The Evolutionary Process of Recombination

"Balancing Entropy and Relatedness"

Technology Evolution in Regional Economies
ERC StG #715631 – TechEvo

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Back on the Agenda? Industrial Policy Revisited
Cambridge, UK. July 12th, 2018.

The Origin of Innovation? Recombination

To produce means to combine materials and forces within our reach ... To produce other things ... means to combine these materials and forces differently. (Schumpeter, 1934: 65)

Most innovations derive from a novel manner of…

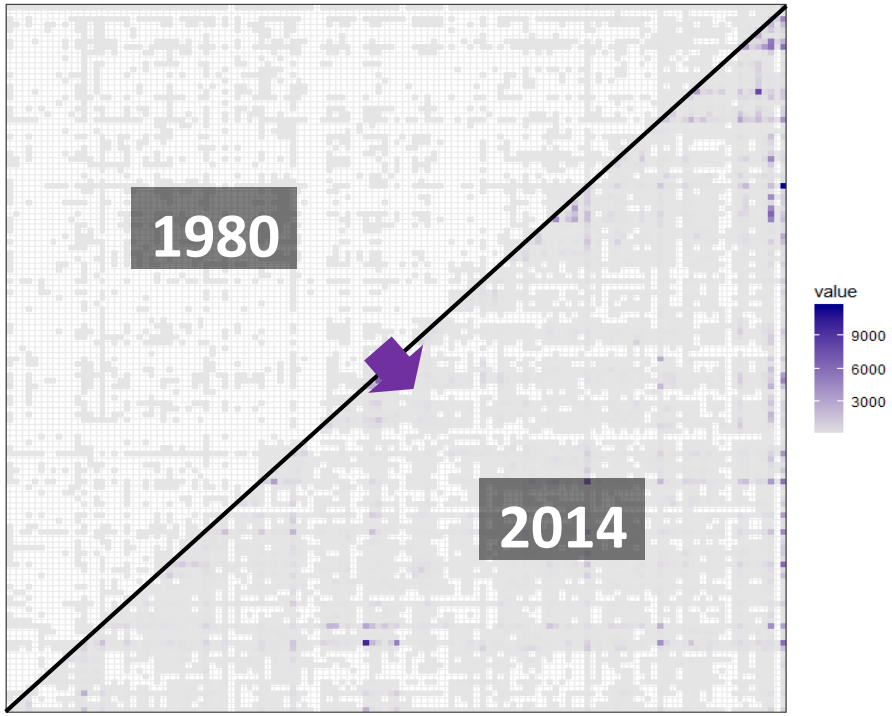
(1) combining existing technology
(Carnabuci and Bruggeman, 2009; Fleming, 2001; Nelson and Winter, 1982; Schumpeter, 1934)

→ **Exploration**

(2) improving existing technological combinations
(Henderson and Clark, 1990; Yayavaram and Ahuja, 2008)

→ **Exploitation**

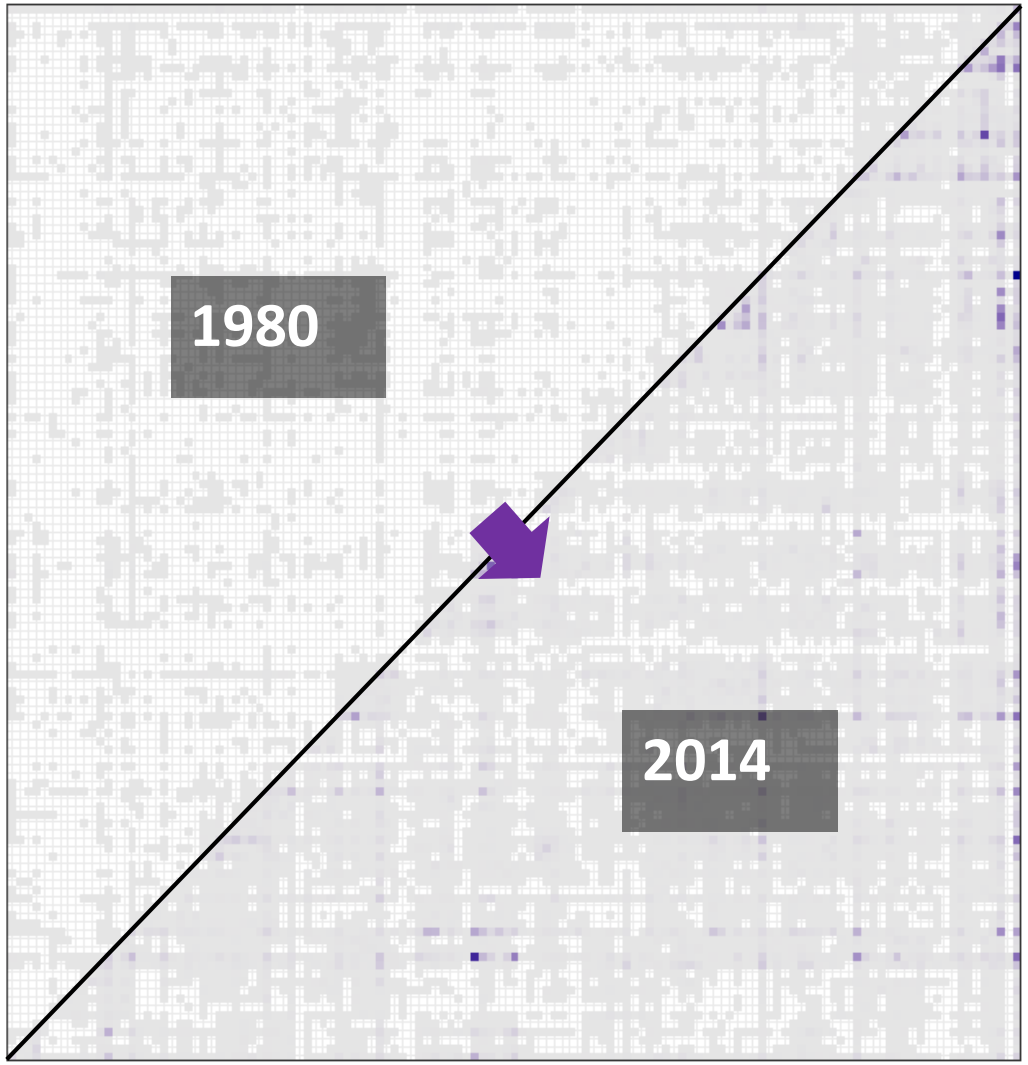
CPC Co-Occurrence Matrix



Source: PATSTAT, authors' own calculation

The Origin of Innovation? Recombination

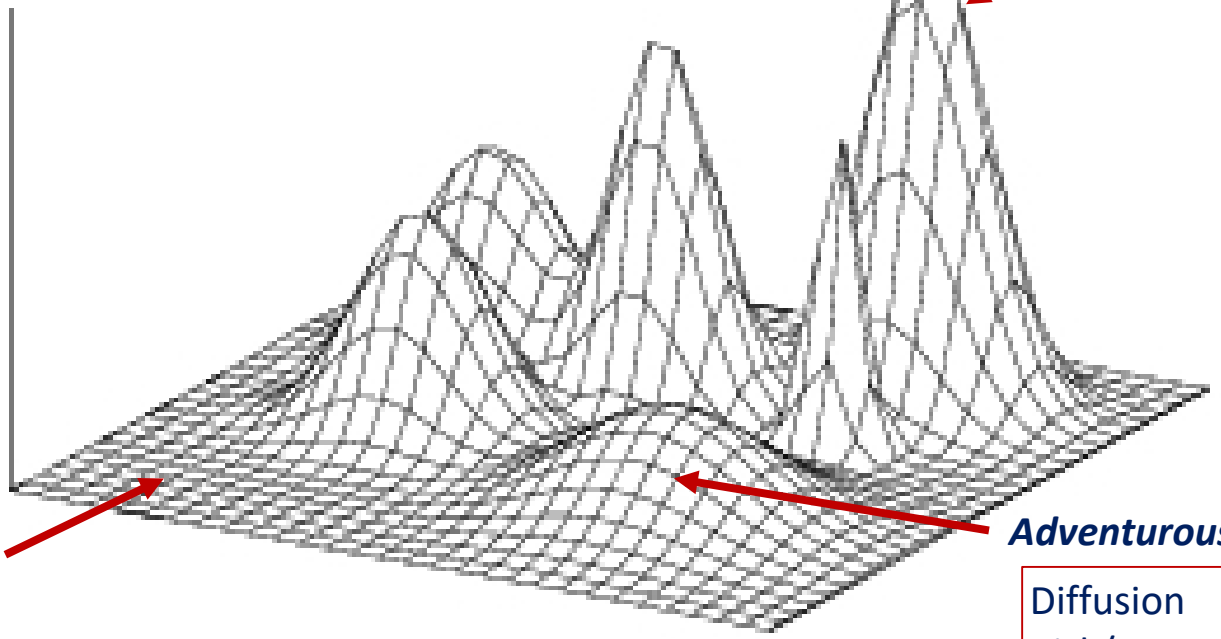
- **Recombination** of existing technological knowledge is an ongoing process
- **Density** of technology class co-occurrence matrix has increased
- **knowledge complexity** (# of classes per invention) has increased



CPC Co-Occurrence Matrix

Source: PATSTAT, authors' own calculation

The Origin of Innovation? Recombination



Crowded Space

Productivity ↑
Potential ↓

"Crazy Space"

Potential ↑
Risk ↑

Breakthrough/ Disruptive Innovation?

Adventurous Space

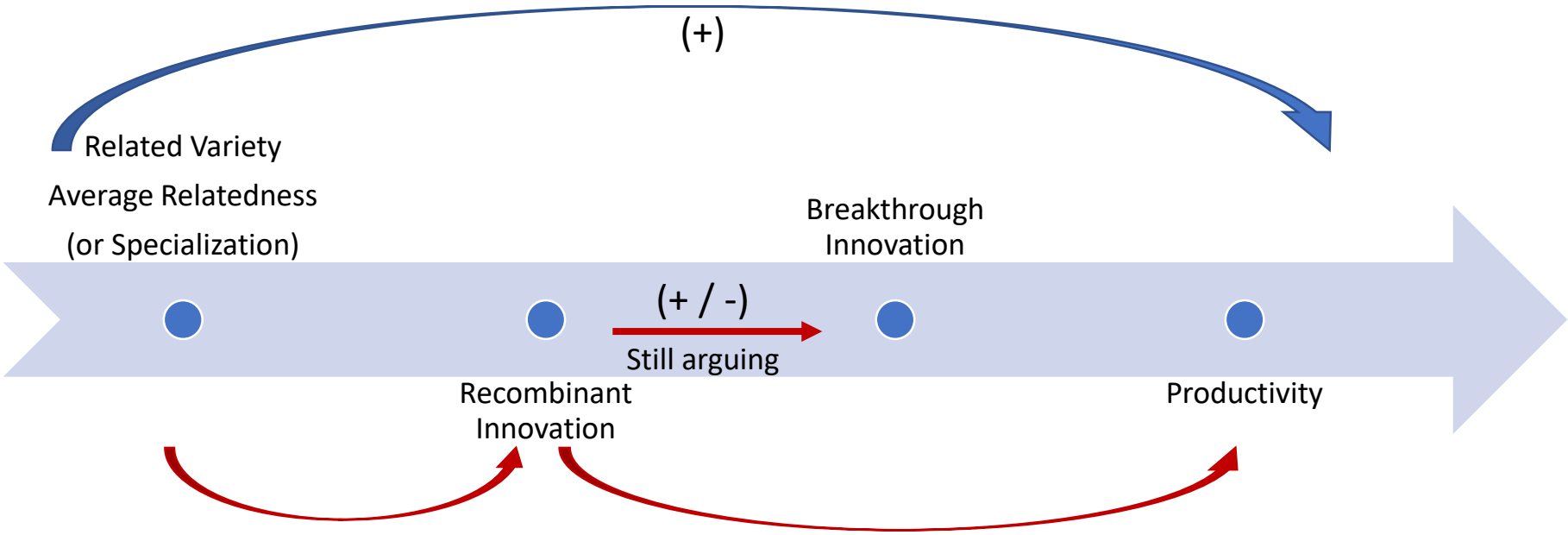
Diffusion ↑
Risk/Potential ≈

Incremental Innovation?

Technological Recombination and Regional Productivity

In EconGeo literature, several of empirical papers discuss this relationship

i.e. ESSLETZBICHLER, 2007; FRENKEN et al., 2007; BOSCHMA and IAMMARINO, 2009; BISHOP and GRIPAIOS, 2010; QUATRARO, 2010, 2011; ANTONIETTI and CAINELLI, 2011; BRACHERT et al., 2011; BOSCHMA et al., 2012; HARTOG et al., 2012; MAMELI et al., 2012



Research Gap #1

This paper is about that…

Research Gap #2

We are working on that…

Proximity and Variety (different, but complementary)

*…good **Selection** is made in high **Diversity**…*

(well-known fact in evolutionary biology)

Variety or Entropy

≠

Proximity or Relatedness

Proximity and Variety (different, but complementary)

Certain technologies are easily matched (high-proximity), but some are not (low- proximity)

→ Novel recombinations are <u>frequently</u> created between technologies with high proximity to each other; lots of Related Variety is helpful

→ New recombinations are <u>rarely</u> created between technologies with low proximity to each other, to encourage that it needs Unrelated Variety

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In order to boost the production of new recombinant technological knowledge it requires both **Entropy (RV + UV)** and **Relatedness (Proximity)**

However, little is known regarding the balance of these two different, but complementary factors!?!

New Recombination Activities – Exploitation vs. Exploration

*Relatedness **vs**. Entropy ≈ Exploitation **vs**. Exploration*

Innovating firms have to establish a **balance** between technology exploitation and exploration activities in order to stay competitive in the short run, but also in light of survival in the long run.

(Levinthal and March 1993; March 1991; Benner and Tushman 2003; Gupta et al. 2006; Lavie et al. 2011)

Technology exploitation: Refinement and extension of existing technologies, leading to predictable, short-term returns.

- Exploitation activities increase average relatedness, and subsequently the number of high-related recombinations

Technology exploration: Experimentation with new technologies, implying more uncertain returns unfolding over longer timeframes.

- Exploration activities increase entropy, and in turn the number of new or less-related recombinations

Patent and Regional Socio-Economic Data (1981-2014)

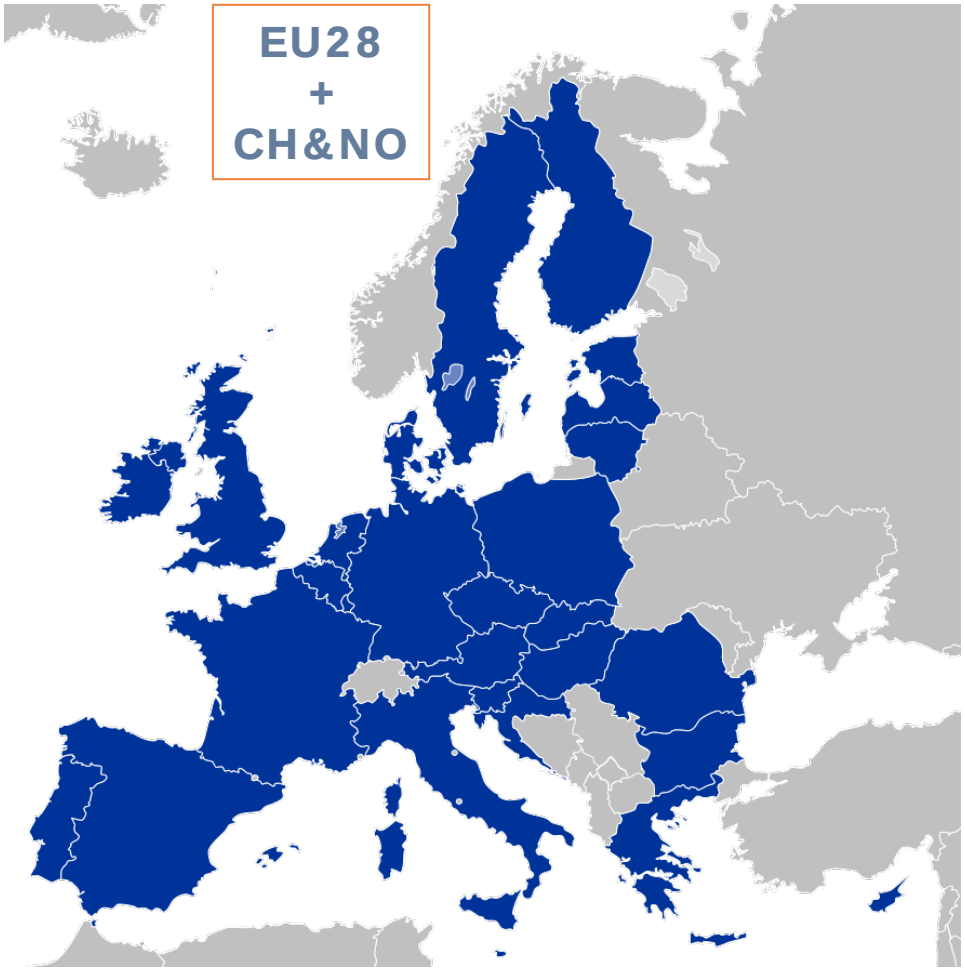
PATSTAT (EPO)

- Priority year: 1981-2014
- Inventors' residency information (NUTS2 codes)
- Patents' CPC classes

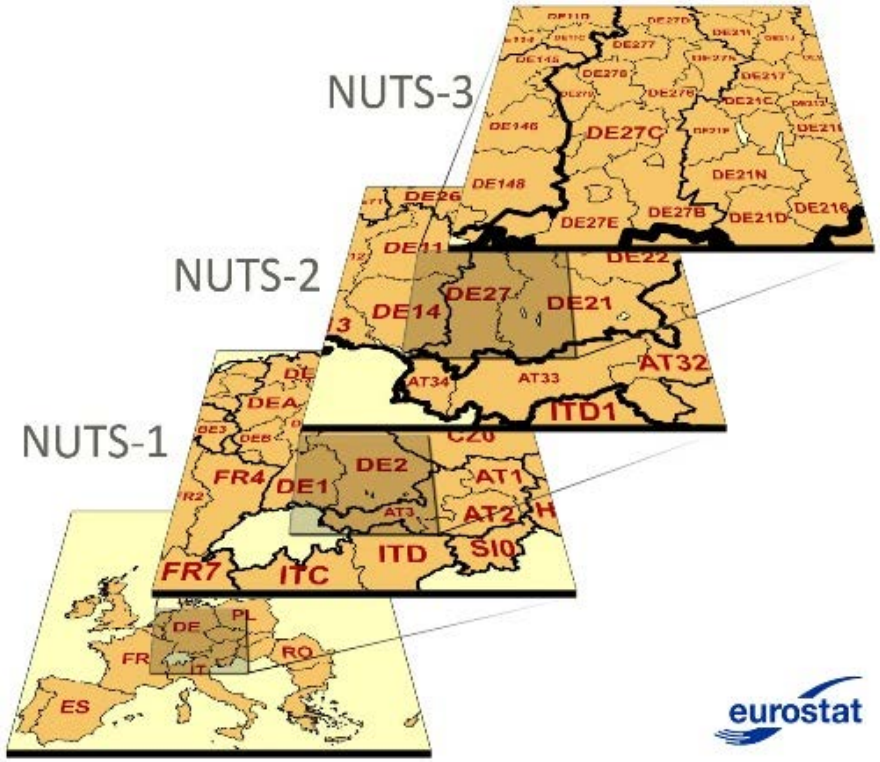
Regional Socio-Economic Data
(Eurostat & Cambridge Econometrics

- Years: 1981-2014
- Variables (selection):
  - Gross Value Added
  - No. of Employees
  - Compensation of Employees
  - Gross Fixed Capital

NUTS Regions (Nomenclature of territorial units for statistics)



NUTS 2 …the appropriate level for analyzing regional-national problems…



98 regions at NUTS 1, **276 regions at NUTS 2** and 1342 regions at NUTS 3 level for EU28

EPO Patent Data – PATSTAT (1981-2014)

Classification

Location

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 711 947 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
26.03.2014 Bulletin 2014/13

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H01F 38/18 *(2006.01)* ***F03D 11/00*** *(2006.01)*
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24.09.2012 GB 201216963

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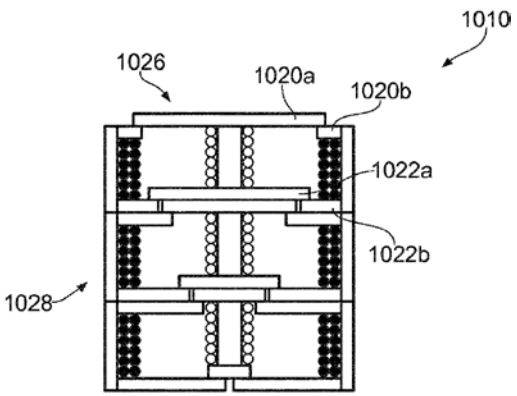


FIG. 10

(54) **A power transfer device**

(57) Described is an electrical power transfer device for transferring power between two coaxial relatively rotatable components, comprising: an outer core having a magnetic flux guide, an outer electrical winding and a cavity for receiving an inner core; an inner core located at least partially within the cavity, the inner core having a magnetic flux guide and an inner winding, wherein the inner and outer core are arranged to be movable between a first configuration in which the magnetic flux guides of the inner and outer cores separated by a first distance in which power is transferred in use, and a second configuration in which the inner and outer cores are separated by a second distance, in which relative rotation of the inner and outer cores is possible in the second configuration, wherein in the first configuration the magnetic flux guides of the inner and outer cores abut one another.

Avg Relatedness and Entropy, and New Recombination

The Path to a Novel Recombination…

- The availability of many and diverse building blocks (technology categories) increases the chance to produce a new recombination;
- However, even if a regional economy is home to a variety of building blocks, ability to recombine these in an unexplored way is necessary;
- A highly specialized region might be disadvantaged as this may limit the opportunities to generate new recombinations in untraditional ways.

***Average Relatedness**: Degree of regional technological specialization*

= co-occurrence of CPC codes on patent documents

(Kogler *et al.*, 2013; Kogler *et al.*, 2017)

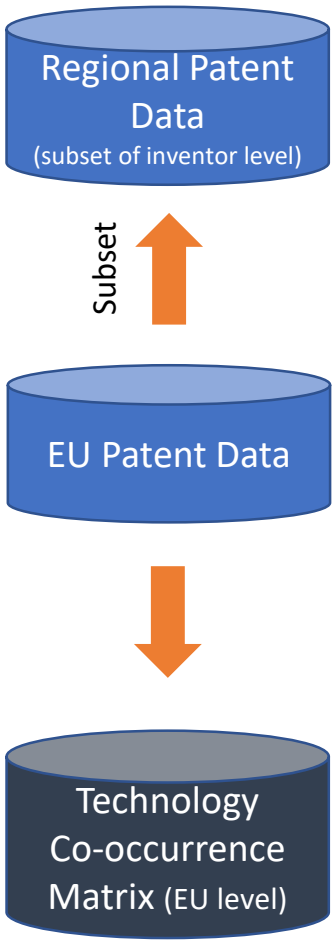
***Entropy:** Unrelated variety + Related variety*

= upper-level hierarchy (1-digit distribution of CPC codes) +
lower-level hierarchy (3-digit distribution of CPC codes)

(Frenken *et al.*, 2007)

Regional Average Technological Relatedness

(Kogler *et al*. 2013)



Regional weight

$$X_{ijr}^{t} = \frac{(P_{ir}^{t} + P_{jr}^{t})(P_{ir}^{t} + P_{jr}^{t} - 1)}{\sum_i P_{ir}^{t}(P_{ir}^{t} - 1)}$$

- X_{ijr}^{t} = share of all possible patent-to patent links within region *r* at time *t* that link technology classes *i* and *j*
- P_{ir}^{t} = no. patents in class *i* within region *r* at time *t*

Regional Average Technology Relatedness

$$AR_{r}^{t} = \sum_i \sum_j X_{ijr}^{t} S_{ij}^{t}$$

Knowledge Space

Technology Relatedness

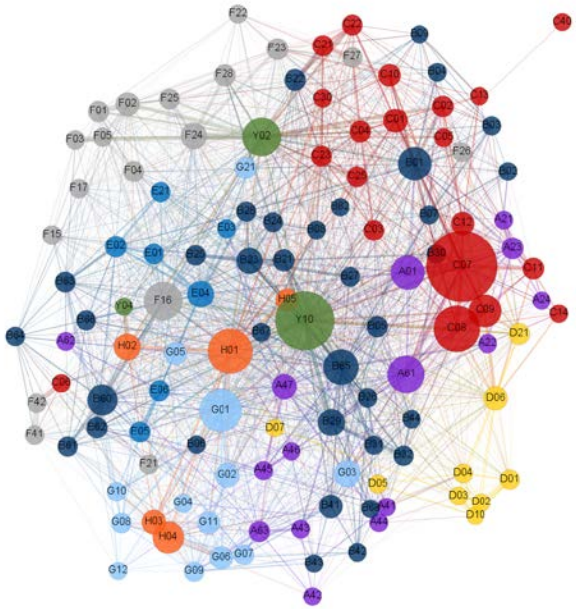
$$S_{ij}^{t} = \frac{N_{ij}}{\sqrt{N_i N_j}}$$

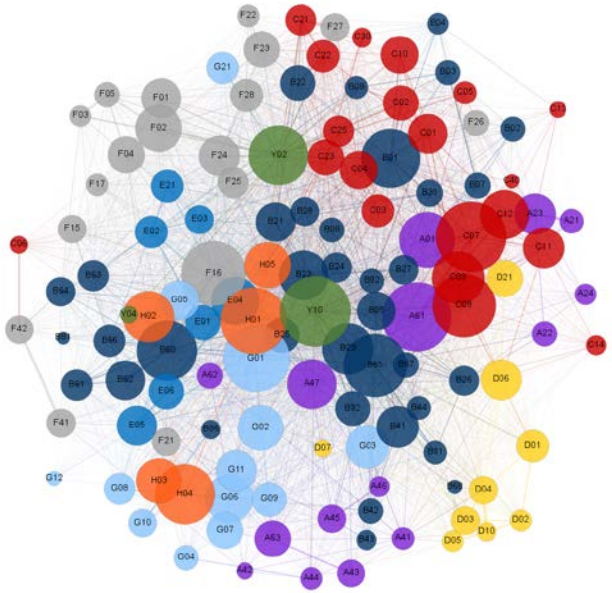
- S_{ij}^{t}: Relatedness (Proximity) btw *i* and *j* (UK level) at *t*
- N_{ij}: No. patents listing both *i* and *j*
- N_i : No. patents listing *i*
- N_j : No. patents listing *j*

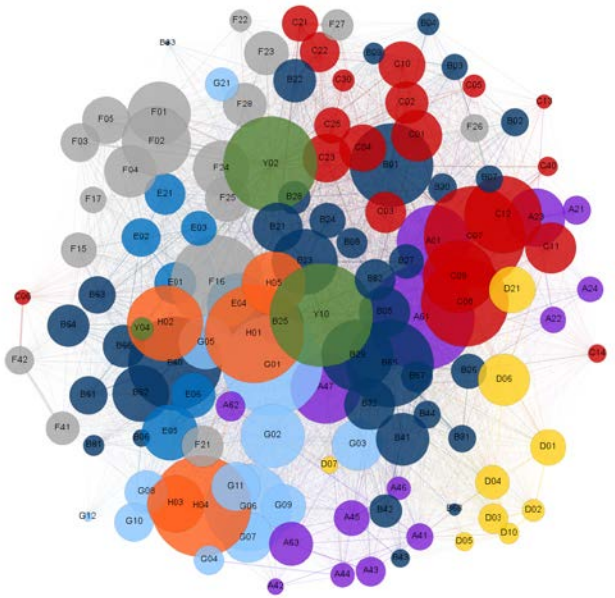
Evolution of the Knowledge Space and Recombination

	1980	2000	2014
Node	125	126	127
Edge	2,463	4,959	6,128
Network Density	0.318	0.620	0.766
Ave. CC	0.612	0.782	0.854
Ave. Path length	1.687	1.370	1.234

- Chemistry and Metallurgy
- Electricity
- Textiles, Paper
- New, Cross-over Technologies
- Construction
- Physics
- Transport and Operations
- Consumer goods
- Mechanical Engineering







Regional Technology Entropy

(Franken *et al*. 2007)

Method (Measurement)

$$Entropy = \sum_{g=1}^{G} P_g log_2\left(\frac{1}{P_g}\right) + \sum_{g=1}^{G} P_g H_g$$

Unrelated Variety | Related Variety

,where

- p_i is 3 digit share
- P_g is 1 digit share $P_g = \sum_{i \in S_g} p_i$
- $H_g = \sum_{i \in S_g} \frac{p_i}{P_g} log_2\left(\frac{1}{p_i/P_g}\right)$

Region #1 - Patents by CPC class

1 Digit	3 Digit	No. Patent	P_g	p_i
Chemistry and Metallurgy	C07 ORGANIC CHEMISTRY	6	14/55	6/55
	C12 BIOCHEMISTRY	8		8/55
Physics	G02 OPTICS	7	9/55	7/55
	G04 HOROLOGY	2		2/55
Consumer goods	A43 FOOTWEAR	5	15/55	5/55
	A45 EQUIPMENT	4		4/55
	A47 FURNITURE	6		6/55
Mechanical Engineering	F01 ENGINES IN GENERAL	3	13/55	3/55
	F21 LIGHTING	4		4/55
	F41 WEAPONS	6		6/55
Textiles, Paper	D04 KNITTING	1	1/55	1/55
Transport	B23 MACHINE TOOLS	3	3/55	3/55
Total		55	1	1

Region #1 Entropy (3.43) = UV (2.27) + RV (1.16)

Region #2 – Patents by CPC class

1 Digit	3 Digit	No. Patent	P_g	p_i
Electrocity	H01 BASIC ELECTRIC ELEMENTS	4		4/55
	H02 CONVERSION POWER	9		9/55
	H03 ELECTRONIC CIRCUITRY	15	33/55	15/55
	H04 COMMUNICATION	3		3/55
	H05 ELECTRIC TECHNIQUES	2		2/55
Physics	G01 MEASURING / TESTING	3		3/55
	G02 OPTICS	2		2/55
	G03 PHOTOGRAPHY	3		3/55
	G05 CONTROLLING	7	22/55	7/55
	G06 COMPUTING	2		2/55
	G07 CHECKING-DEVICES	2		2/55
	G09 DISPLAY	3		3/55
Total		55	1	1

Region #2 Entropy (3.20) = UV (0.97) + RV (2.23)

Novel Regional Recombinations – Modelling Approach

New Recombinations – AR & Entropy

$$Y_{it} = \beta_0 + \beta_1 AR_{it} + \beta_2 Entropy_{it} + \beta_3 (AR_{it} \times Entropy_{it}) + \boldsymbol{\beta_4 Controls_{it}} + \boldsymbol{\beta_5 Year.FE_t} + \boldsymbol{\beta_6 Country.FE_i} + \boldsymbol{\beta_7 Regional.FE_i} + \varepsilon_{it}$$

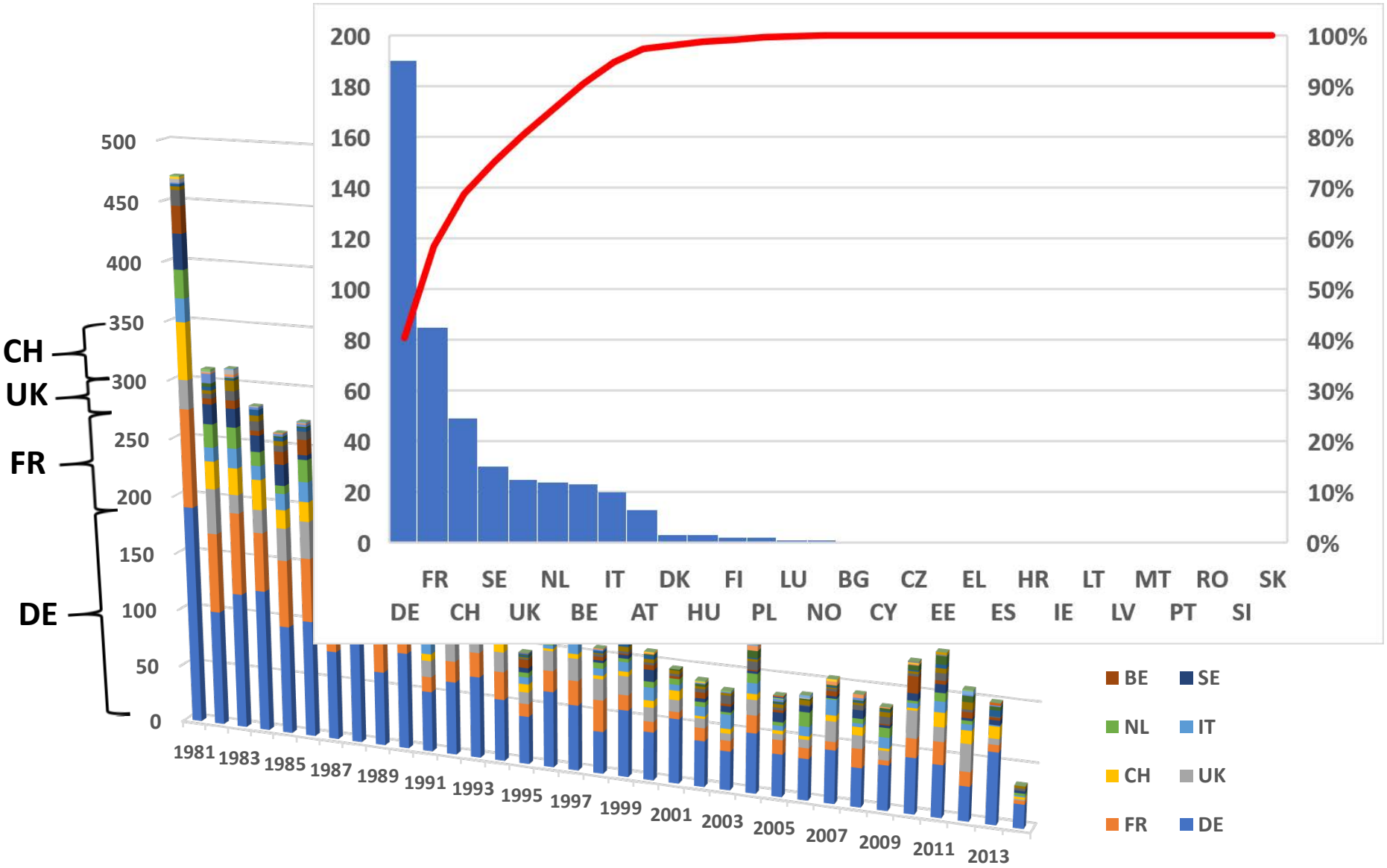
1. **Whether or Not** (Logit specification)

   Y_{it} = 1 if the region *i*'s number of RCA in new recombination at $t \geq 1$; otherwise Y_{it} = 0

2. **How many:** (Heckman two stage specification)

   Y_{it} = The number of RCAs in new recombination in region *i* at time *t*

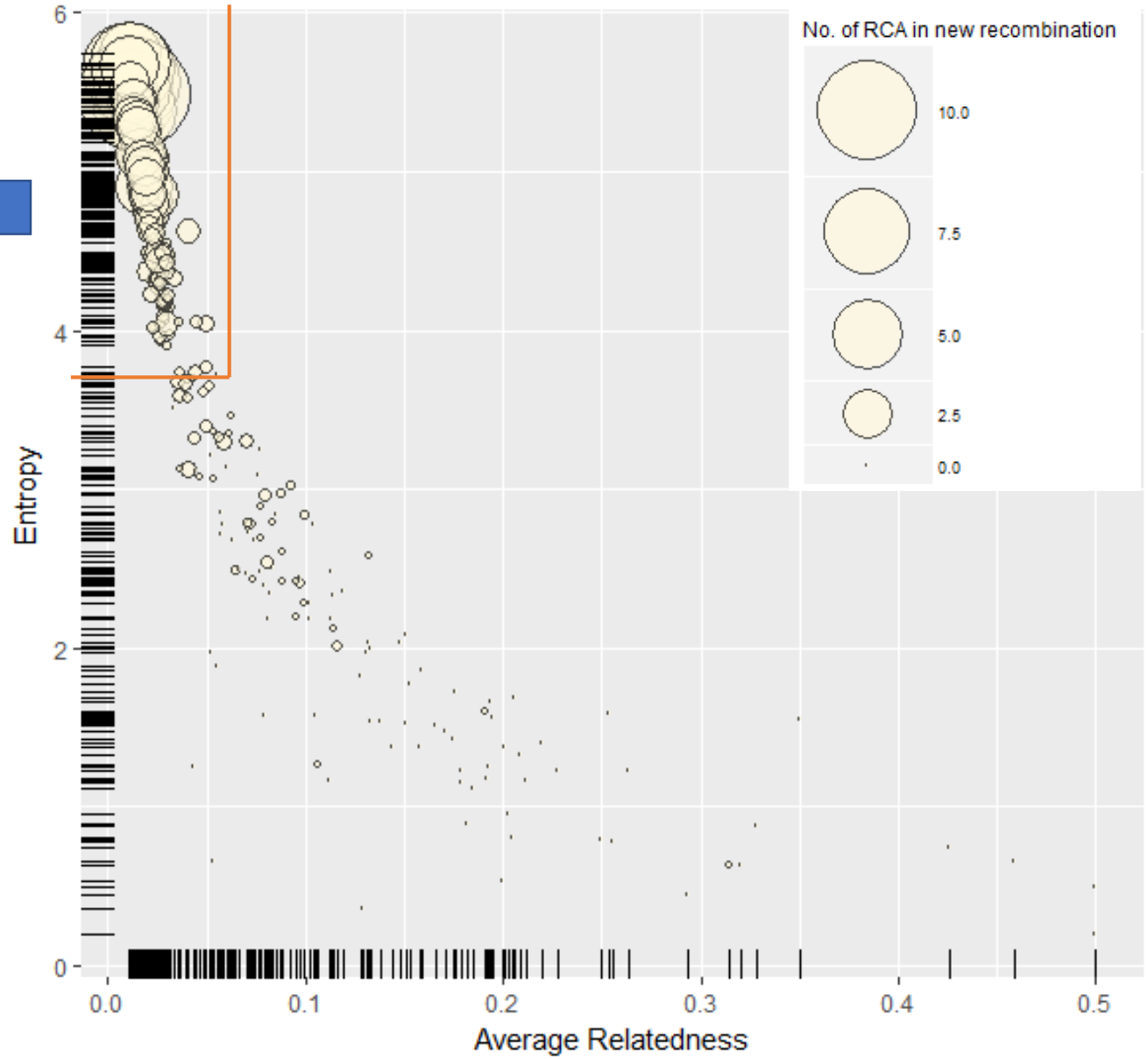
Distribution of New Recombinations by Country/NUTS



Entropy tops AR for Generating RCA in New Recomb.

AR <= 0.066 (Mean)
ETP >= 3.72 (Mean)

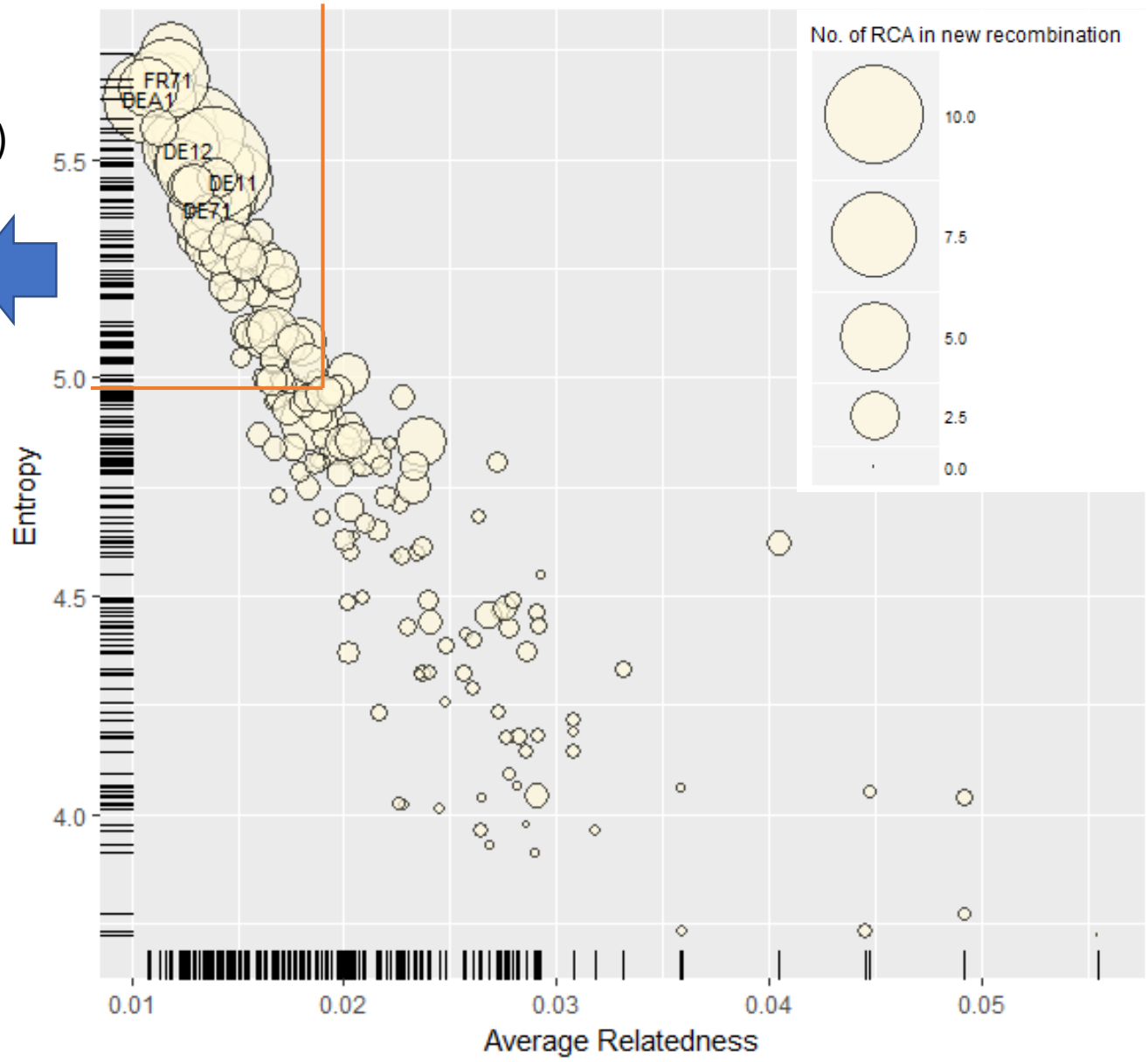
6,093 of 8,801 observations ≈70%



Top Quartile of Entropy and Bottom Quartile of AR

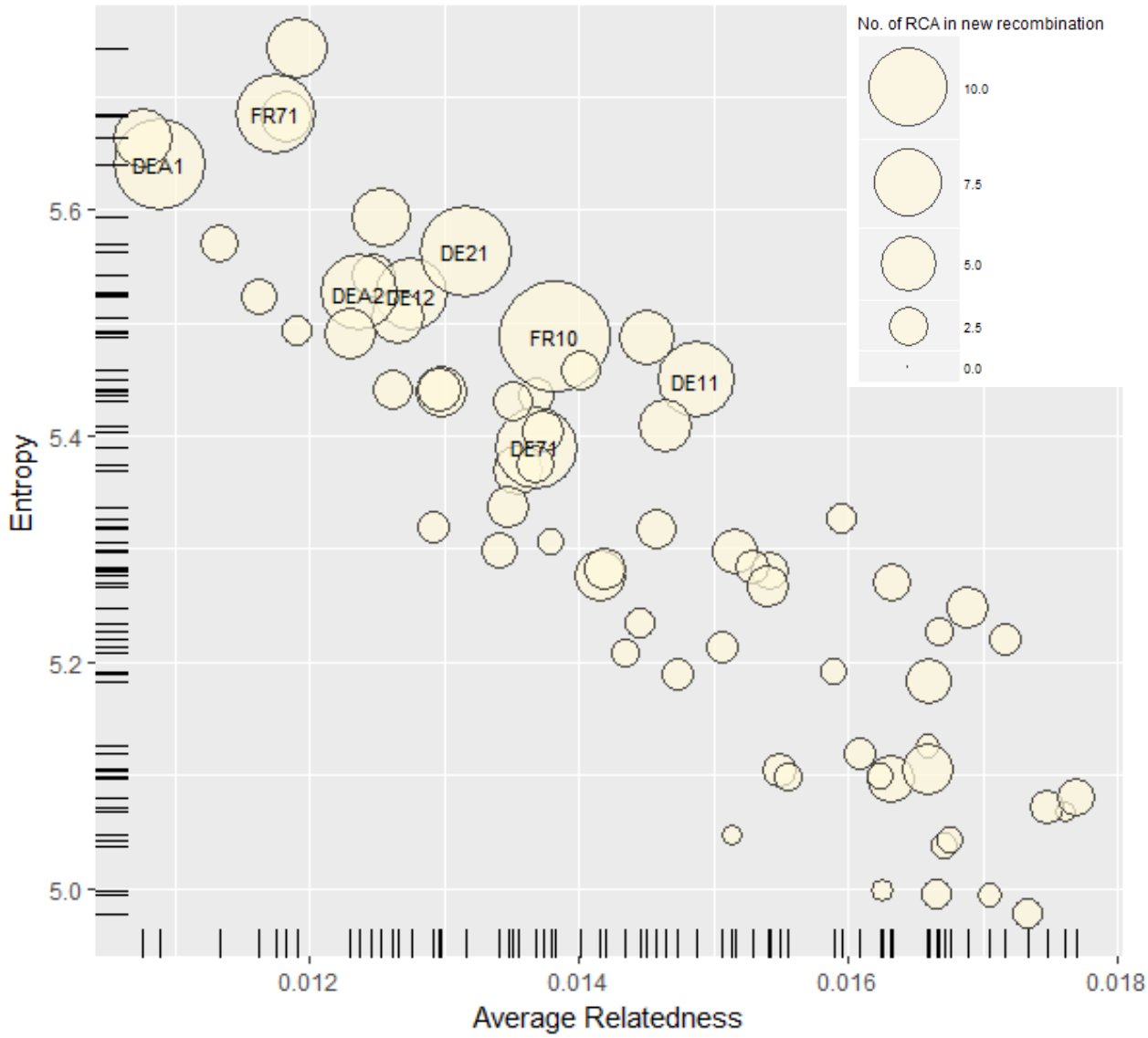
AR <= 0.018 (first quartile)
ETP >= 4.96 (last quartile)

2,668 of 8,801
observations ≈ 30%



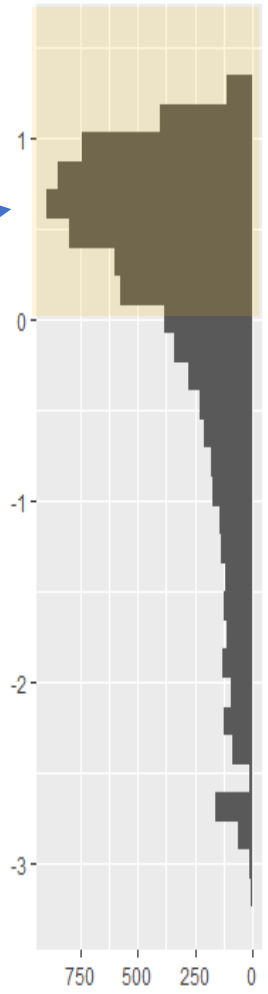
Top Performing Regions in Producing New Recomb.

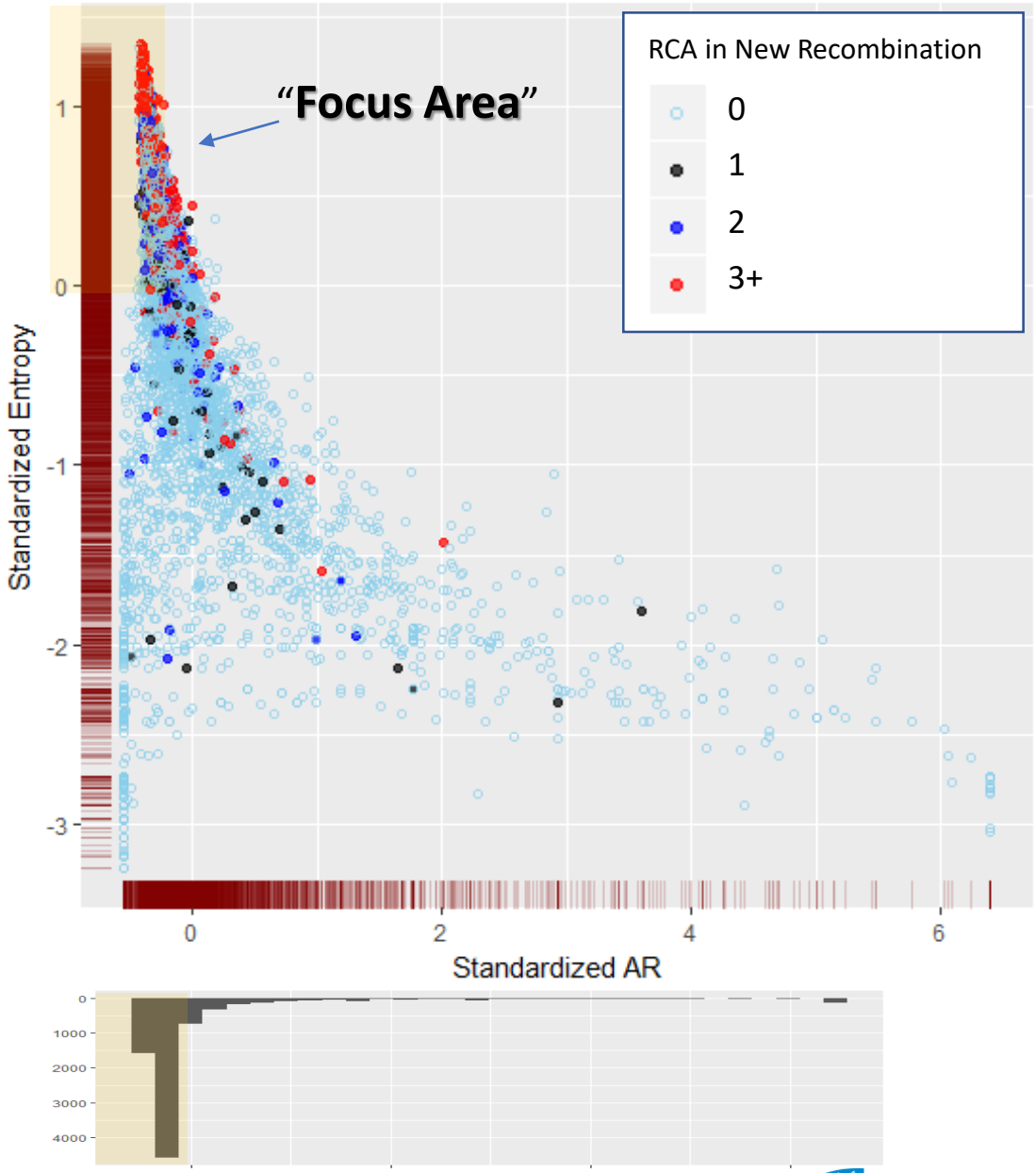
NUTS2	Country	Region	Avg new recomb-ination
FR10	FRA	Île de France	10.114
DEA1	GER	Düsseldorf	6.943
DE21	GER	Oberbayern	6.771
DE71	GER	Darmstadt	5.400
FR71	FRA	Rhône-Alpes	5.286
DE11	GER	Stuttgart	4.829
DEA2	GER	Köln	4.771
DE12	GER	Karlsruhe	4.200



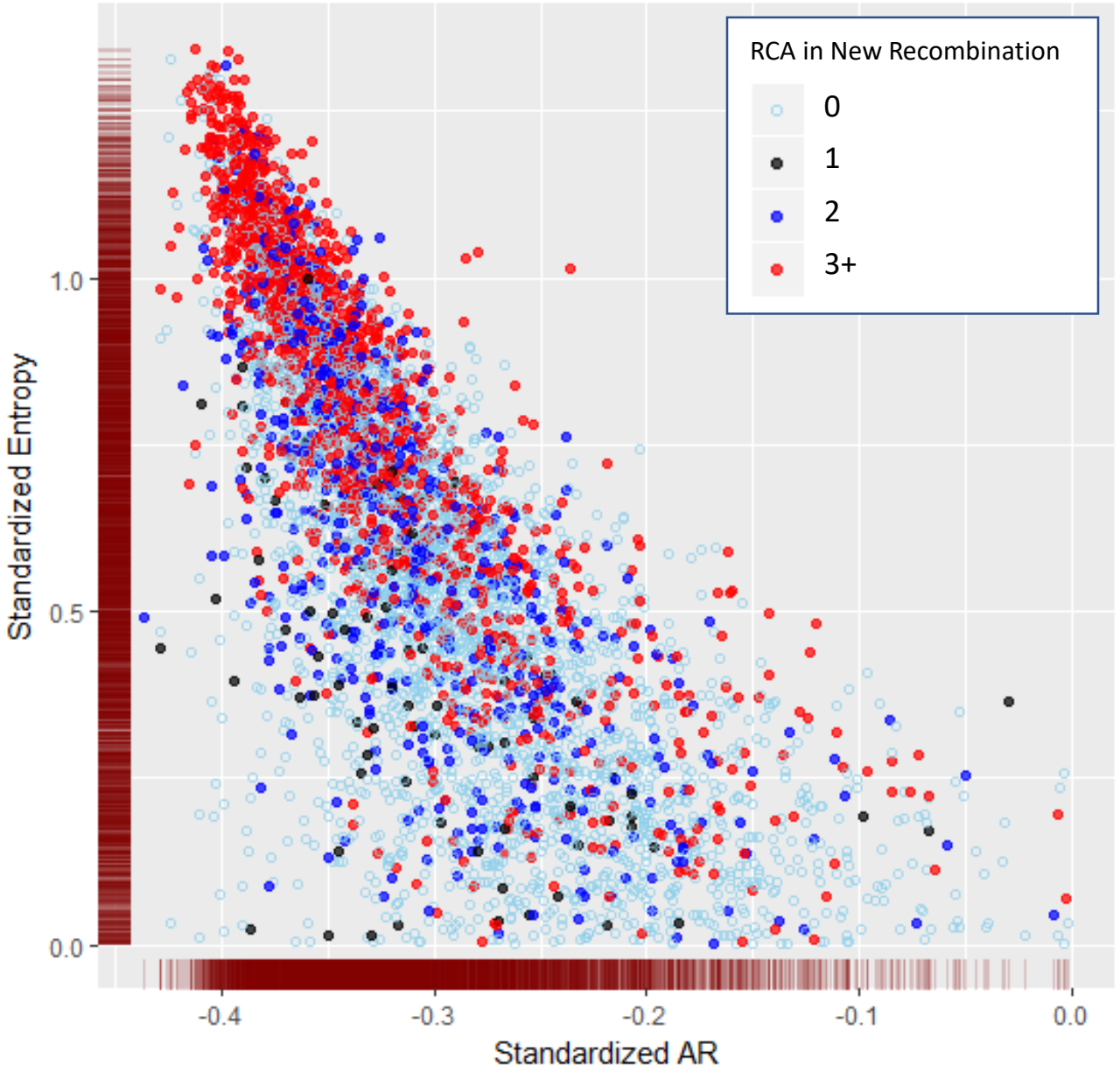
Entropy & Avg Relatedness – Standardized

5,170 of 8,081
≈ 60%





Entropy & Avg Relatedness – Standardized



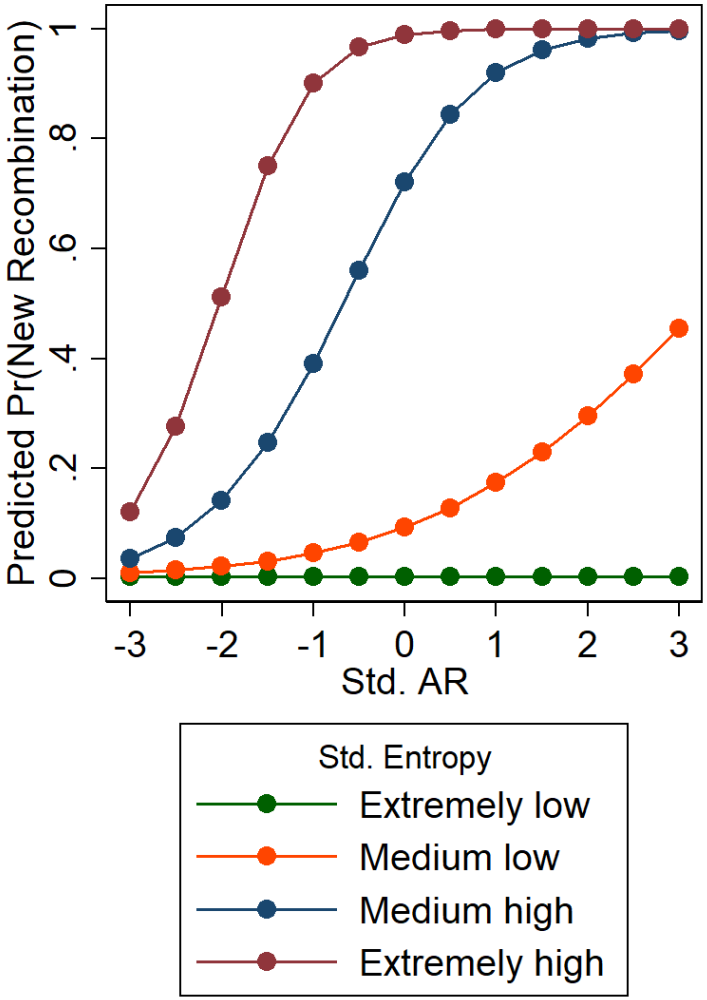
RESULTS – AR & Entropy for New Recombination

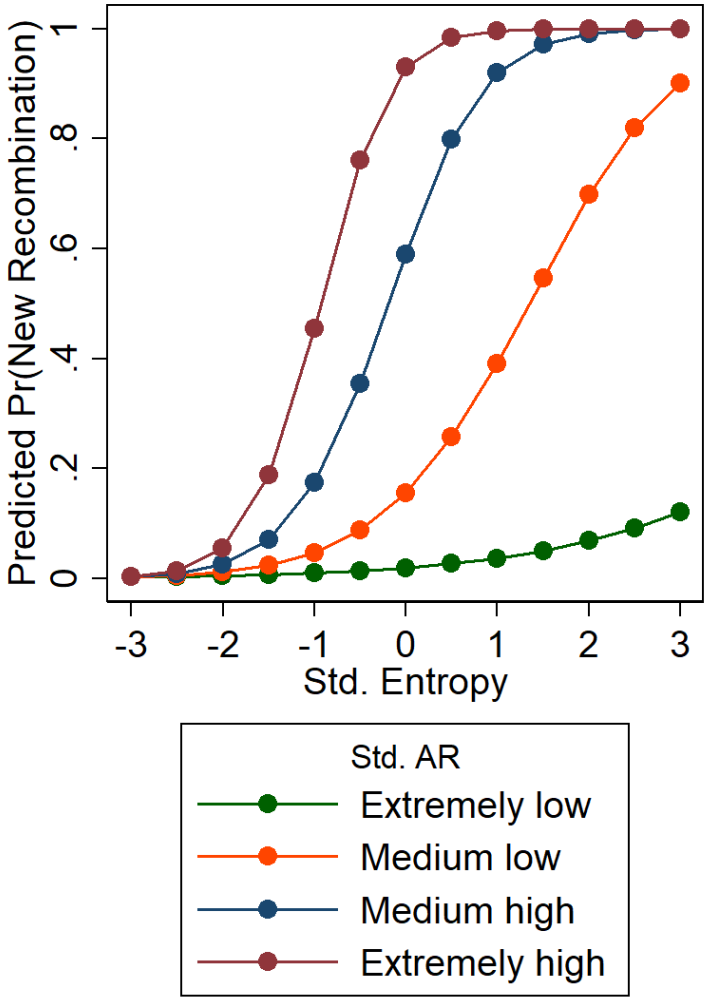
For regions that go from 0 to having at least 1 RCA value in new recombinations

Dep. Var.: **New recombination (0/1)**	**Logit w/o regional FE**		**Logit with regional FE**	
	Odds ratio	S.E.	Odds ratio	S.E.
Std. AR	3.916***	(1.667)	3.355***	(1.361)
Std. ETP	10.787***	(2.156)	6.513***	(1.201)
Std. AR × Std. ETP	1.405**	(0.206)	1.481**	(0.246)
Controls	Y		Y	
Year FE	Y		Y	
Country FE	Y		Y	
Regional FE	X		Y	
No. of Regions-year	8,081		8,081	
No. of Regions	277		277	

Discussion

For creating a new recombination for those regions that don't have one…





RESULTS – AR & Entropy for New Recombination

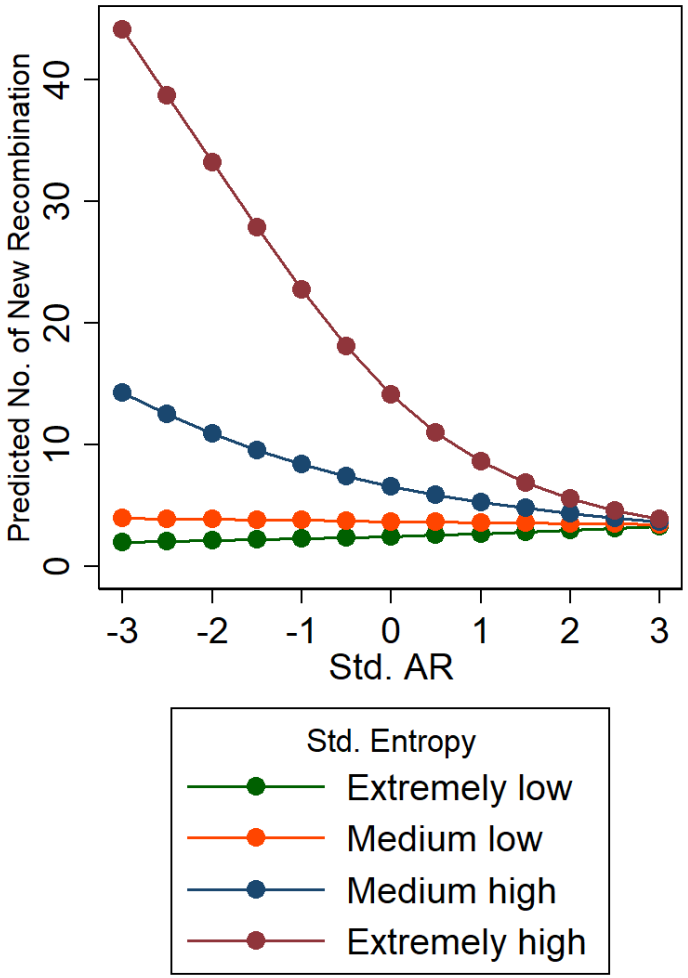
To generate more RCAs in new recombination for all regions, for those who have already at least one RCA…

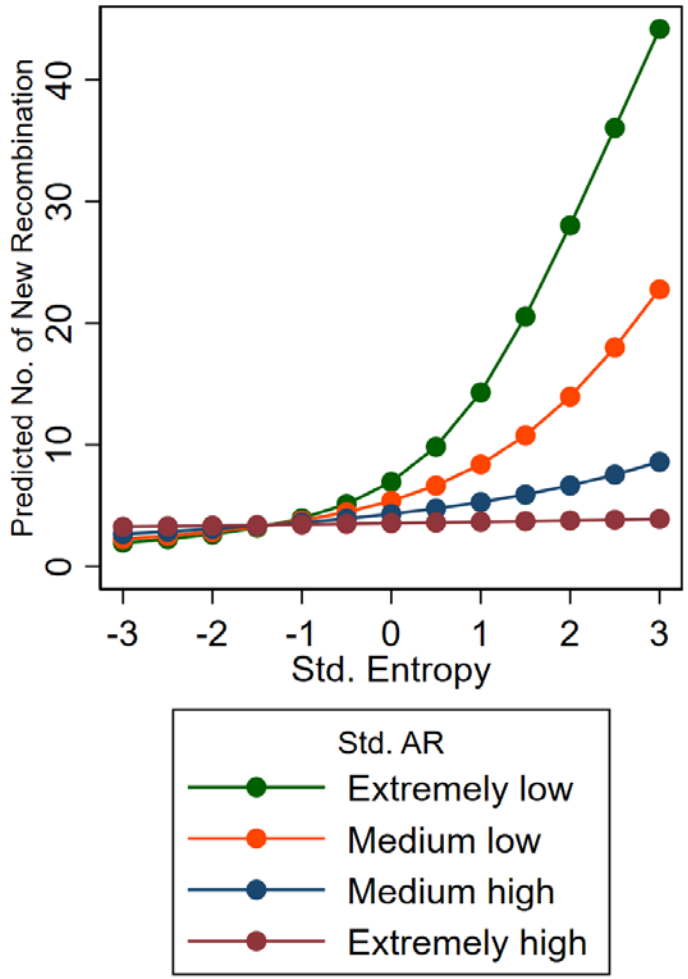
Heckman sample selection model

Dep. Var.: **New recombination**	**First stage**		**Second stage (New recombination ≥ 1)**	
	Coef.	S.E.	Coef.	S.E.
Std. AR	-0.153**	(0.075)	-3.353***	(0.915)
Std. ETP	1.004***	(0.043)	8.696***	(2.594)
Std. AR × Std. ETP	-0.109***	(0.036)	-2.531***	(0.569)
Controls	Y		Y	
Year FE	Y		Y	
Regional FE	Y		Y	
No. of Regions-year	8,081		2,302	
No. of Regions	277		207	

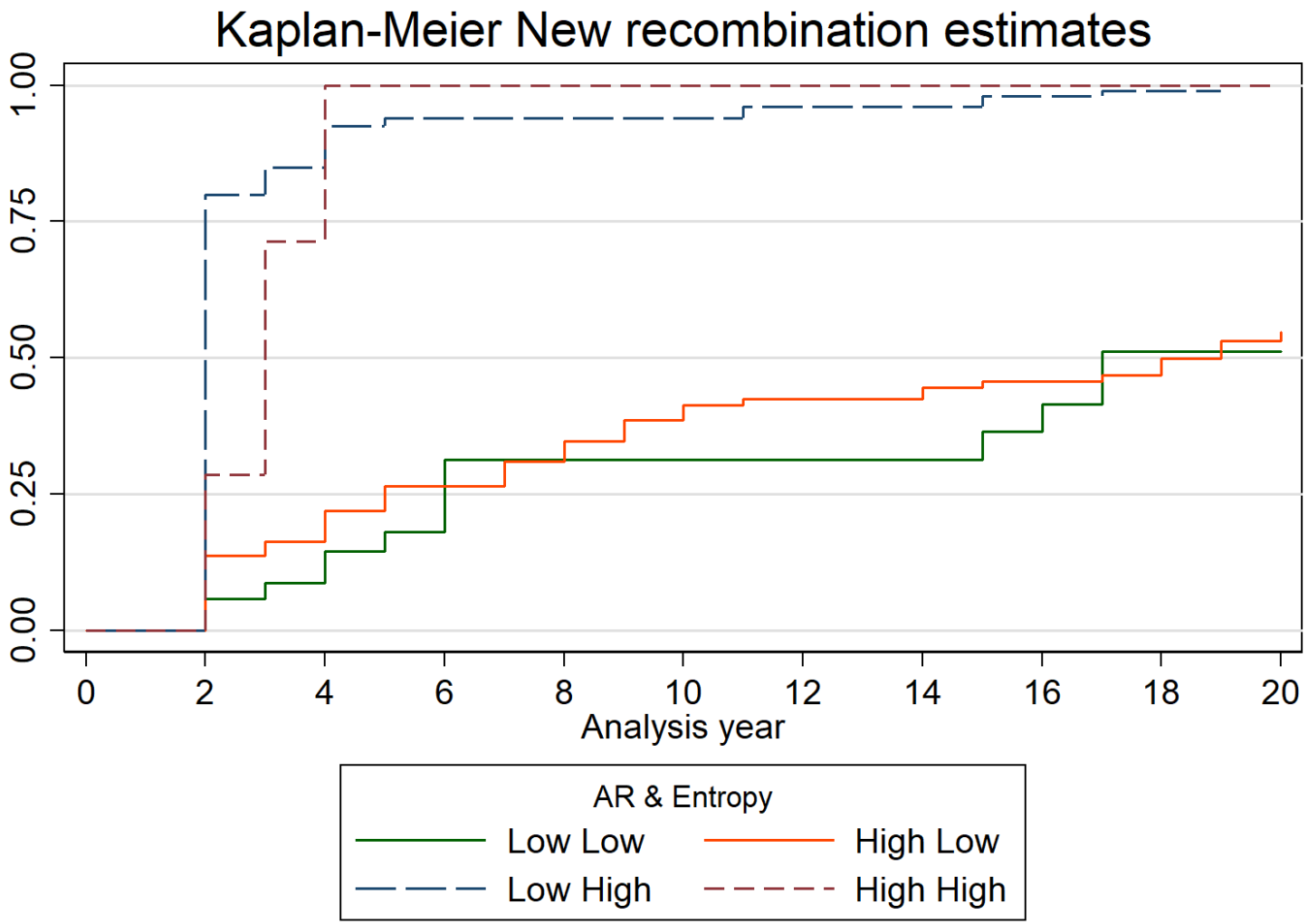
Discussion

*For creating **more** RCAs in new recombination for all regions…*



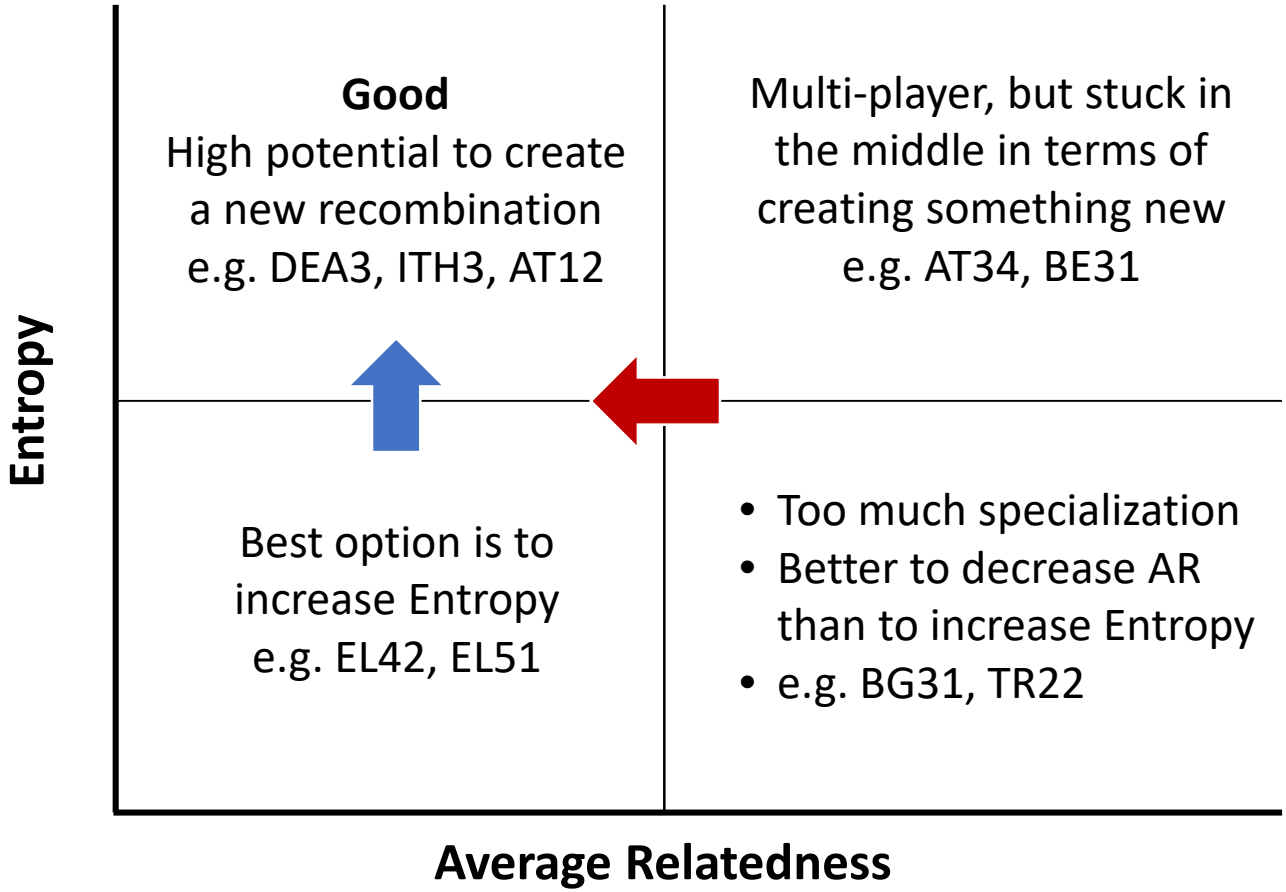


Survival Analysis – Kaplan-Meier Estimator



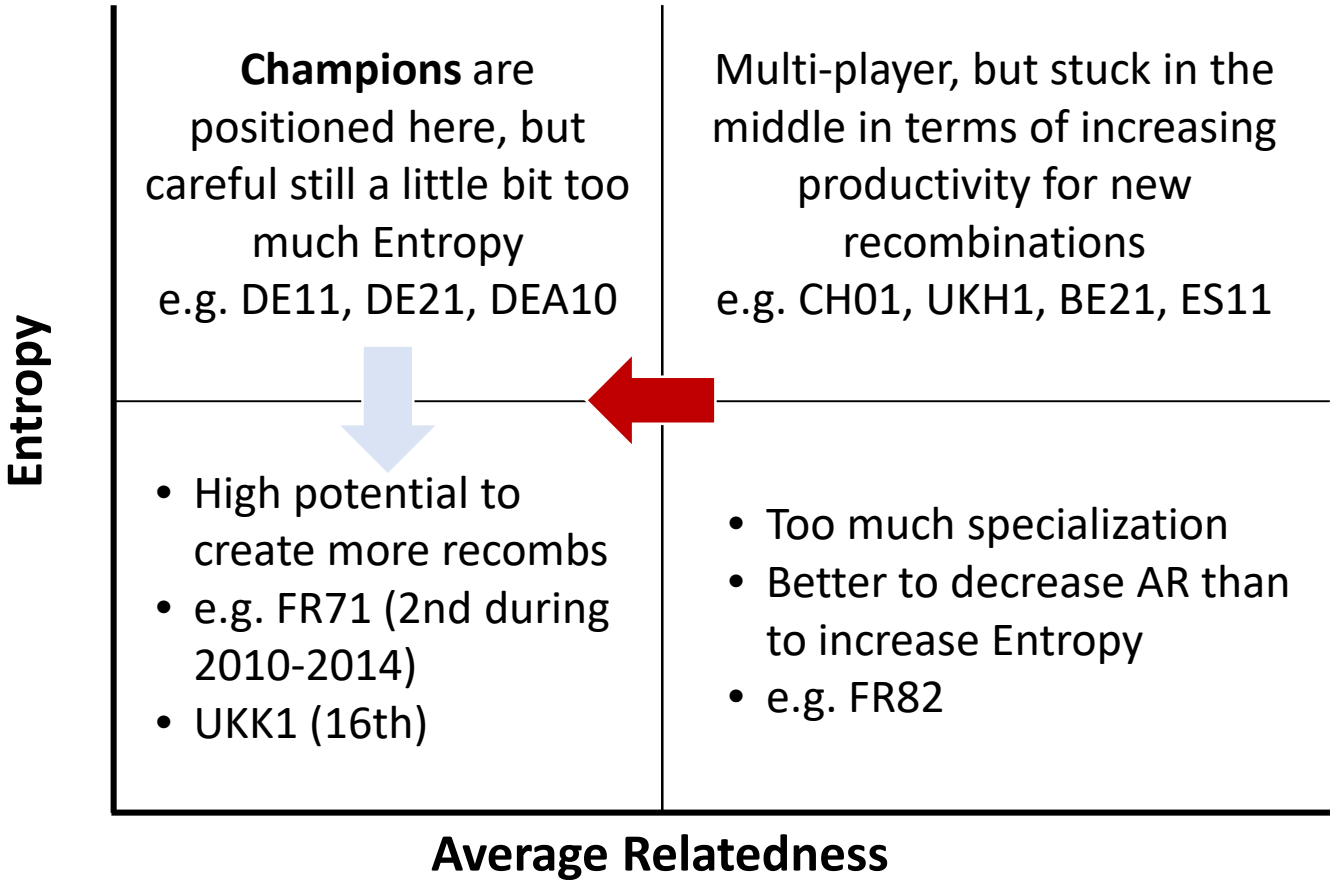
Policy Implications

*For those regions that have **not** managed to created a new recombination, but aim to do so in the future.*

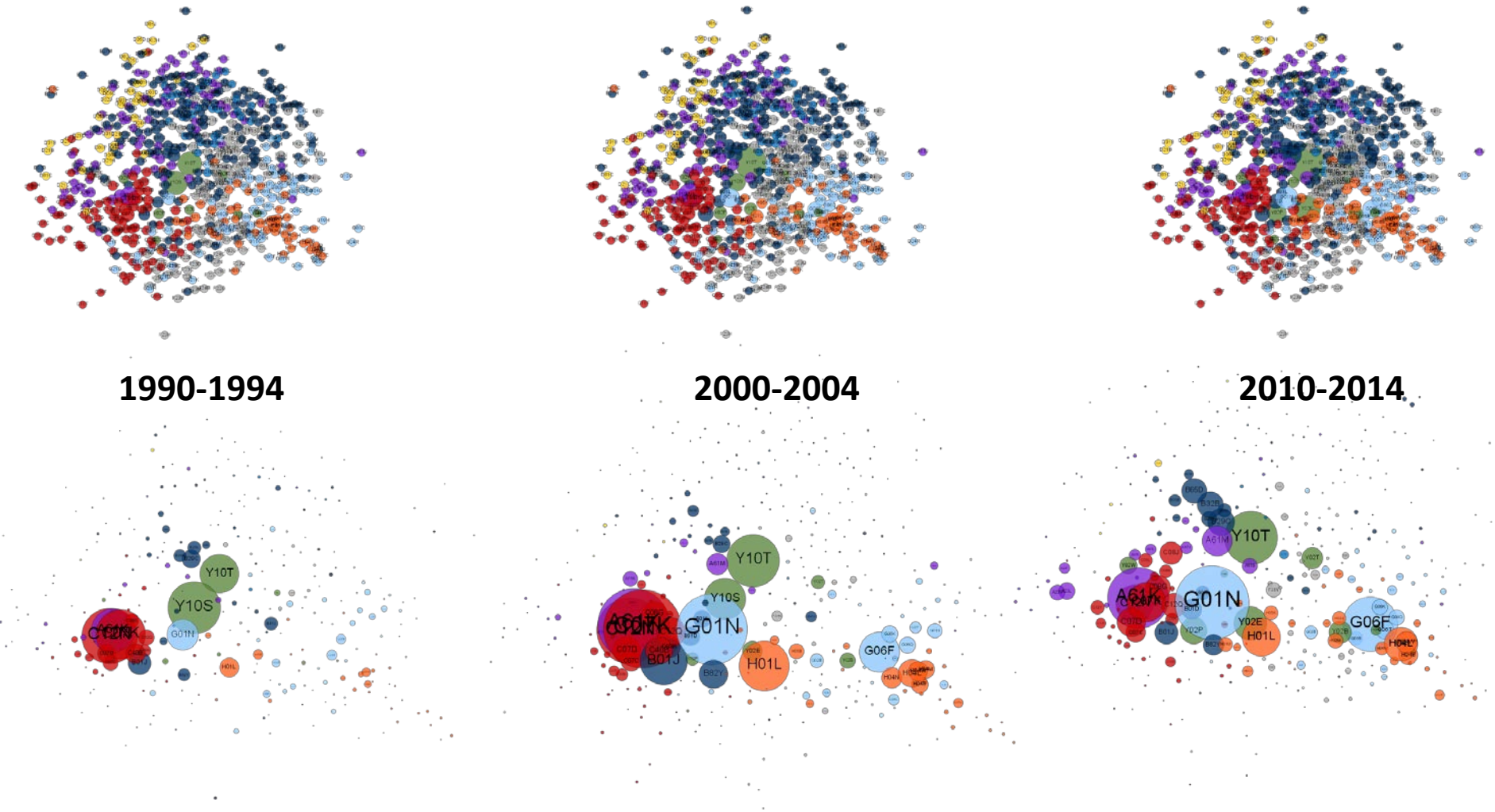


Policy Implications

*For those regions that have managed to created a new recombination, but hope to generate **more***



The Evolution of the Cambridge Knowledge Space



C12N = MICROORGANISMS OR ENZYMES; COMPOSITIONS THEREOF
G01N = INVESTIGATING OR ANALYSING MATERIALS BY DETERMINING THEIR CHEMICAL OR PHYSICAL PROPERTIES

The Evolutionary Process of Recombination

"Balancing Entropy and Relatedness"

Comments are Welcome – Thank you!

Technology Evolution in Regional Economies
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