New patterns of scientific growth? Longitudinal comparison of breakthroughs in physics and chemistry

Prof. Dr. Thomas Heinze

Bergische Universität Wuppertal

Context

- My talk is based on a recently published paper...

  Heinze, T. et al. (2013): New patterns of scientific growth. How research expanded after the invention of Scanning Tunneling Microscopy and the discovery of Buckminsterfullerenes. *Journal of the American Society for Information Science and Technology* 64: 829–843.

- ... and on the outline of a bibliometric research project that aims to go beyond these initial findings.

  Heinze, T. & Jappe, A.: New patterns of scientific growth? Longitudinal comparison of theoretical, methodological, empirical, and instrumental research breakthroughs in physics and chemistry. Submitted to German Research Foundation (DFG), August 2013.

Two standard models of scientific progress & growth

- It is commonly believed that the formulation of new theories represents the major route to the advancement of knowledge:

  „Theory model of scientific progress“

  Popper (1959); Merton (1968); Lakatos (1970); Kuhn (1970); Latour & Woolgar (1979); Laudan (1984); Gähde (2009).

- It is commonly believed that scientific growth unfolds as a process of segmentary differentiation into new specialties and disciplines:

  „Discipline model of scientific growth“

  Griffith & Mullins (1972); Stichweh (1984); Whitley (1984); Luhmann (1992); Vinck (2010).

Model criticism and research desiderata

- **Model criticism**
  - Experiments and experimental systems matter much more than acknowledged by the theory model: Hacking (1983); Rheinberger (1997); Heidelberger & Steinle (1998); Meli (2006).
  - Creative research contributions occur over a wider spectrum than acknowledged by the theory model, including the development of new instrumentation, empirical discoveries, and methodological advances: Gützkow et al. (2004); Heinze et al. (2007); Heinze (2013).
  - Amount of science occuring outside the disciplinary matrix is much larger than acknowledged by the discipline model: Lambert & Mulvay (1996); Shinn & Jörges (2002); Radder (2003).

- **Research desiderata**
  - Is there quantitative, longitudinal evidence that different types of scientific advances lead to different patterns of scientific growth?
  - Is there quantitative, longitudinal evidence of growth patterns that are distinct from segmentary differentiation?

Research questions

- **Growth of follow-up research**

  Q-a: How quickly are breakthroughs taken up by peers?

  Q-b: Does follow-up research reach a peak and then decline?

- **Spectrum and concentration of disciplines in follow-up research**

  Q-c: How many subdisciplines are active in following-up?

  Q-d: Is follow-up research broadly distributed or concentrated?

  Q-e: How interdisciplinary is follow-up research?

- **Intellectual connectivity of follow-up research**

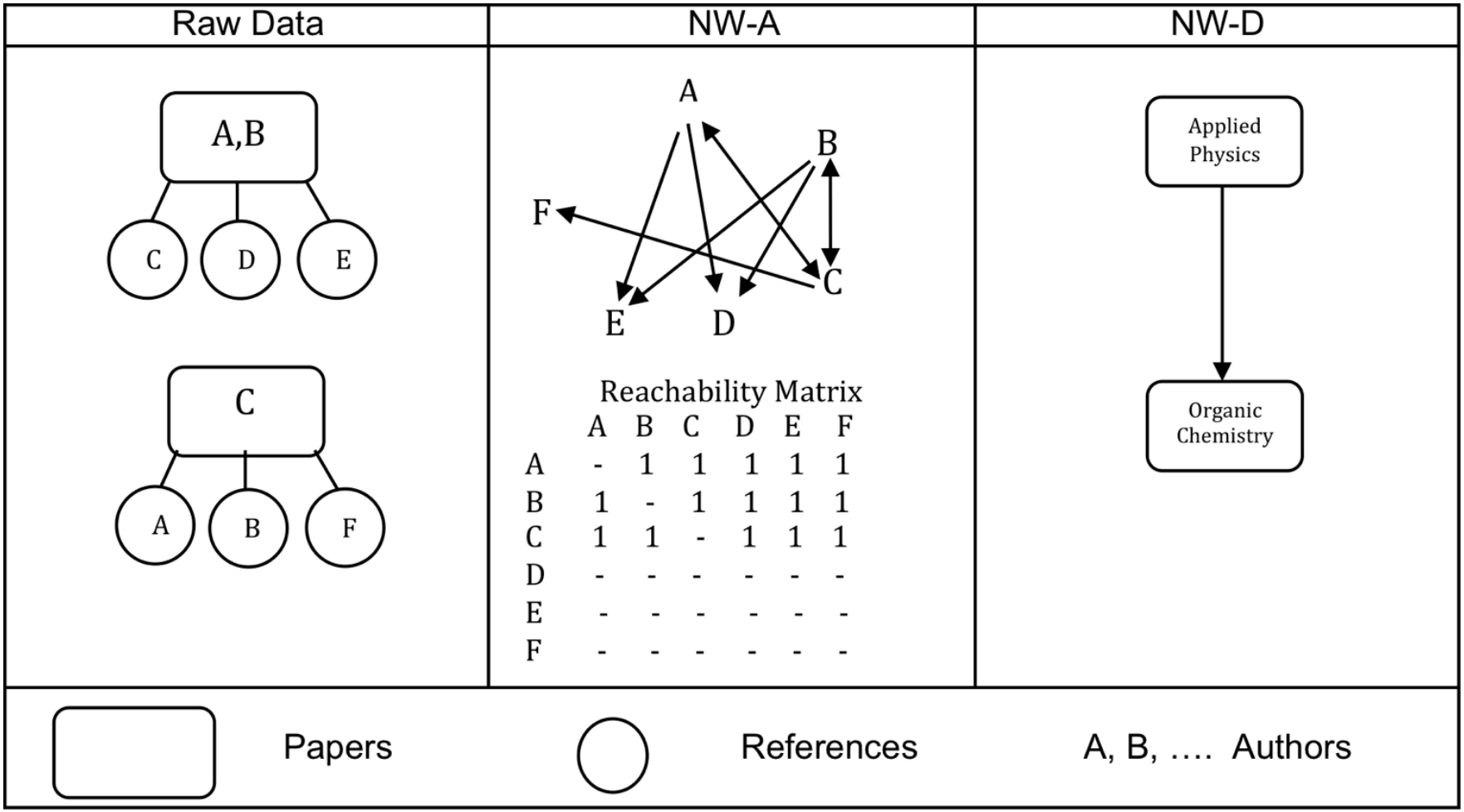
  Q-f: How often do citing scientists recognize each other?

  Q-g: How interconnected is the network of citing scientists?

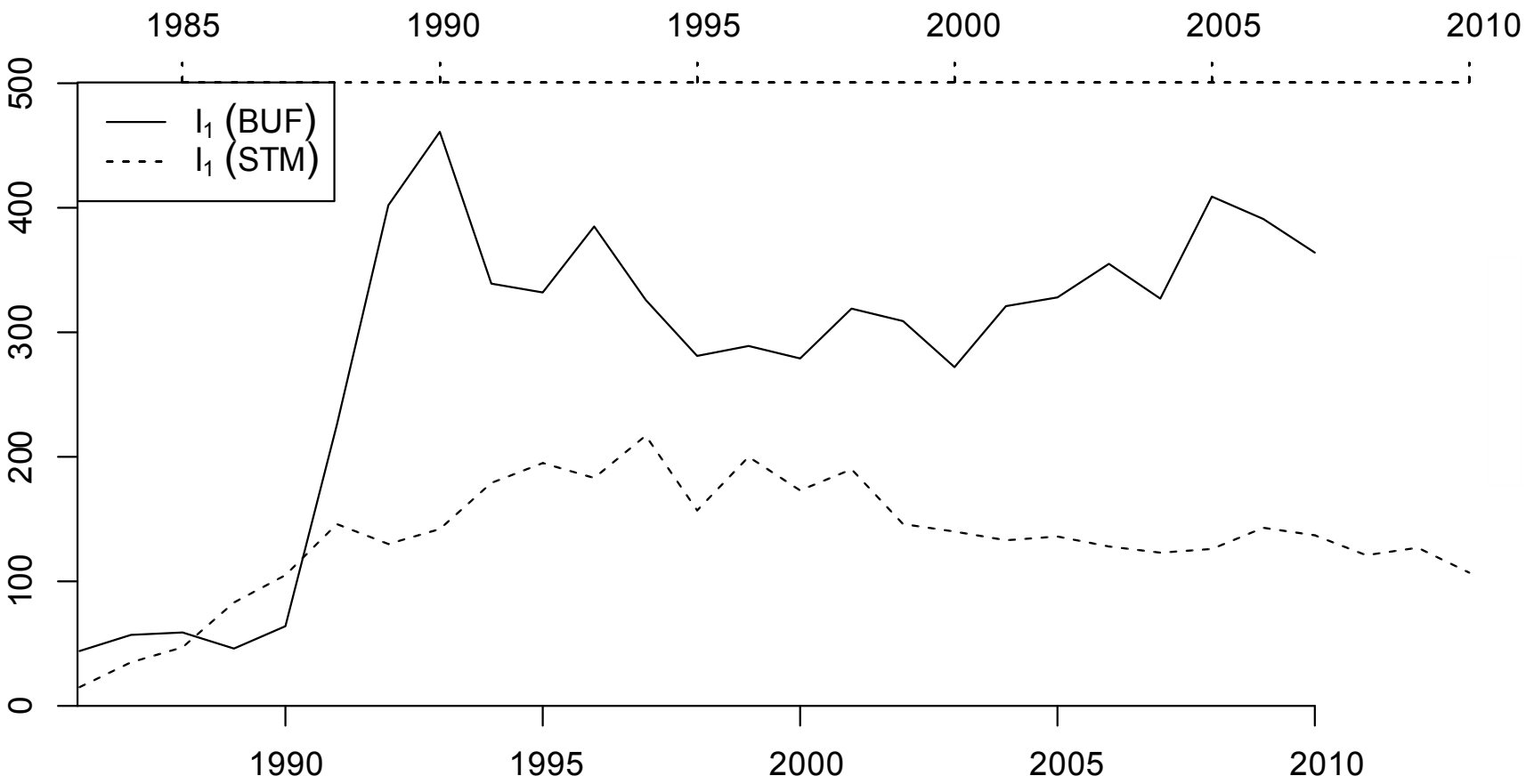
Two breakthroughs: STM and BUF

- Two criteria: high number of citations, Nobel-Prize
- Scanning Tunneling Microscopy (Binnig, Rohrer: Nobel Prize in Physics 1986)
- Buckminster Fullerenes (Kroto, Smalley, Curl: Nobel Prize in Chemistry 1995)
- Using „flag“ articles, we constructed three datasets:
  - publication dataset
  - author citation network dataset
  - subdiscipline citation network dataset

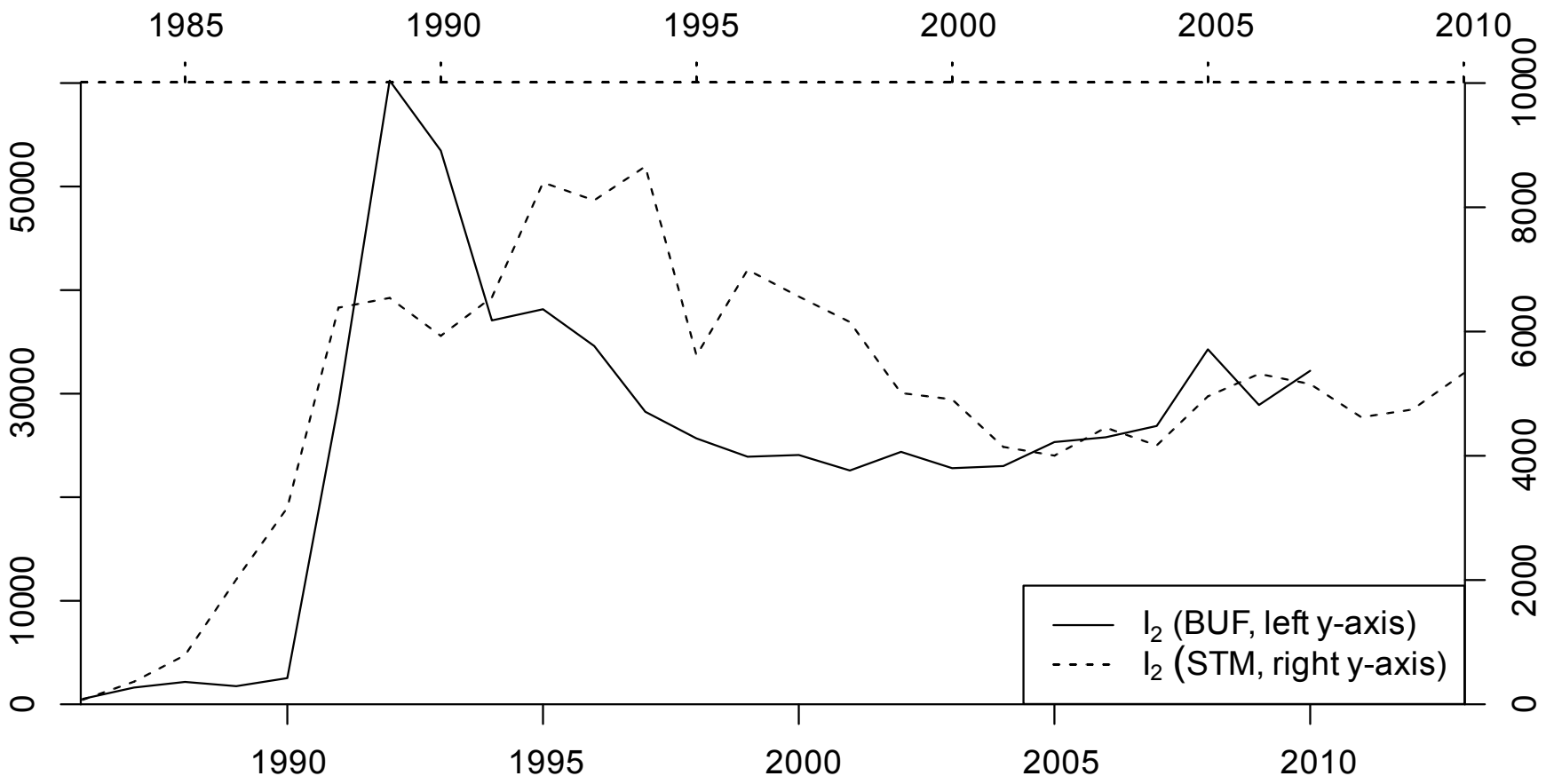
Three databases



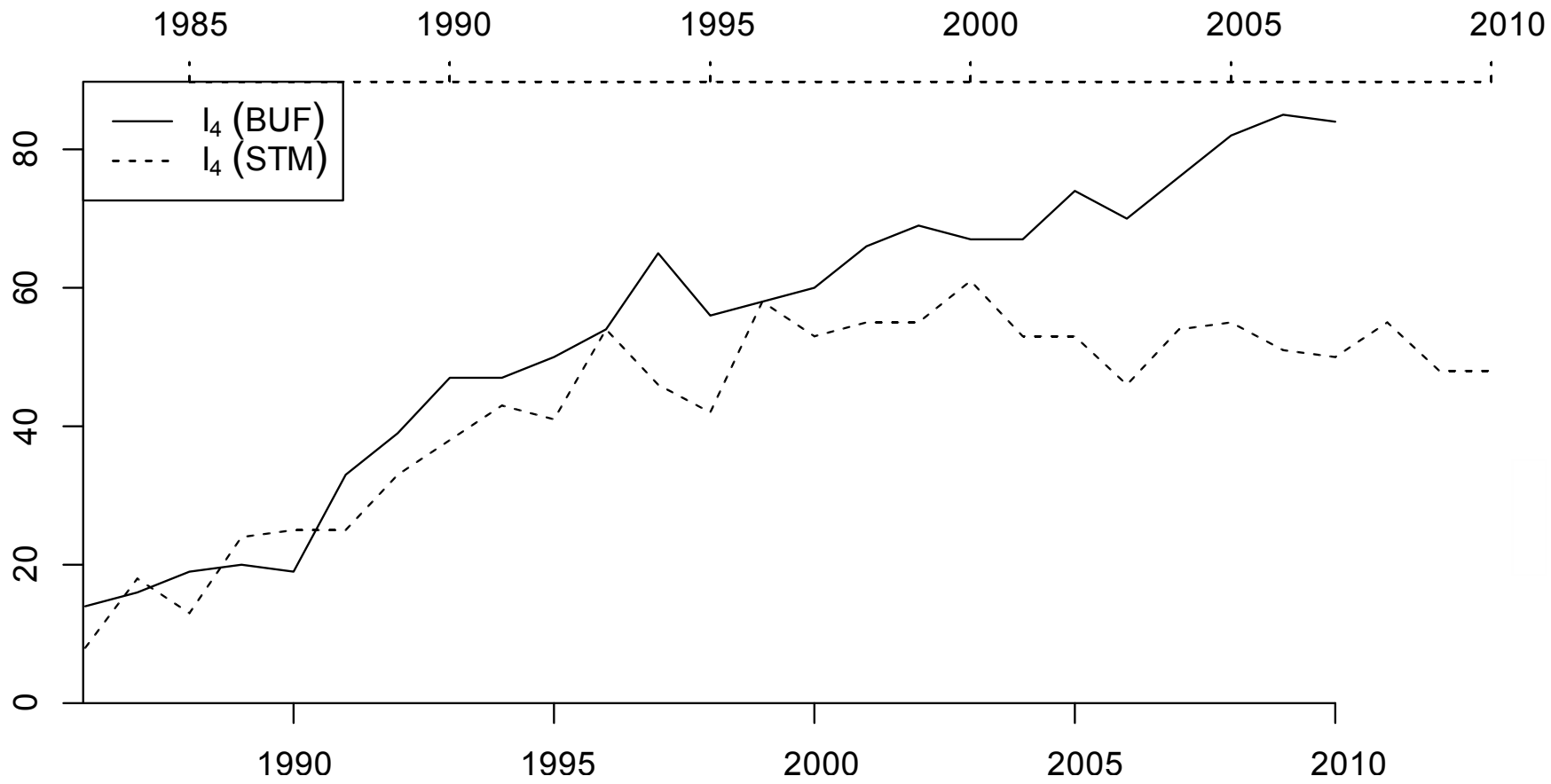
Growth of follow-up research
(Q-a, Q-b/I_1: number of citing articles)



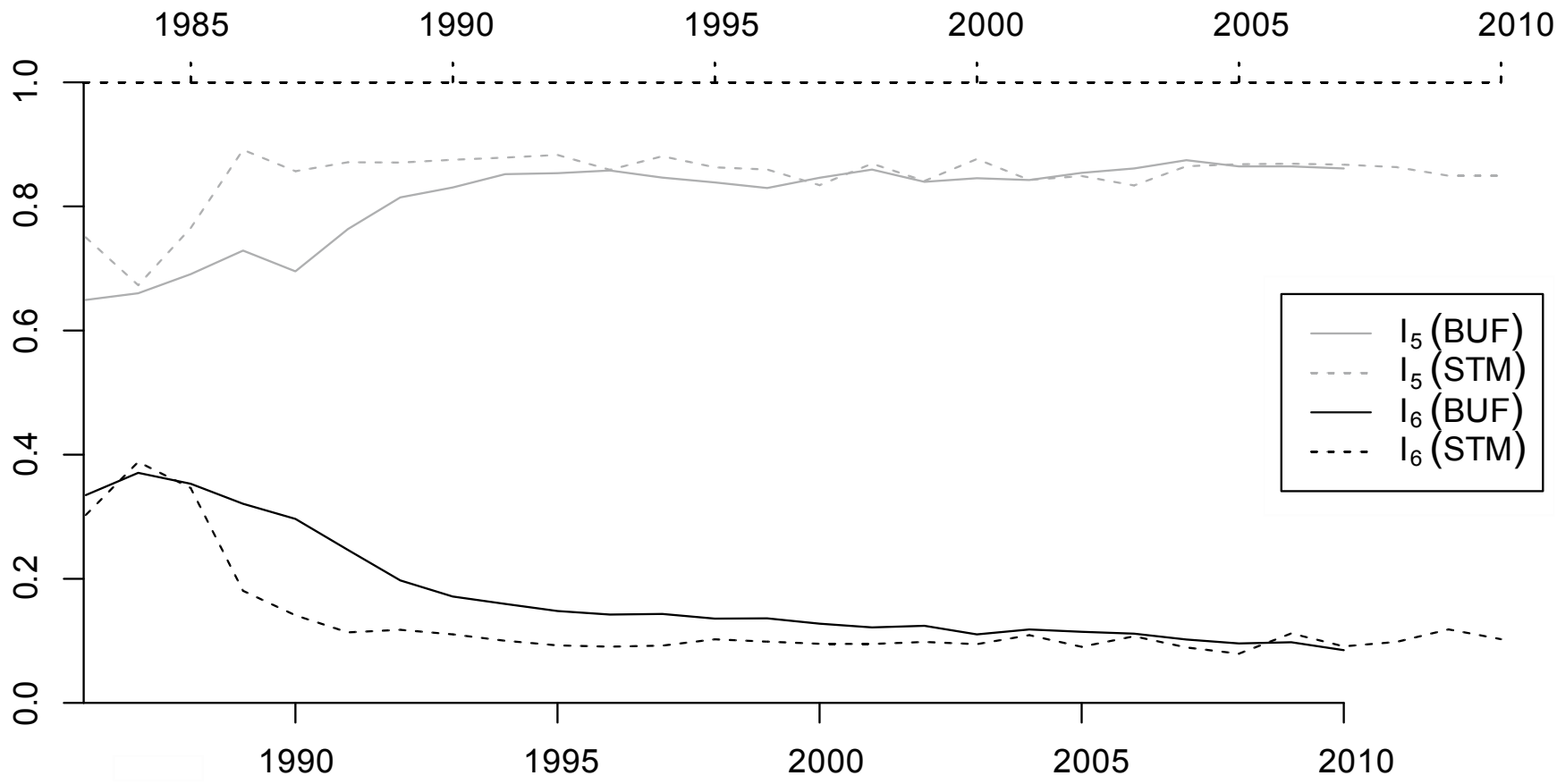
Growth of follow-up research
(Q-a, Q-b/I_2: number of citing authors)



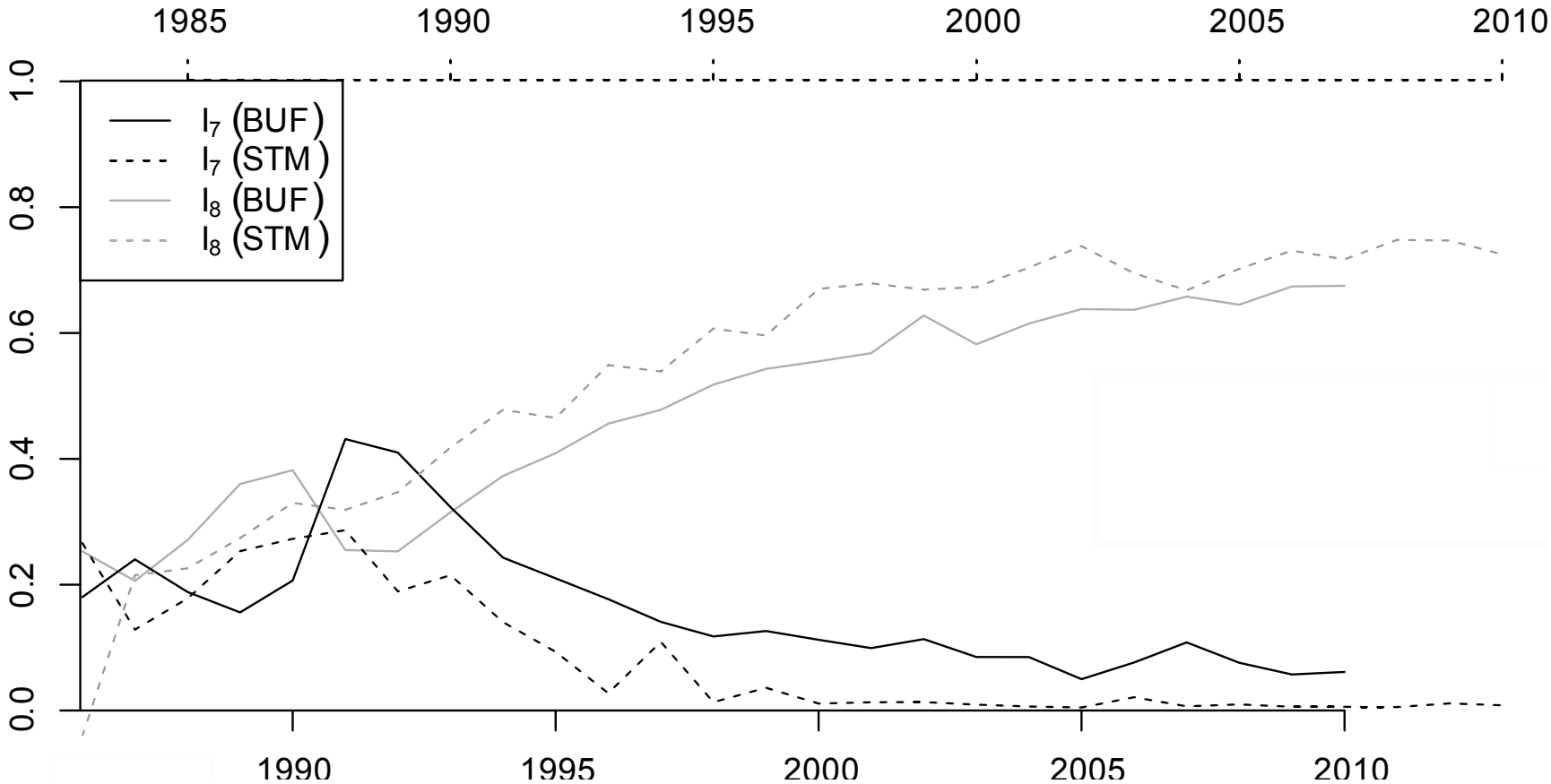
Spectrum of disciplines in follow-up research
(Q-c/I_4: number of citing WoS subject codes)



Spectrum and concentration of disciplines in follow-up research (Q-d/I_5: share of citations between WoS subject codes) (Q-e/I_6: Herfindahl-Index for ingoing WoS subject code citations)



Intellectual connectivity
(Q-f/I_7: Reachability index; Q-g/I_8: Modularity index)



Conclusions and limitations

- Empirical findings suggest that scientific growth is a complex phenomenon, but it is worthwhile to investigate different types of breakthroughs.

- Limitation 1: neither theory case nor method case have been empirically investigated so far.

- Limitation 2: it is not clear whether STM and BUF can be used for generalization regarding research instrumentation and new empirical phenomena/ discoveries.

New research project (1): objectives

- Objective 1: complement the existing two case studies (BUF and STM) by two further cases of Nobel Prize winning contributions, one theoretical advance and one method advance.
- Objective 2: apply the same method to a larger sample of cases: all scientific accomplishments recognized with a Nobel Prize in physics or chemistry in a period where bibliometric data are available.

New research project (2): population

Nobel Prize winning research in physics or chemistry between 1975-2012.

	Physics	**Chemistry**
theoretical advance	17 (3)	7 (0)
new empirical phenomenon	25 (7)	26 (7)
new method	14 (4)	27 (7)
new instrument	13 (6)	2 (0)
lifetime achievement	5	9
Total	**64 (10)**	**64 (7)**

Source: www.nobelprize.org, own classification, double assignments in brackets

New research project (3): sample

Nobel Prize winning research in physics or chemistry between 1975-2012, and published between 1970-1986.

	Physics	**Chemistry**
theoretical advance	6	0
new empirical phenomenon	9	12 (2)
new method	2	13 (2)
new instrument	2	1
Total published 1970-1986	**19 (0)**	**24 (2)**

Source: www.nobelprize.org, own classification, double assignments in brackets