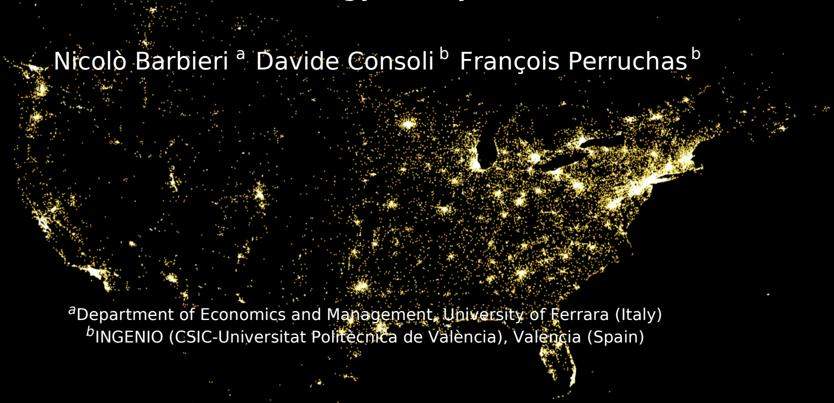
Specialization, diversification and environmental technology life-cycle

Nicolò Barbieri [a] Davide Consoli [b] François Perruchas [b]

[a]Department of Economics and Management, University of Ferrara (Italy)
[b]INGENIO (CSIC-Universitat Politècnica de València), València (Spain)



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Literature on green technological developments:

- **Insights:**
  - Recent insights emphasise that Green Technologies (GT) require different competences that are far form traditional knowledge bases of industries (De Marchi, 2012; Ghisetti et al. 2015).
  - Recent empirical findings suggest that GT are more complex, radical, pervasive and impactful than non-GT (Barbieri et al. 2018)
- **Gaps:**
  - Some literature treats Green Technology (GT) as if it were a *homogeneous* body of techniques
  - Others focus on *specific GTs* but lack a global view of their relative positioning in the knowledge space

Main questions:

- Which **knowledge structures** are associated with GT growth?
  - ✗ Related versus Unrelated Variety
- Does **GT maturity** imply a differential role of the knowledge structure?
  - ✗ Identification of life-cycle stage: geographical diffusion & intensity of patenting

Related literature

Innovation: knowledge accumulation and recombination (Aghion & Howitt, 1992; Weitzman, 1998; Basalla, 1988; Arthur, 2007)

Location matters:

- Marshall (1920): repeated interaction and proximity of goals and of competences
- Jacobs (1969): diversity of competences

Synthesis:

- Within-industry diversity (Related Variety)
- Between-industry diversity (Unrelated Variety)

(Frenken et al, 2007; Boschma et al., 2009; Boschma and Frenken, 2011)

Related literature

Complementarity:

RV & UV distinct but connected dimensions in the multi-stage innovation gradient

- RV: innovations that develop incrementally out of established cognitive structures across connected domains
- UV: more uncertain and initially costly but a catalyst for breakthroughs that span, by necessity or by design, new functionalities

(Castaldi et al, 2015)

Related literature

Life-Cyle:

Technologies co-evolve with the know-how that is needed to implement, use, adapt them (Vona & Consoli, 2014)

- *Early*: exploration, experimentation, competition between different designs, highly localised
- *Development*: standardisation of design, shake out of inferior variants, some diffusion
- *Diffusion*: stabilisation of design, wider geographical diffusion
- *Maturity*: dominant design, high standardisation, widest geographical diffusion

Our conjecture

Complementarity between RV and UV is a dynamic process along the life cycle

- Early phases of technology development call upon more dispersed, unrelated knowledge inputs
- As standardisation increases, established connections across related bits of know-how are better suited to accommodate incremental adaptations of an emerging design

Data

Green patents - Identification

- Collected using **Env-Tech (2016)** - Patent classification based on IPC and CPC
- Env-Tech includes a list of climate change adaptation and mitigation technologies, related to:
  - Water, energy, transportation, buildings, waste and env. goods
- 1,321,000 Green patent families identified in PATSTAT 2016 from 1971 to 2010 worldwide.

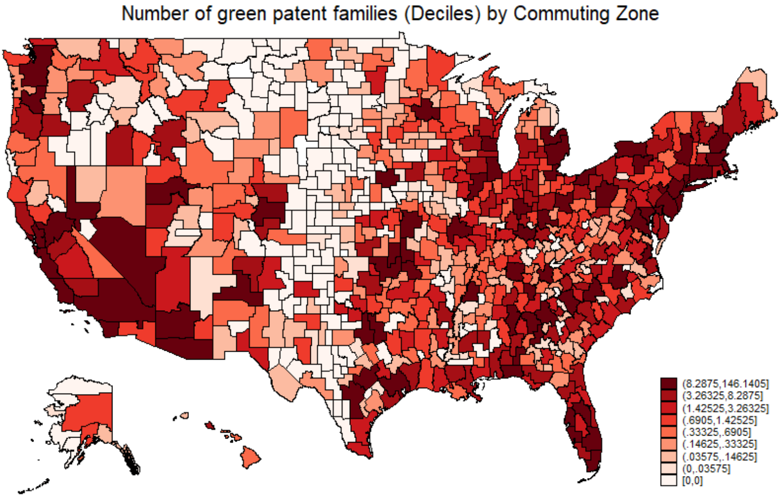
Green patents - Geolocalisation

- Geolocalisation of inventors at **city level** → 243 000 patent families in the US
- Projection on 741 commuting zones (CZ, areas identified with journey-to-work data by the US Census Bureau)

Other data

Employment data for each CZ for 1990, 2000, 2010 (calculated from County Business Patterns, US Census Bureau)

Descriptives



Variety: Example

Level I (k) - UV	Level II (l) - SRV	Level III (m) - RV
C Chemistry	**C01B Non-metallic elements**	**C01B 6/10 Monoborane; Diborane; Addition complexes thereof**
. .	**. .**	**C01B 6/11 Preparation from boron or inorganic compounds containing boron and oxygen**
. .	**. .**	**C01B 6/13 Addition complexes of monoborane or diborane, e.g. with phosphine, arsine or hydrazine**
. .	**. .**	**C01B 6/15 Metal borohydrides; Addition complexes thereof**
. .	**C01C Ammonia**	**.**
. .	**C01D Lithium, sodium, potassium, etc**	**.**
. .	**C01F Compounds of the metals beryllium, magnesium**	**.**
D Textiles	. .	. .
F Mechanical Engineering	. .	. .

Measuring Diversification with Entropy

We measure variety of the CZ knowledge base using patent families and technology classification codes (Castaldi et al., 2015):

$$UV_{it} = \sum_k s_{k,it} ln\left(\frac{1}{s_{k,it}}\right)$$

$$SRV_{it} = \sum_l s_{l,it} ln\left(\frac{1}{s_{l,it}}\right) - \sum_k s_{k,it} ln\left(\frac{1}{s_{k,it}}\right)$$

$$RV_{it} = \sum_m s_{m,it} ln\left(\frac{1}{s_{m,it}}\right) - \sum_l s_{l,it} ln\left(\frac{1}{s_{l,it}}\right)$$

where:
i: commuting zone
k, l, m: Technological categories at IPC 1-digit, 4-digit, 8-digit
$s_{k,it}$: Share of patents in category k (l, m)

Technology Life-Cycle (TLC)

Identification of TLC stages: Methodologies

- Patent indicator(s) compared to observed benchmark technologies (e.g. experts, literature,etc.) → e.g. curve fitting techniques, vector comparison, etc.
  Haupt et al. (2007); Gao et al. (2013); Chang and fan, (2016)
- Stochastic technology life cycle → Hidden Markov Model, etc.
  Lee et al. (2012;2016)
- Normalised maturity index (for Industry LC)
  Neffke et al. (2011)

Technology Life-Cycle (TLC)

Identification of TLC stages: Proposed approach

- **Ubiquity** of GT → Country specialisation / Technology diffusion
- **Patenting intensity** → Efforts in developing GT

		Ubiquity	
		Low	*High*
Patenting	*High*	**Development**	**Diffusion**
	Low	**Emergence**	**Maturity**

Technology Life-Cycle: Indicators

Ubiquity:

- We calculate the Revealed Technological Advantage (RTA) for each Env-Tech class / country / time period:

$$RTA_{cjt} = \frac{Patents_{cjt} / \sum_j Patents_{cjt}}{\sum_c Patents_{cjt} / \sum_{cj} Patents_{cjt}}$$

  c: country
  j: GT
  t: time intervals (1971-80; 1981-90; 1991-2000; 2001-10)

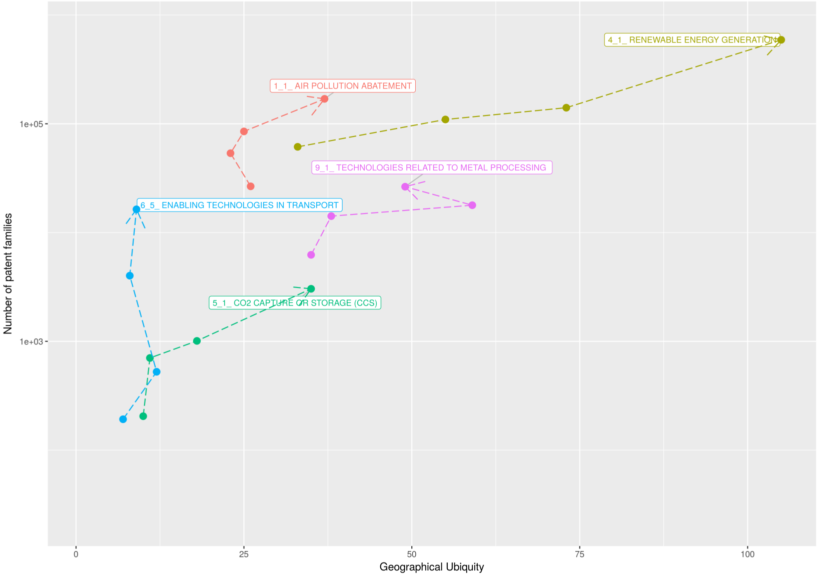
- Then, the indicator for each GT is given by the number of countries that exhibit RTA in a particular GT (Petralia et al., 2017; Balland &Rigby, 2017):

$$UBIQUITY_{j,t} = \sum_c M_{c,j}$$

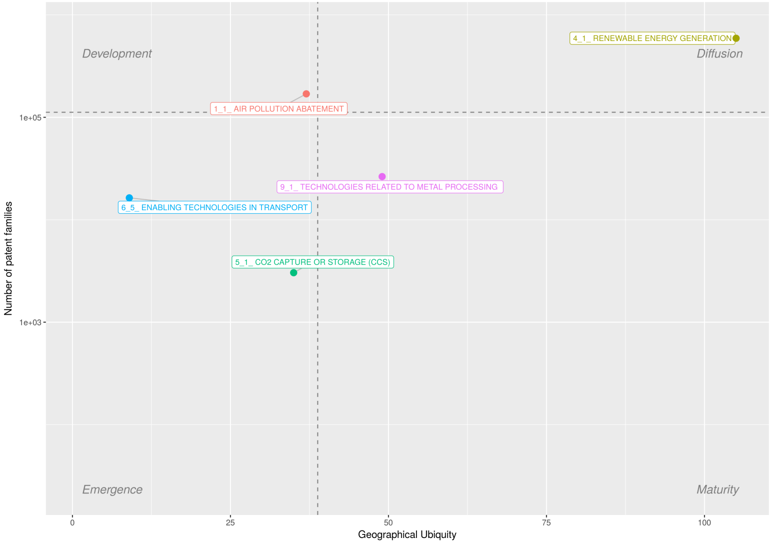
  With $M_{c,j} = 1$ if $RTA > 1$

- Therefore, higher ubiquity → higher number of countries having an RTA in that GT

Example of some green technologies - evolution



Example of some green technologies - TLC stages



Example of some green technologies during the 2001-2010 period. Dashed lines represent the mean of all GT for the period

Research design

- We assess the relationship between variety (Related, Semi-Related and Unrelated) and green patent (GP) stock:

$$\Delta GP_{cz,L,t} = \beta_1 UV_{cz,t_0} + \beta_2 SRV_{cz,t_0} + \beta_3 RV_{cz,t_0} + \theta Controls_{cz,t_0} + \eta_{cz} + \gamma_{s(cz)} + \delta_t + e_{cz,s,t}$$

- Dependent variable: Stock of green patent families in commuting zones (cz) over time intervals t (1990-2000 and 2000-2010) of:
  - Green patent families
  - Non-Green patent families
  - Green patent families over the LC stages
- Controls
  - % of people with higher education
  - Share of employment in R&D intensive sectors
  - Population density
  - Total patent intensity
- η_{cz}: CZ dummies
- $\gamma_{s(cz)}$: Year-by-state dummies
- δ_t: Year dummies

Preliminary results

Table: linear model with Driscoll and Kraay's standard errors - Patent stock 1991-2000 & 2001-2010

	GP		Non-GP
UV	0.047***	0.056**	0.074
	(0.005)	(0.011)	(0.040)
SRV	0.295**	0.302***	0.207**
	(0.039)	(0.028)	(0.035)
RV	-0.004	0.019	0.068*
	(0.018)	(0.020)	(0.019)
Controls	YES	YES	YES
CZs dummies	YES	YES	YES
Year Dummies	YES	YES	YES
Year-by-state Dummies	YES	NO	YES
Obs.	1,545	1,545	1,545

Preliminary results

Table: Model estimation along life cycle stages - Stocks (1991-2000 & 2001-2010) of green patents in each LC stage

	Emerging	**Developing**	**Diffusing**	**Mature**
UV	-0.220*	0.177	0.048	-0.367*
	(0.054)	(0.173)	(0.017)	(0.103)
SRV	0.334**	0.272	0.257**	0.023
	(0.074)	(0.097)	(0.053)	(0.050)
RV	0.073	0.324**	0.087	0.050
	(0.105)	(0.056)	(0.057)	(0.045)
Controls	YES	YES	YES	YES
CZ dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Year-by-state Dummies	YES	YES	YES	YES
Observations	954	1,104	1,410	921

Concluding remarks and further extensions

- Unrelated and Semi-related Variety have a positive and significant effect on GP, not so much on Non-GP
- Different types of knowledge, and of knowledge connections, are relevant to technology development along the life cycle
- Future avenues
  - Local drivers: skill endowment, policy, etc;
- Policy implications
  - Specialisation trap: timing of investing in GT in the life cycle
  - Opportunity to develop green technologies according to local production structure