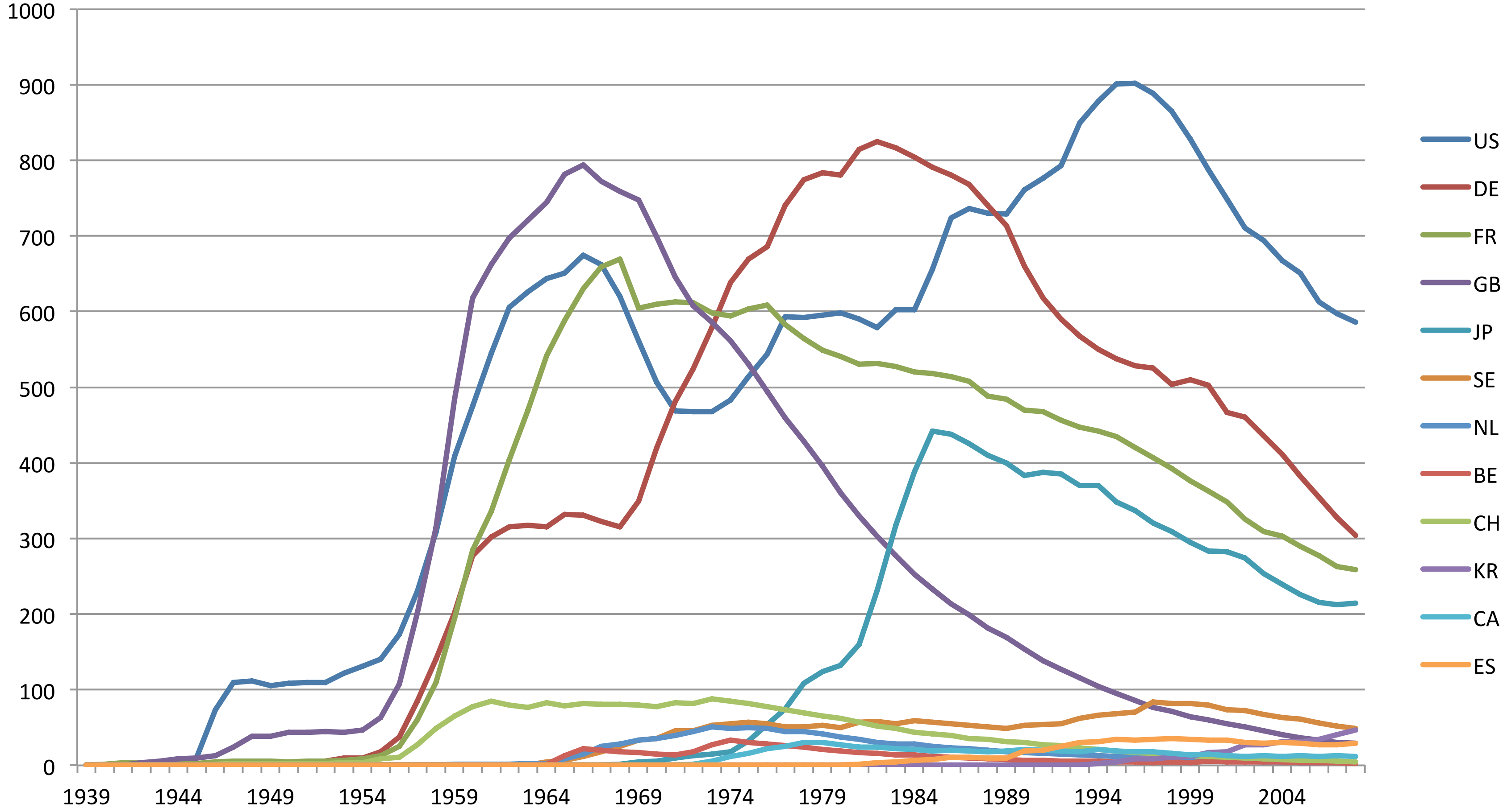
- **Public R&D expenditures** play a significant role in nuclear innovation
  - Stronger impact on patents weighted by citation
- NPPs new-build is an international market: both **domestic and foreign demand** matter for innovators
  - Difference in coefficients can be explained by the fact that innovators may have larger incentives to seek IPR for projects abroad;
  - 4 years lag is consistent with nuclear industry technology development cycle
- Knowledge stock illustrates the building on giants' shoulders effect

Conclusions

- Safety regulation and policy shocks following nuclear accidents impact nuclear innovation
  - What will be the impact of Fukushima on innovation towards nuclear power technologies?
- In turn, what is the impact of innovation on NPPs economic and safety performance?
  - *Work in progress*

Thank you

National innovation in nuclear power technologies (1939 – 2008)



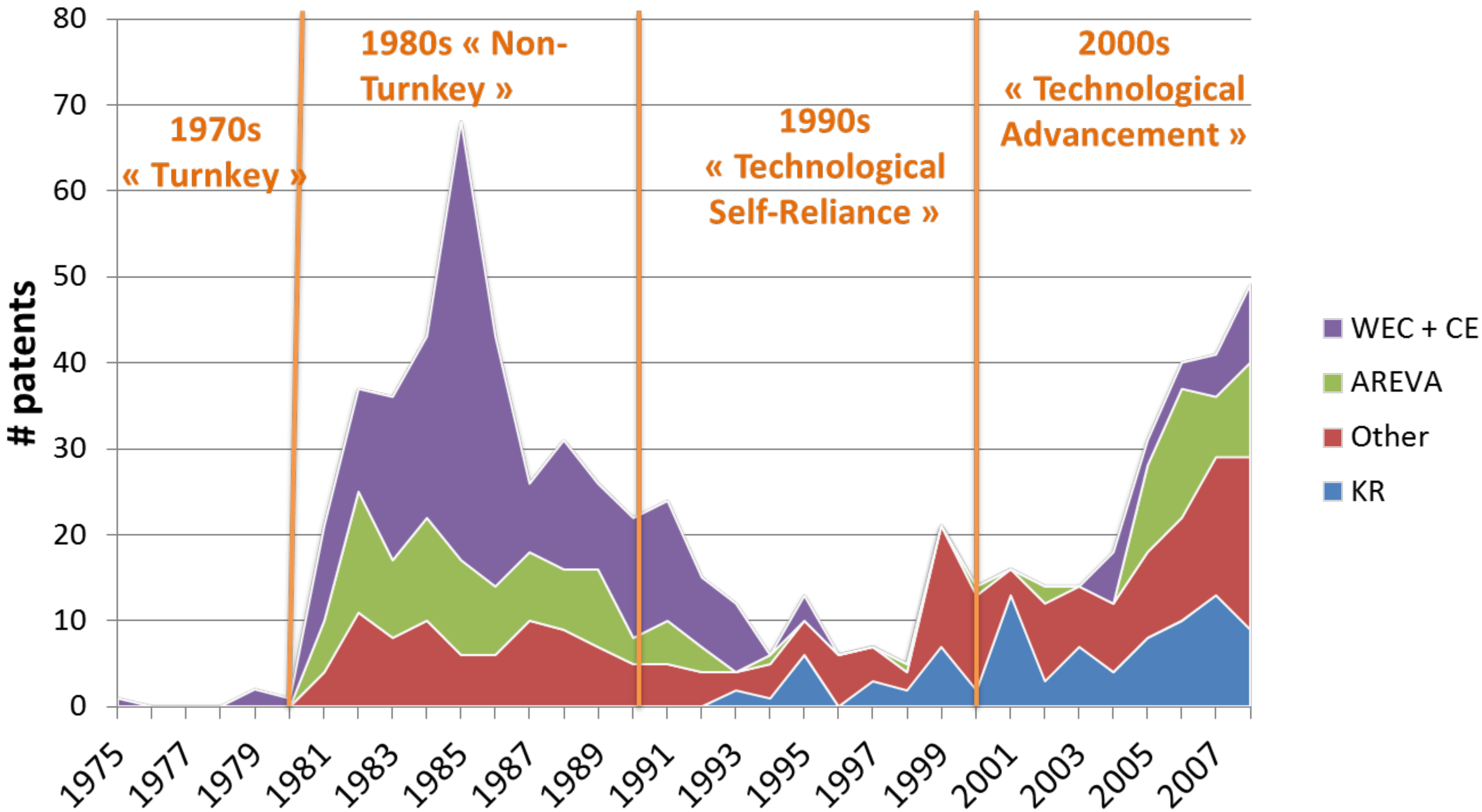
Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
$Patent_{i,t}$	21.1	32.0	0	151
$Weighted\_patent_{i,t}$	34.2	69.9	0	410
$Know_{i,t}$	219.7	261.9	0	902.4
$Weighted\_Know_{i,t}$	321.2	543.7	0	2525.6
$RD_{i,t}$	105.1	147.8	0	681.6
$Cap_{i,t+4}$	381.1	1462.9	0	19256
$Cap_{row,t+4}$	8354.7	8207.5	0	39426
$Cancelled_{i,t}$	139.5	999.4	0	13189
$Regulatory\_outage_{i,t}$	0.033	0.079	0	0.66
$Inspection_{i,t}$	1.06	0.448	0	4
$GDP_{i,t}$	1613.6	2329.1	130.7	11670.8

Robustness tests

- Robustness tests for
  - NPPs construction abroad sample restriction (excluding Russian built NPPs);
  - Knowledge depreciation rate (5 %, 40 %);
  - Drop small countries

International nuclear technology diffusion: the case of Korea



Patent application as a measure of innovation

- Advantages
  - Ex post indicator of innovation effort;
  - Proxy of patent quality using forward citations.

- Caveats
  - Secrecy is the direct alternative to patent protection, secrecy has been important in nuclear at the beginning of nuclear programs du to military connections;
    - Nuclear : patent + secrecy ..
  - Patent laws differ among countries and over time;
  - Strategic behaviors of companies.