Network Dynamics in the Case of Emerging Technologies

[work in progress]

Daniele Rotolo

SPRU (Science Policy Research Unit), University of Sussex

www.danielerotolo.com — *d.rotolo@sussex.ac.uk*

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Outline

Research aim

Research aim

To explore how collaborative networks form, evolve, and are configured in the case of emerging technologies (*which mechanisms affect the likelihood of observing certain network configurations*)

Theoretical framework

Theoretical framework

Research on emerging technologies

- Emerging technologies are technologies characterised by [Rotolo et al., 2015]
  - Radical novelty: achievement of a new or an existing purpose/function with different basic principles [Arthur, 2007]
  - Relatively fast growth: actors, funding, publications, patents, products, etc. [Cozzens et al., 2010]
  - Coherence: technologies that have moved beyond the conceptual stage [Srinivasan, 2008]
  - Prominent impact: technologies capable of changing the *status quo* [Day and Schoemaker, 2000]
  - Uncertainty and ambiguity: challenges in predicting outcomes (e.g. uses and applications) and probabilities associated with those outcomes [Stirling, 2007]

Theoretical framework

Research on emerging technologies

- Considerable attention has been paid towards the development of techniques for the detection/analysis of technological emergence*
  - Indicators/trend analysis [Porter and Detampel, 1995, Moed, 2010]
  - Citation analysis [Boyack et al., 2014, Morris et al., 2002]
  - Co-word analysis [Furukawa et al., 2015, Ohniwa et al., 2010]
  - Overlay mapping [Rafols et al., 2010, Kay et al., 2014]
  - Hybrid techniques [Chen, 2006, Small et al., 2014]
  - 'Big data' (e.g. NESTA's work on Meetup.com)

*For a review see Rotolo, D., Hicks, D., Martin, B. R. (2015). What is an emerging technology? Research Policy, 44(10): 1827-1843.

Theoretical framework

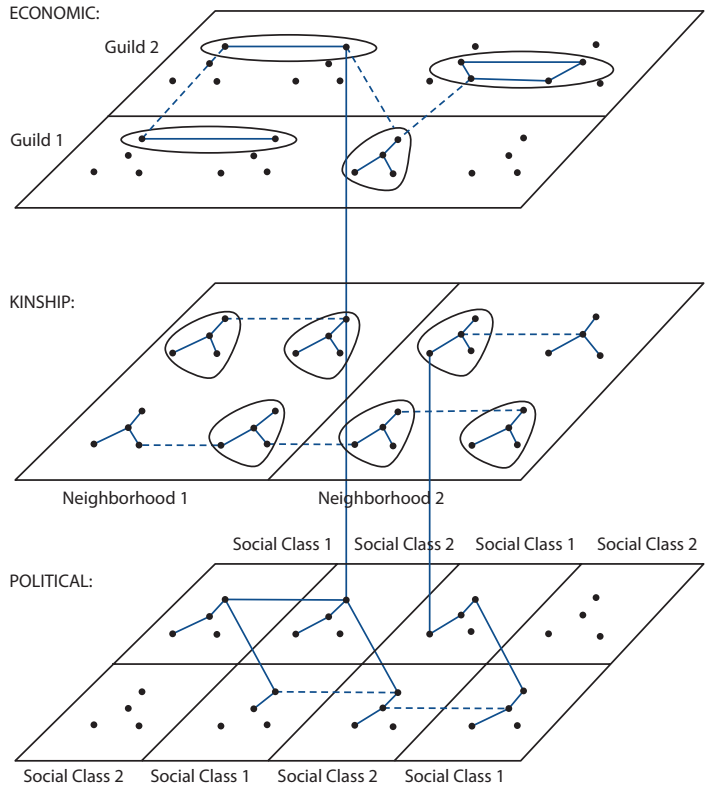
Emerging technologies and networks

- The directionality of emerging technologies is the result of a variety of factors including visions and expectations of the actors involved [Collingridge, 1981, Stirling, 2007, van Lente and Rip, 1998]
- Technological change is not driven by a single actor, but it is "found in the interstices between firms, universities, research laboratories, suppliers, and customers" [Powell, 1990]
- Networks
  - provide actors with access to knowledge and resources (social capital theory) [Nahapiet and Ghoshal, 1998, Burt, 1992]
  - enable actors to engage with the 'problematisations' of the given technology [Blume, 1992]
  - 'signal' actors (e.g. reputation) [Gulati, 1999]

Theoretical framework

Emerging technologies and networks

- The configurations of these networks may significantly affect the distribution of power among the involved actors
- Certain network configurations can increase the involvement of some actors in the emergence process, at the same time excluding others [Willer and Willer, 2000]



Source: [Padgett and Powell, 2012]

Theoretical framework

Literature gap/Contribution

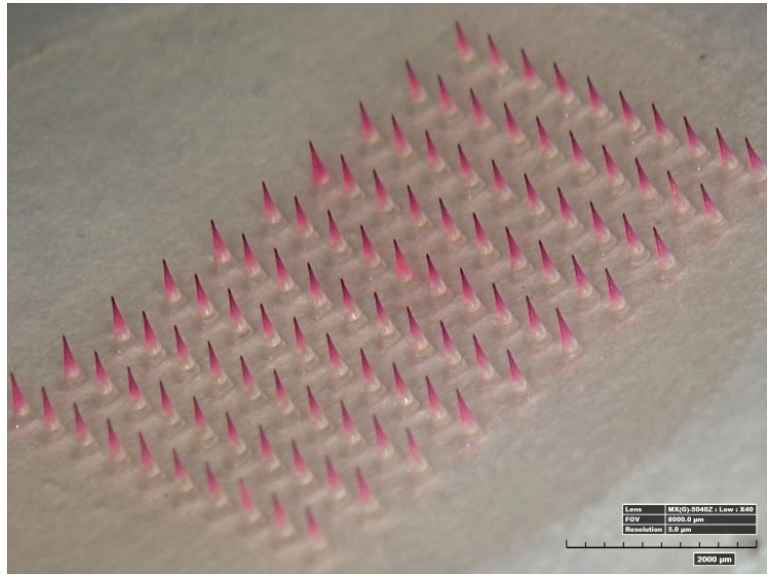
- Limited understanding of the genesis and dynamics of networks in the case of emerging technologies
- Extensive research on network theory, while the theory of network is largely unexplored across many disciplines/contexts

Methods and Data

Methods and Data

Case-study: Microneedles

- **Microneedles** are needles the size of which (i.e. diameter, length) is on the *micrometer* length scale
- Radical novelty: Patch-like structures of microneedles create painlessly micro-holes through which macromolecular drugs can be delivered [Koutsonanos et al., 2012]

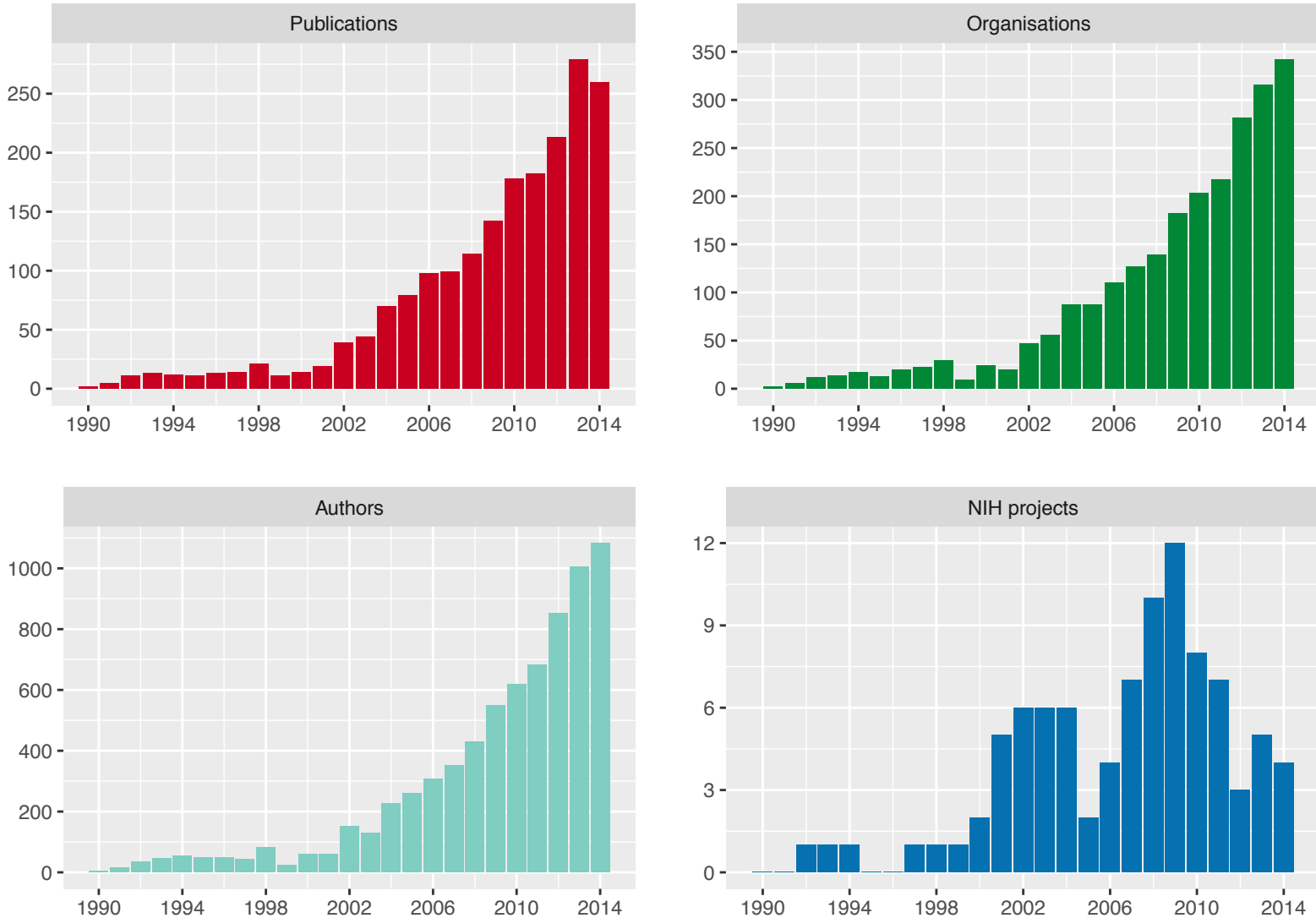


Source: http://www.news.gatech.edu/

Methods and Data

Case-study: Microneedles

Relative fast growth

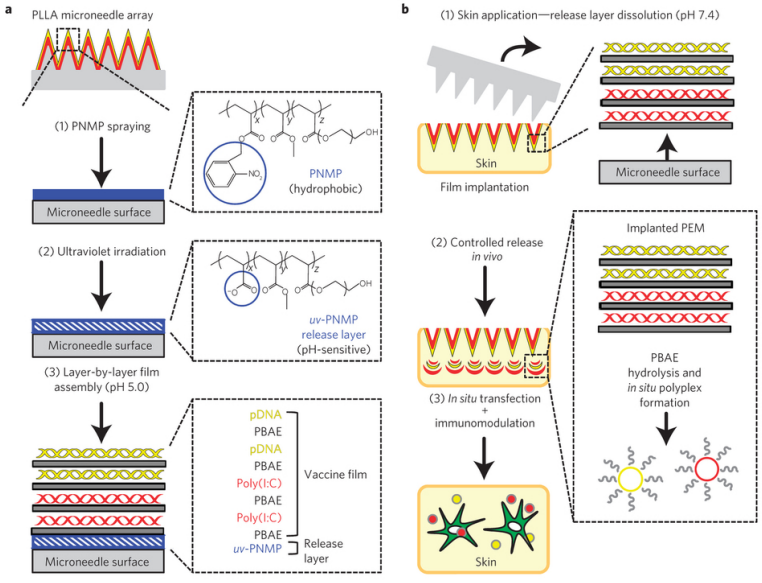


Source: Author's elaboration

Methods and Data

Case-study: Microneedles

- Prominent impact: numerous potential applications (e.g. vaccines, insulin, reduction of biohazard waste)
- Coherence: approach proposed in the 1970s, but demonstrated in the 1990s as a result of to the advancements in microelectronic industry
- Uncertainty and ambiguity: approaches to deliver drugs, materials, and safety (e.g. skin irritation), etc.



Source: [DeMuth et al., 2013]

Methods and Data

Data collection and disambiguation

- Expert-defined keywords
- Keyword-based search in publications' titles, abstracts, and authors' keywords (SCOPUS)
- 1,943 publications (1990-2014 period)
- 1,240 organizations (disambiguation of 3,849 names)
- 5-year window co-authorship networks

  [with all the limitations that come with that!]

Keywords
*microneedle**
*micro-needle**
*microprojection patch**
*micro-projection patch**
micro-projection array
*micromechanical piercing structure**
*micro-mechanical piercing structure**
*microscopic needle**
*micron-scale needle**

Source: Author's elaboration

Methods and Data

Modelling

- The aim is to examine how characteristics of network members and social forces can explain or predict the observed network
- Standard econometric approaches rely on the independence of observations assumption, which is unrealistic in the case of relational data [Snijders, 2011, Robins et al., 2012]
- The statistical analysis of networks requires a different class of models, i.e. Exponential Random Graph Models (ERGM)

Methods and Data

Modelling

- ERGM: the observed network is generated by a stochastic process, i.e. the presence of a given tie is affected by the presence/absence of other ties and/or nodes' attributes
  - The observed network constitutes one possible realization from a distribution of networks
  - A distribution of similar networks (e.g. same number of nodes, ties, etc.) can be generated and compared with the observed network
  - If the value of a given network statistic for the observed network (e.g. number of triangles) is relatively higher than the 'typical' value of the statistic for the distribution of simulated networks, then the mechanism associated with that statistic (e.g. transitivity) is a feature of the observed network

Methods and Data

Modelling

An ERGM model can be specified as:

$$P(Y = y) = \frac{exp(\theta^T g(y))}{k(\theta)} \tag{1}$$

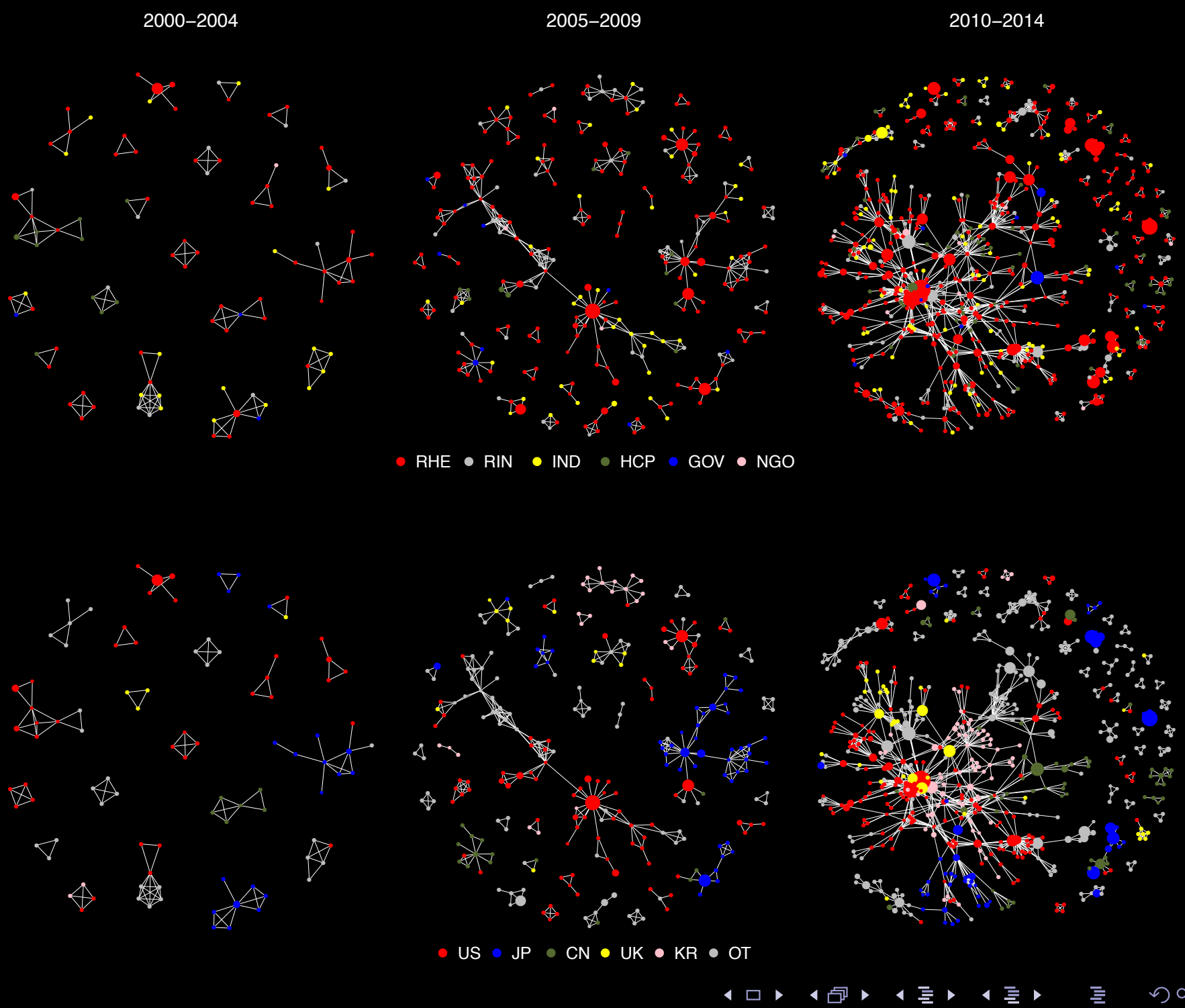
$$logit(Y_{ij} = 1 | y_{ij}^c) = \theta^T \delta(y_{ij}) \tag{2}$$

- Y, random network configuration of n nodes
- $g(y)$, vector of model statistics, **dyad dependent** or **dyad independent** terms
- θ, vector of the coefficients of the model statistics
- $k(\theta)$, normalizing constant
- Y_{ij}, random variable indicating the state of the node pair i and j
- y_{ij}^c, complement of y_{ij}
- $\delta(y_{ij})$, 'change statistic', i.e. how $g(y)$ changes if the y_{ij} tie is added/removed

Methods and Data

Modelling

- Dyad dependent terms [Snijders et al., 2006]
  - Geometrically weighted degree (GWDEGREE)
  - Geometrically weighted edgewise shared partnership (GWESP)
  - Geometrically weighted dyadwise shared partnership (GWDSP)
- Dyad independent terms
  - Organisation country (homophily)
  - Organisation type (homophily): Research and Higher Education (RHE), Healthcare Provider (HCP), Government (GOV), Research Institute (RIN), Industry (IND), Non-Gov. Organization (NGO)
  - Publication activity (number of publications to which an organization contributed in the previous 5 year)
- 5-year co-authorship networks: 2000-04, 2005-09, 2010-14


2000–2004
2005–2009
2010–2014
RHE
RIN
IND
HCP
GOV
NGO
US
JP
CN
UK
KR
OT

Preliminary results

Preliminary results

ERGM estimation

	Model 1 (2000-04 period)	Model 2 (2005-09 period)	Model 3 (2010-14 period)
Structural terms			
Edges	-6.88^{***}	-9.05^{***}	-9.92^{***}
	(0.64)	(0.33)	(0.17)
GWDEGREE	0.92^{**}	1.95^{***}	1.60^{***}
	(0.34)	(0.21)	(0.11)
GWDSP	-0.51^{***}	-0.10^{***}	-0.06^{***}
	(0.10)	(0.03)	(0.01)
GWESP	3.18^{***}	3.59^{***}	4.40^{***}
	(0.25)	(0.15)	(0.11)
Main effects			
Organisation type	0.05	0.10	0.21^{***}
	(0.16)	(0.09)	(0.05)
Organisation country	1.96^{***}	2.10^{***}	1.66^{***}
	(0.16)	(0.09)	(0.05)
Publication activity	0.16^{**}	0.07^{***}	0.05^{***}
	(0.06)	(0.02)	(0.01)
AIC	1082.12	3512.52	10842.40
BIC	1136.24	3577.77	10918.55
Log Likelihood	-534.06	-1749.26	-5414.20
Nodes	184	407	886
Edges	158	460	1347

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$; MCMC diagnostics provided evidence of a robust model specification.

Discussion and conclusions

Discussion and conclusions

- Two geographically co-located actors are more likely to establish a co-authorship tie through the entire emergence process [*proximity and tacit knowledge*]
- Two organizations of the same type are more likely to co-author publications in the most recent phase of the emergence process [*access to complementary knowledge* $\Longrightarrow$ *division of labour*]
- Previous publication activity generates signaling effects that increase the likelihood of forming co-authorship ties [*preferential attachment*; [Leydesdorff and Rafols, 2011]]

Discussion and conclusions

Limitations and future research

- Co-authorship data provide a limited perspective on collaboration activity [Katz and Martin, 1997]
- Counterfactual case and generalizability (need of multiple case-studies)
- Temporal ERGM models for tie formation/dissolution — challenges with the rapidly changing composition of the co-authorship network
- Multi-level networks: authors - affiliations - publications
- Impact of actors' specialization/diversity on the formation of ties

Thank you

www.danielerotolo.com — *d.rotolo@sussex.ac.uk*

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References I

Arthur, W. B. (2007).

The structure of invention.
Research Policy, 36(2):274–287.

Blume, S. S. (1992).

Insight and industry: On the dynamics of technological change in medicine, Cambridge, MA: The MIT Press.
MIT Press, Cambridge, MA.

Boyack, K. W., Klavans, R., Small, H., and Ungar, L. (2014).

Characterizing the emergence of two nanotechnology topics using a contemporaneous global micro-model of science.
Journal of Engineering and Technology Management - JET-M, 32:147–159.

Burt, R. (1992).

Structural holes: The social structure of competition.
Harvard Business Press, London.

Chen, C. (2006).

CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature.
Journal of the American Society for Information Science and Technology, 57(3):359–377.

Collingridge, D. (1981).

The social control of technology, volume 7.
Open University Press, Milton Keynes.

Cozzens, S., Gatchair, S., Kang, J., Kim, K.-S., Lee, H. J., Ordóñez, G., and Porter, A. (2010).

Emerging Technologies: Quantitative Identification and Measurement.
Technology Analysis & Strategic Management, 22(3):361–376.

Day, G. S. and Schoemaker, P. J. H. (2000).

Avoiding the pitfalls of emerging technologies.
California Management Review, 42(2):8–33.

References II

DeMuth, P. C., Min, Y., Huang, B., Kramer, J. a., Miller, A. D., Barouch, D. H., Hammond, P. T., and Irvine, D. J. (2013).

Polymer multilayer tattooing for enhanced DNAvaccination.
Nature materials, 12(4):367–76.

Furukawa, T., Mori, K., Arino, K., Hayashi, K., and Shirakawa, N. (2015).

Identifying the evolutionary process of emerging technologies: A chronological network analysis of World Wide Web conference sessions.
Technological Forecasting and Social Change, 91(February):280–294.

Gulati, R. (1999).

Network Location and Learning: The Influence of Network Resources and Firm Capabilities on Alliance Formation.
Strategic Management Journal, 20(5):397–420.

Katz, J. and Martin, B. R. (1997).

What is research collaboration?
Research Policy, 26(1):1–18.

Kay, L., Newman, N., Youtie, J., Porter, A. L., and Rafols, I. (2014).

Patent overlay mapping: Visualizing technological distance.
Journal of the Association for Information Science and Technology, 65(12):2432–2443.

Koutsonanos, D. G., Vassilieva, E. V., Stavropoulou, A., Zarnitsyn, V. G., Esser, E. S., Taherbhai, M. T., Prausnitz, M. R., Compans, R. W., and Skountzou, I. (2012).

Delivery of subunit influenza vaccine to skin with microneedles improves immunogenicity and long-lived protection.
Sci Rep, 2:357.

Leydesdorff, L. and Rafols, I. (2011).

Local emergence and global diffusion of research technologies: An exploration of patterns of network formation.
Journal of the American Society for Information Science and Technology, 62(5):846–860.

Moed, H. F. (2010).

Measuring contextual citation impact of scientific journals.
Journal of Informetrics, 4(3):265–277.

References III

Morris, S. a., Yen, G., Wu, Z., and Asnake, B. (2002).

Timeline Visualisation of Research Fronts.
Journal American Society for Information Science and Technology, 54(5):1–25.

Nahapiet, J. and Ghoshal, S. (1998).

Social Capital, Intellectual Capital, and the Organizational Advantage.
The Academy of Management Review, 23(2):242–266.

Ohniwa, R. L., Hibino, A., and Takeyasu, K. (2010).

Trends in research foci in life science fields over the last 30 years monitored by emerging topics.
Scientometrics, 85(1):111–127.

Padgett, J. F. and Powell, W. W. (2012).

The emergence of organizations and markets.
Princeton University Press, Princeton, New Jersey.

Porter, A. L. and Detampel, M. J. (1995).

Technology opportunities analysis.
Technological Forecasting and Social Change, 49(3):237–255.

Powell, W. W. (1990).

The Transformationof Organizational Formes: How useful is organization theory in accounting for social change?
In Friedland, R. O. and Robertson, A., editors, *Beyond the Marketplace: Rethinking Economy and Society*, pages 301–325.
Walter de Gruyter, New York, NY, USA.

Rafols, I., Porter, A. L., and Leydesdorff, L. (2010).

Science Overlay Maps: A new tool for research policy and library management.
Journal of the American Society for Information Science and Technology (JASIST), 61(9):1871–1887.

Robins, G., Lewis, J. M., and Wang, P. (2012).

Statistical Network Analysis for Analyzing Policy Networks.
Policy Studies Journal, 40(3):375–401.

References IV

Rotolo, D., Hicks, D., and Martin, B. R. (2015).

What is an emerging technology?
Research Policy, 44(10):1827–1843.

Small, H., Boyack, K. W., and Klavans, R. (2014).

Identifying emerging topics in science and technology.
Research Policy, 43(8):1450–1467.

Snijders, T. A. B. (2011).

Statistical Models for Social Networks.
Annual Review of Sociology, 37(1):131–153.

Snijders, T. A. B., Pattison, P. E., Robins, G. L., and Handcock, M. S. (2006).

New specifications for exponential random graph models.

Srinivasan, R. (2008).

Sources, characteristics and effects of emerging technologies: Research opportunities in innovation.
Industrial Marketing Management, 37(6):633–640.

Stirling, A. (2007).

A general framework for analysing diversity in science, technology and society.
Journal of the Royal Society, Interface / the Royal Society, 4(15):707–19.

van Lente, H. and Rip, A. (1998).

The Rise of Membrane Technology: From Rhetorics to Social Reality.
Social Studies of Science, 28(2):221–254.

Willer, R. and Willer, D. (2000).

Exploring dynamic networks: hypotheses and conjectures.
Social Networks, 22(3):251–272.