Who does innovation in the Electricity Supply Industry? Lessons from the UK

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Motivation

Observation

- Energy transition requires a *sustained* stream of innovation
- Yet,
  - innovation in the ESI (generation) has slowed down in recent years
  - the nature of innovative actors has changed

Context: two major *shocks* in the ESI

- liberalisation: Electricity Act (UK, 1989), Energy Policy Act (US, 1992)
- decarbonisation: e.g. in the UK – 2001/77/EC, with effect 27/10/2003
  - Electricity produced from renewable sources rose from 3.5% in 2000 to 24.6% in 2016
  - CO2-intensity of the generation portfolio from 479g CO2/kWh to 349g CO2/kWh

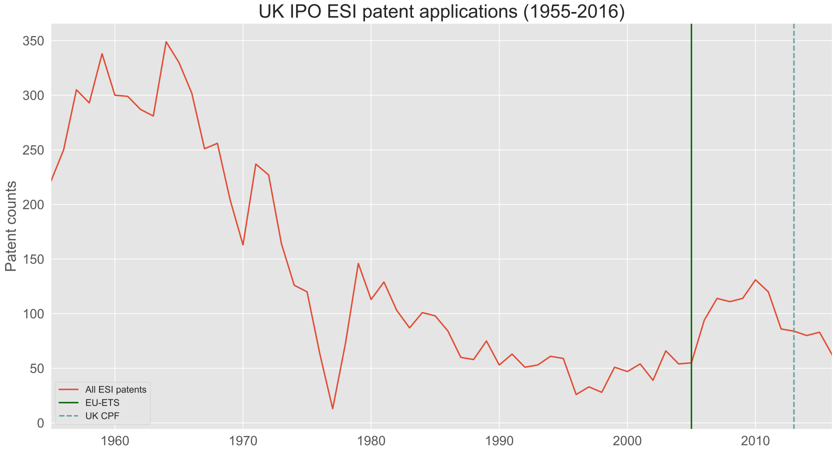
Focus

- "Actors" performing that innovation in Electricity Supply Technologies
  - Original equipment manufacturers – upstream
  - Generation, Transmission, Distribution – downstream
- in the UK, 1955-2016
- heterogeneity of UK OEMs

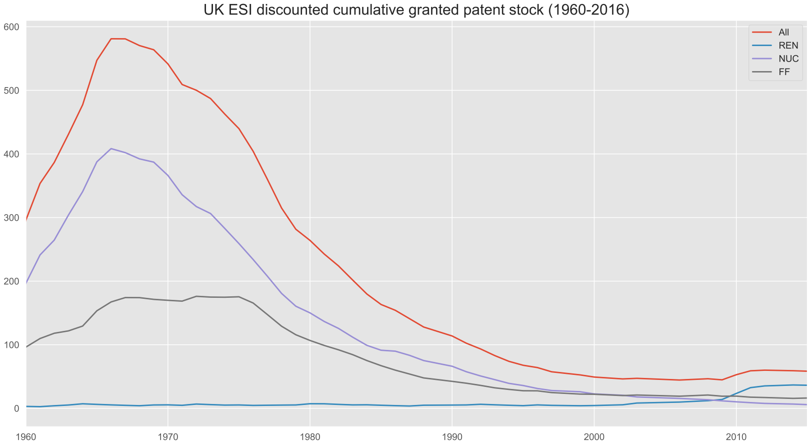
Questions

- Has the origin of innovation (patent filings) changed over time? If yes, how so?
- What is the nature of the heterogeneity of (new) innovative actors? How does it affect their innovation activity?

Patent flow


UK IPO ESI patent applications (1955-2016)
Patent counts
0
50
100
150
200
250
300
350
1960
1970
1980
1990
2000
2010
All ESI patents
EU-ETS
UK CPF

Patent stock



Dataset

Dataset

Patents

Patent counts, knowledge stock – European Patent Office (EPO) Worldwide Statistical Patents Database (2018)

Business Structure Data

Firm size, ownership, date of incorporation – Bureau van Dijk FAME (2018)

Other

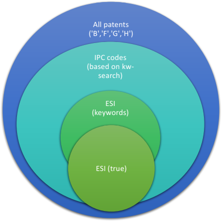
Government R&D, carbon price,. . . – IEA (2019), own data

Patent search

- Patents with GB priority in IPC classes 'B','F','G', or 'H' for the years 1955-2017: 354760 patents
- (Machine learning) keywords-based & actor-based (Jamasb and Pollitt (2011),Ofgem register)

Machine learning-keywords search

1. Keywords search, based on Jamasb and Pollitt (2011)
2. IPC search, based on search results of step 1 – 59757 patents
3. Apply random-forest classifier to patent set identified in step 2



ML procedure – text-based classification

1. Select training sample
   - ESI vs non-ESI
   - Random selection of 240 patents (126 ESI; 114 non-ESI). Chosen from keywords-,ipc- and all patents ensembles
   - Manual assignment to either ESI or non-ESI class
2. Prepare text data for classification
   - 2.1 Structure the text data (application title and abstract).
   - 2.2 Derive normalised word and n-gram frequencies (across all patent applications)
   - 2.3 Select features for classification.
3. Train random forest classifier on training sample.

Table: Classification report

	Precision	Recall	f1 score	No of patents in test set (support)
Non ESI	0.77	1	0.87	23
ESI	1	0.81	0.9	37
Avg./total	0.91	0.88	0.88	60

4. Apply trained classifier to “full sample” (i.e. IPC ensemble).

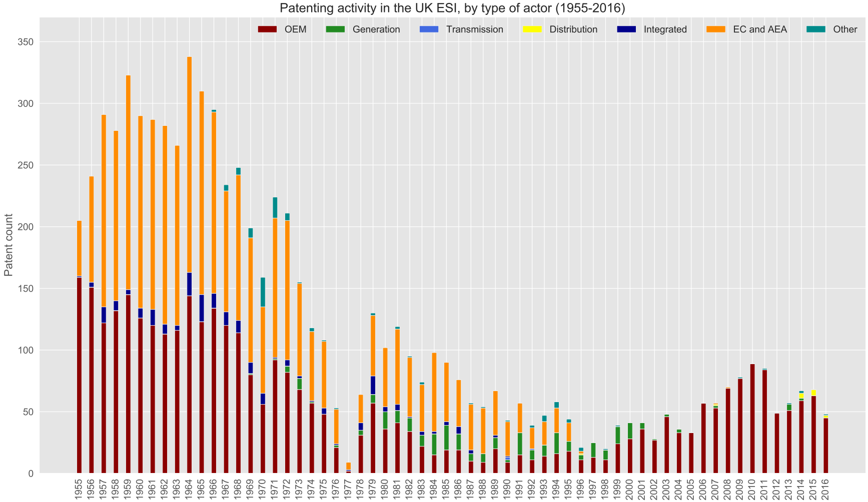
Table: Patent searches summary (1955-2016)

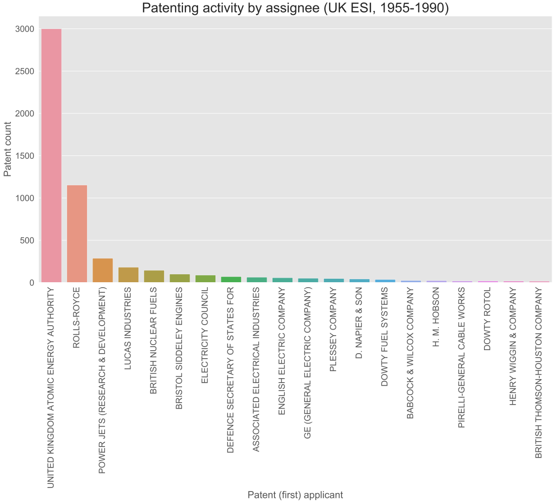
	Actor type	ESI stage	KW	ML	Actors	ML ∩ Actors	Total
N. Patents	Companies	OEM	2364	3677	-	0	3677
		Generation	2	3	279	3	279
		Transmission	-	0	3	0	3
		Distribution	-	0	13	0	13
	Integrated utilities		10	11	222	11	222
	Universities		19	26	-	-	26
	Individuals		496	696	-	-	696
	EC & AEA		20	87	3189	87	3189
	Other		160	258	24	0	282
	All actors		3072	4759	3731	101	8389
N. applicants/ assignees	Companies	OEM	456	658	-	-	658
		Generation	2	2	10	2	13
		Transmission	0	0	2	0	2
		Distribution	0	0	4	1	4
	Integrated utilities		1	1	3	0	4
	Universities		14	18	-	-	18
	Individuals		428	571	-	-	571
	EC & AEA		1	1	2	1	2
	Other		88	128	3	0	131
	All actors		990	1379	24	3	1400

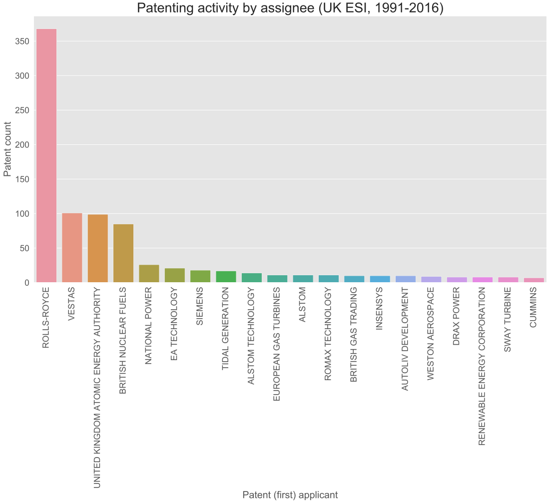
The number of applicants in the table above is based on an author-created unique entity identifier. It differs from the number of distinct 'psn_id''s associated with the identified patents since, at times, several of them refer to a single legal entity. Some patents that have been manually removed (e.g. motor vehicle internal combustion engine)

Exploratory data analysis

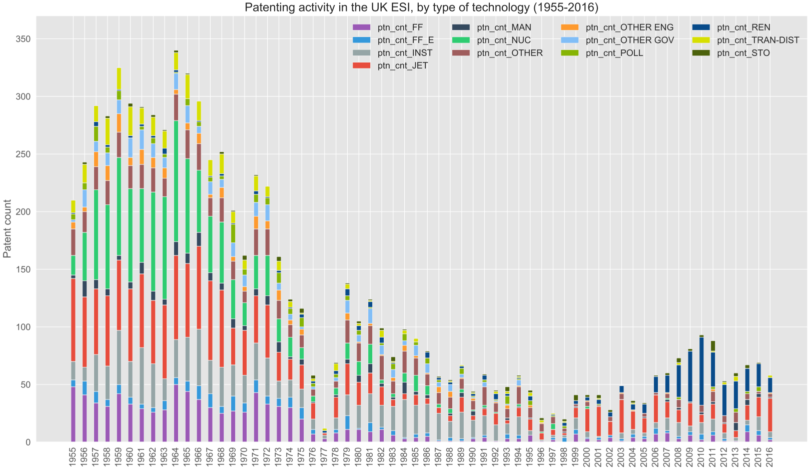
Whose innovation – upstream, downstream and other actors




Patenting activity by assignee (UK ESI, 1955-1990)
Patent count
3000
2500
2000
1500
1000
500
0
UNITED KINGDOM ATOMIC ENERGY AUTHORITY
ROLLS-ROYCE
POWER JETS (RESEARCH & DEVELOPMENT)
LUCAS INDUSTRIES
BRITISH NUCLEAR FUELS
BRISTOL SIDDELEY ENGINES
ELECTRICITY COUNCIL
DEFENCE SECRETARY OF STATES FOR
ASSOCIATED ELECTRICAL INDUSTRIES
ENGLISH ELECTRIC COMPANY
GE (GENERAL ELECTRIC COMPANY)
PLESSEY COMPANY
D. NAPIER & SON
DOWTY FUEL SYSTEMS
BABCOCK & WILCOX COMPANY
H. M. HOBSON
PIRELLI-GENERAL CABLE WORKS
DOWTY ROTOL
HENRY WIGGIN & COMPANY
BRITISH THOMSON-HOUSTON COMPANY
Patent (first) applicant


Patenting activity by assignee (UK ESI, 1991-2016)
Patent count
350
300
250
200
150
100
50
0
ROLLS-ROYCE
VESTAS
UNITED KINGDOM ATOMIC ENERGY AUTHORITY
BRITISH NUCLEAR FUELS
NATIONAL POWER
EA TECHNOLOGY
SIEMENS
TIDAL GENERATION
ALSTOM TECHNOLOGY
EUROPEAN GAS TURBINES
ALSTOM
ROMAX TECHNOLOGY
BRITISH GAS TRADING
INSENSYS
AUTOLIV DEVELOPMENT
WESTON AEROSPACE
DRAX POWER
RENEWABLE ENERGY CORPORATION
SWAY TURBINE
CUMMINS
Patent (first) applicant

What innovation – technological portfolio



Legal entity matching

Matching with firm level data (I)

Hurdles

- Variations in spelling of applicant names
- Variations in naming conventions
- Name change of legal entity
- Ownership assignment (subsidiary versus GUO)
- No common identifier nor standard procedure

A brief history

1. Bound et al. (1984): on US Patent (USPTO) and firm (Compustat) data
2. Magerman et al. (2006): applicant name standardisation (no legal links) $\Rightarrow$ but. . .
3. Bureau van Dijk – ORBIS IP: applicant–legal entity matching

Matching with firm level data (II)

i. Matching based on (secondary) identifying features such as company names and postcodes +residual manual check.

ii. Manually assign an identifying number to the applicants that is also present in the business structure/accounting database (e.g. company registration number – CRN).

Manual match

Associate each applicant with their Company Registration Number (CRN)

1. Entity name and postcode (ECOOM-EUROSTAT-EPO PATSTAT, 2017)
2. Update EEE-PPAT table with Companies House information
3. Aggregate at the legal entity-level (not GUO) with CRN and most recent name*
4. Merge patent data with firm structure data (employees, turnover,. . .) based on CRN as merging key

* Note the difference between a merger and acquisition here. If full absorption, then the CRN assigned is that of the absorbing entity. If it continues to exist as a separate legal entity, then assigned a separate CRN.

Matching summary

- 677 ‘company’ applicants: 428 UK, 180 foreign, 69 unidentified
- 3677 ‘company’ patents: 2925 patents by UK applicants, 604 patents by foreign applicants, 148 patents by unidentified applicants

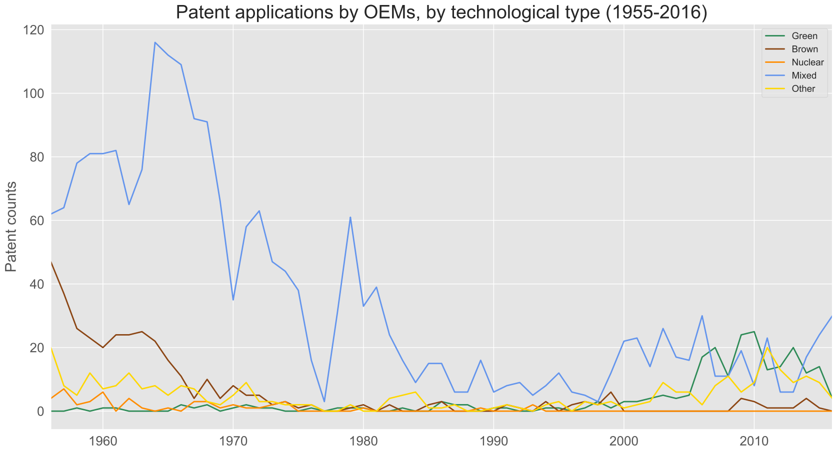
Table: UK patents/applicants matching summary

	ESI Category	Matched patents	Matched applicants
Count	OEM	2925	411
	Generation	279	13
	Transmission	3	2^{+}
	Distribution	12	3
	All actors	3241	428
Share*	OEM	0.8	0.62
	Generation	1	1
	Transmission	1	1
	Distribution	0.92	0.75
	All actors	0.88	0.63

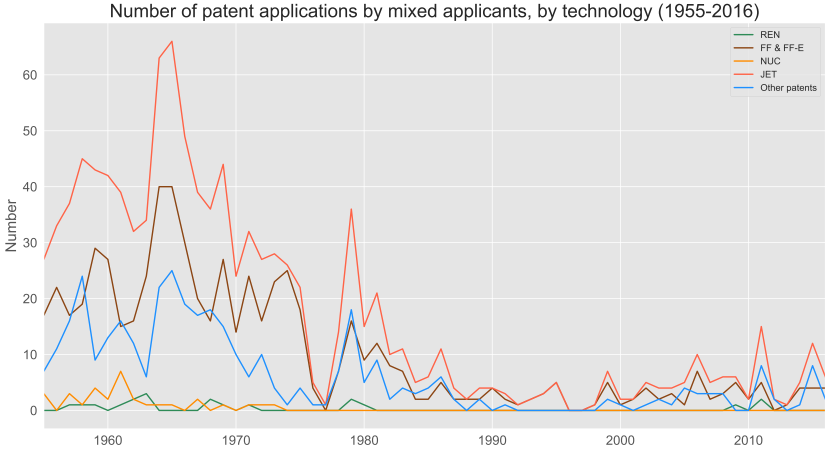
* Share of total number of ‘COMPANY’ applications or applicants.
$^{+}$ Includes NI interconnector

Firm heterogeneity (UK OEMs)

Innovation and technological portfolio



- Number of firms (share of total): 36% green, 12% brown, 4% nuclear, 4% mixed – 46% other


Number of patent applications by mixed applicants, by technology (1955-2016)
REN
FF & FF-E
NUC
JET
Other patents
Number
0
10
20
30
40
50
60
1960
1970
1980
1990
2000
2010

Technological entry (and exit)

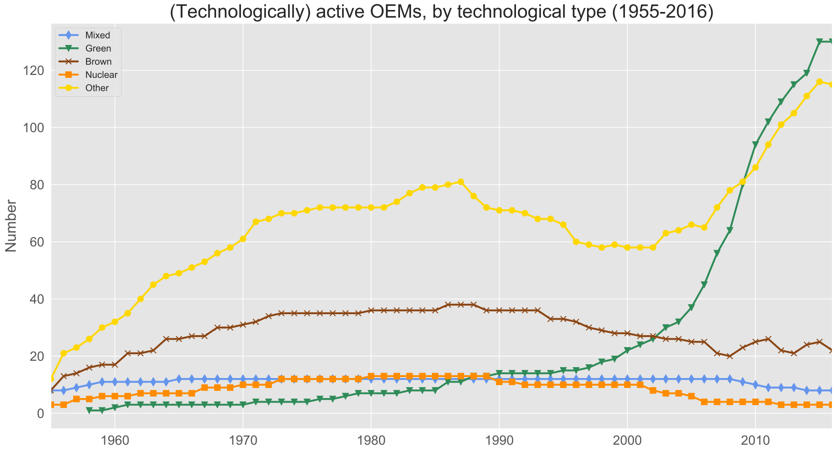
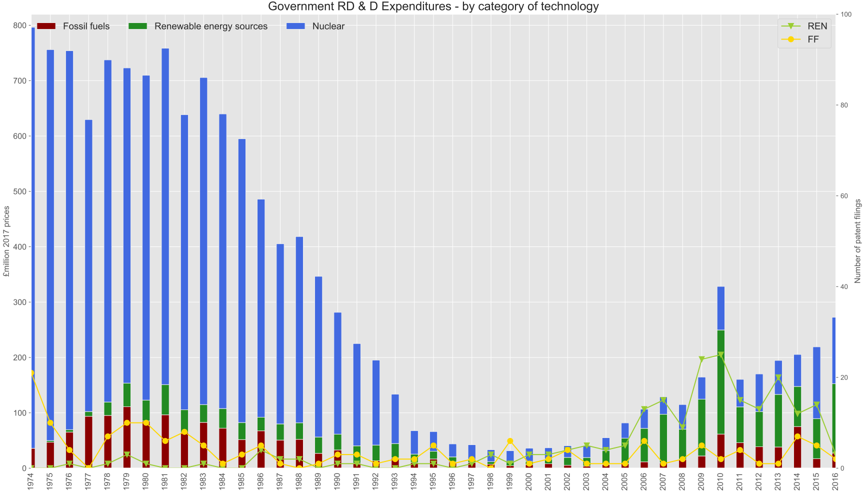


Table: Firm patenting activity: 1955-2016, firm-year observations

Variable	Firm type	Mean	Median
REN patents	Green	0.023	0
	Brown	-	-
	Nuclear	-	-
	Mixed	0.025	0
	Other	-	-
FF patents	Green	-	-
	Brown	0.04	0
	Nuclear	-	-
	Mixed	0.67	0
	Other	-	-
Year of first REN innovation	Green	2005	2009
	Brown	-	-
	Nuclear	-	-
	Mixed	1972	1961
	Other	-	-
Year of first FF innovation	Green	-	-
	Brown	1977	1968
	Nuclear	-	-
	Mixed	1963	1956
	Other	-	-

External drivers

R&D in the ESI – public



Conclusion

Observations

1. Shift of innovation activity to upstream OEMs (in relative terms) and decrease in innovation in renewable generation technologies
2. "Lateral" innovation constituded much of innovation activity in Fossil Fuel electricity generation technologies
3. Innovation in renewable technologies comes from firm entry rather than reallocation of R&D resources within firms

Policy implications

1. Renewed support for renewable generation technologies R&D
2. Keep barriers to (technological) entry low
3. Policies to sustain innovation in renewable generation technologies should support new (& small) firms

Acemoglu, D. (2002). Directed Technical Change. *The Review of Economic Studies*, 69(4):781–809.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., and Howitt, P. (2005). Competition and Innovation : An Inverted-U Relationship. *The Quarterly Journal of Economics*, 120(2):701–728.

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., and Van Reenen, J. (2013). Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry. *Ssrn*, 124(1).

Arrow, K. J. (1962). Economic Welfare and the Allocation of Resources for Invention. In Nelson, R., editor, *The Rate and Direction of Inventive Activity: Economic and Social Factors*, volume 56, pages 191–209. Princeton University Press, Princeton, New Jersey.

Blundell, R., Griffith, R., and Van Reenen, J. (1995). Dynamic Count Data Models of Technological Innovation. *The Economic Journal*, 105(429):333–344.

Bound, J., Cummins, C., Griliches, Z., Hall, B. H., and Jaffe, A. B. (1984). *Who Does R & D and Who Patents ?*

Chakraborty, P. and Chatterjee, C. (2017). Does environmental regulation indirectly induce upstream innovation? New evidence from India. *Research Policy*, 46(5):939–955.

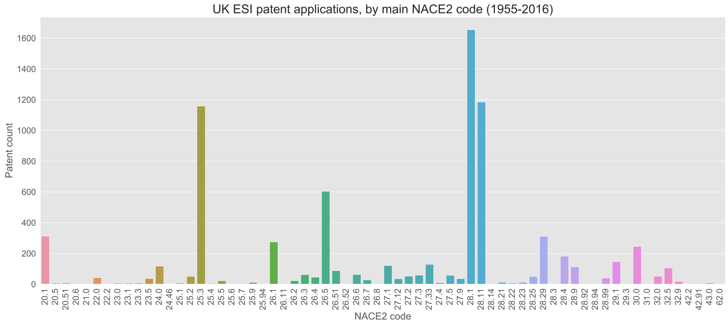
Gilbert, B. R. J. and Newbery, D. M. G. (1982). American Economic Association Preemptive Patenting and the Persistence of Monopoly. *American Economic Review*, 72(3):514–526.

Jaffe, A., Newell, R., and Stavins, R. (2002). Environmental policy and technological change. *Environmental and Resource Economics*, 22(May):41–69.

Jaffe, A. B. and Palmer, K. (1997). Environmental Regulation and Innovation : A

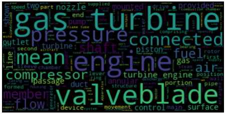
"The Industry"

- International industry classification: NAICS, NACE, SIC,...
  - industry of origin rather than destination (use)
  - multiple categories

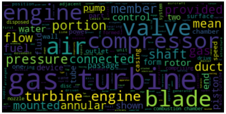


- *Ad hoc* definition
  - Technology-based (IPC codes, keywords) – Noailly and Smeets (2015)
  - Actor-based (e.g. regulated entities) – Jamasb and Pollitt (2011)

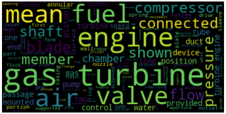
KW vs ML vs Actor



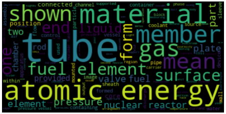
(a) ML&KW



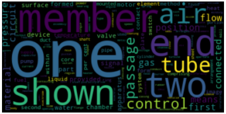
(b) KW



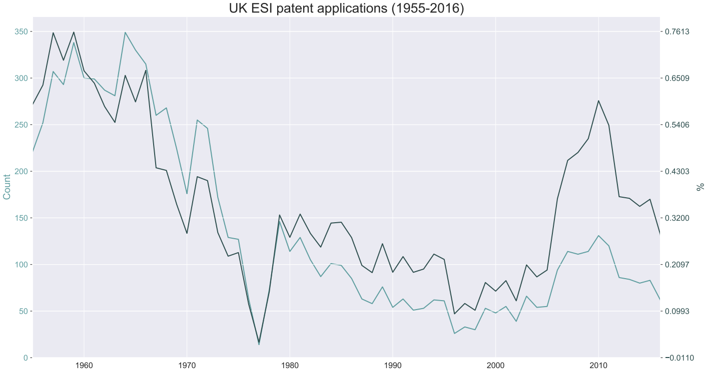
(c) ML



(d) Actors



(e) Non ESI


UK ESI patent applications (1955-2016)
Count
%
0
50
100
150
200
250
300
350
1960
1970
1980
1990
2000
2010
−0.0110
0.0993
0.2097
0.3200
0.4303
0.5406
0.6509
0.7613