News on the history of chemical reactions

Computational history of chemistry

Guillermo Restrepo
Max Planck Institute for Mathematics in the Sciences
Leipzig, Germany

Interdisciplinary Center of Bioinformatics
Leipzig University, Germany

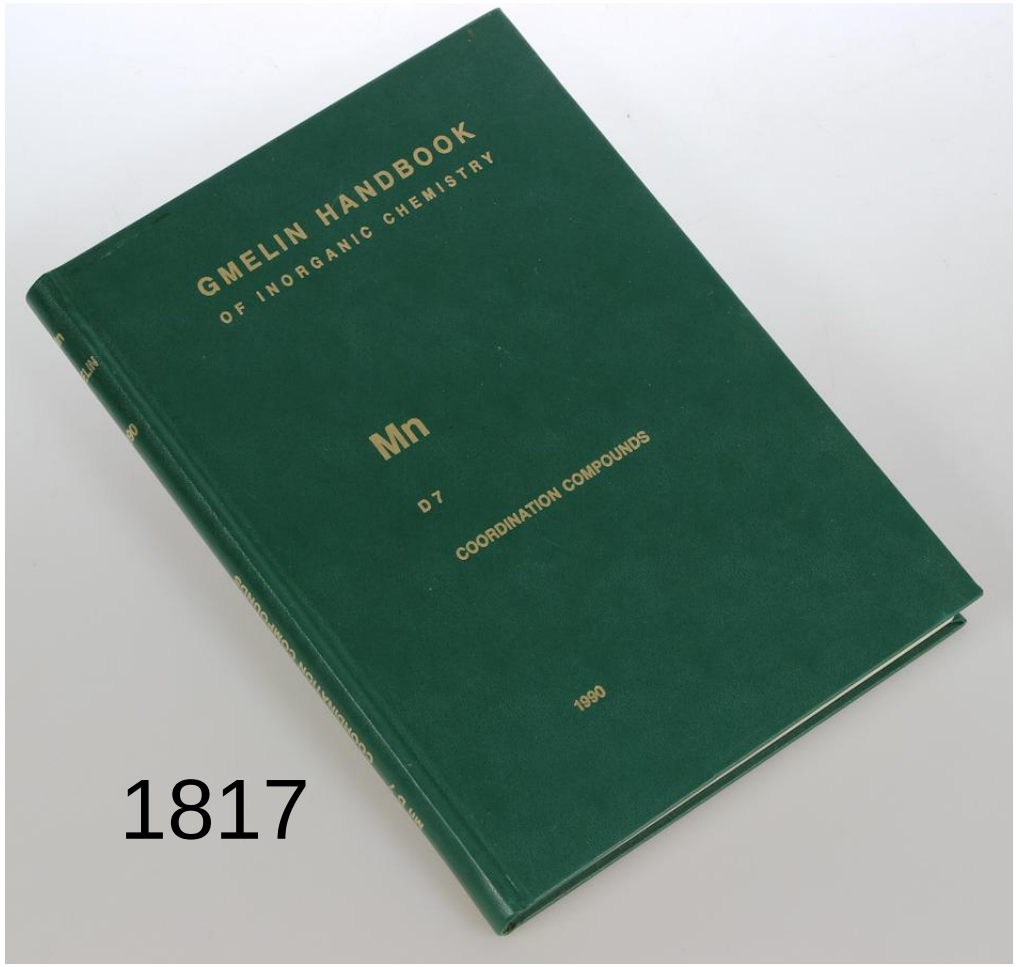
Eugenio Llanos, Wilmer Leal & Peter Stadler

12th February 2018

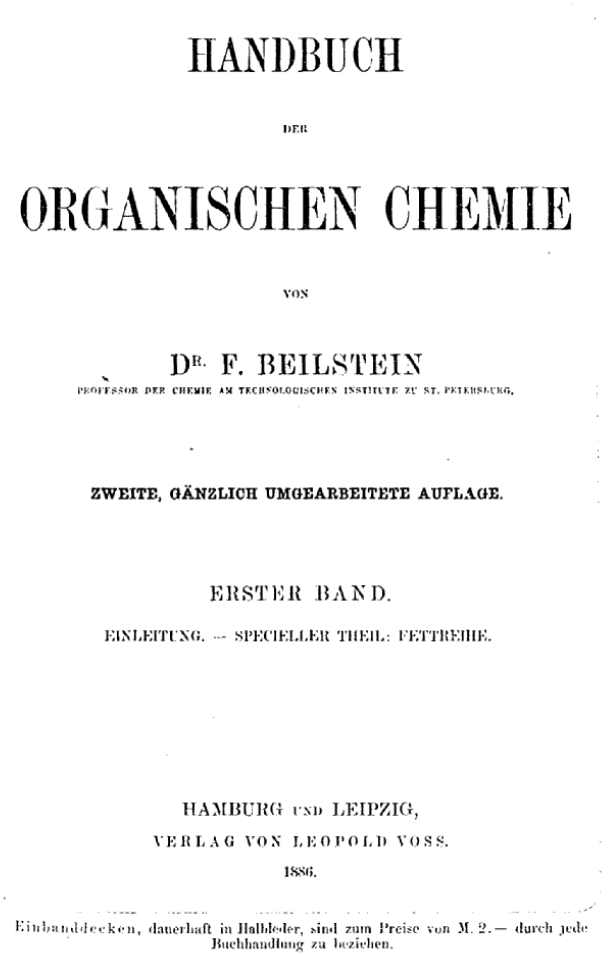
Outline

- Reaxys database
- Model of chemical reactions
- Substances & Reactions
  - Growth
  - War effects
- Exploring the chemical space
  - Educts/Products per reaction
  - Participation of substances in reactions
  - Combinations of chemical elements
- Conclusions

Reaxys database



1817



HANDBUCH

DER

ORGANISCHEN CHEMIE

VON

DR. F. BEILSTEIN

PROFESSOR DER CHEMIE AM TECHNOLOGISCHEN INSTITUTE ZU ST. PETERSBURG.

ZWEITE, GÄNZLICH UMGEARBEITETE AUFLAGE.

ERSTER BAND.

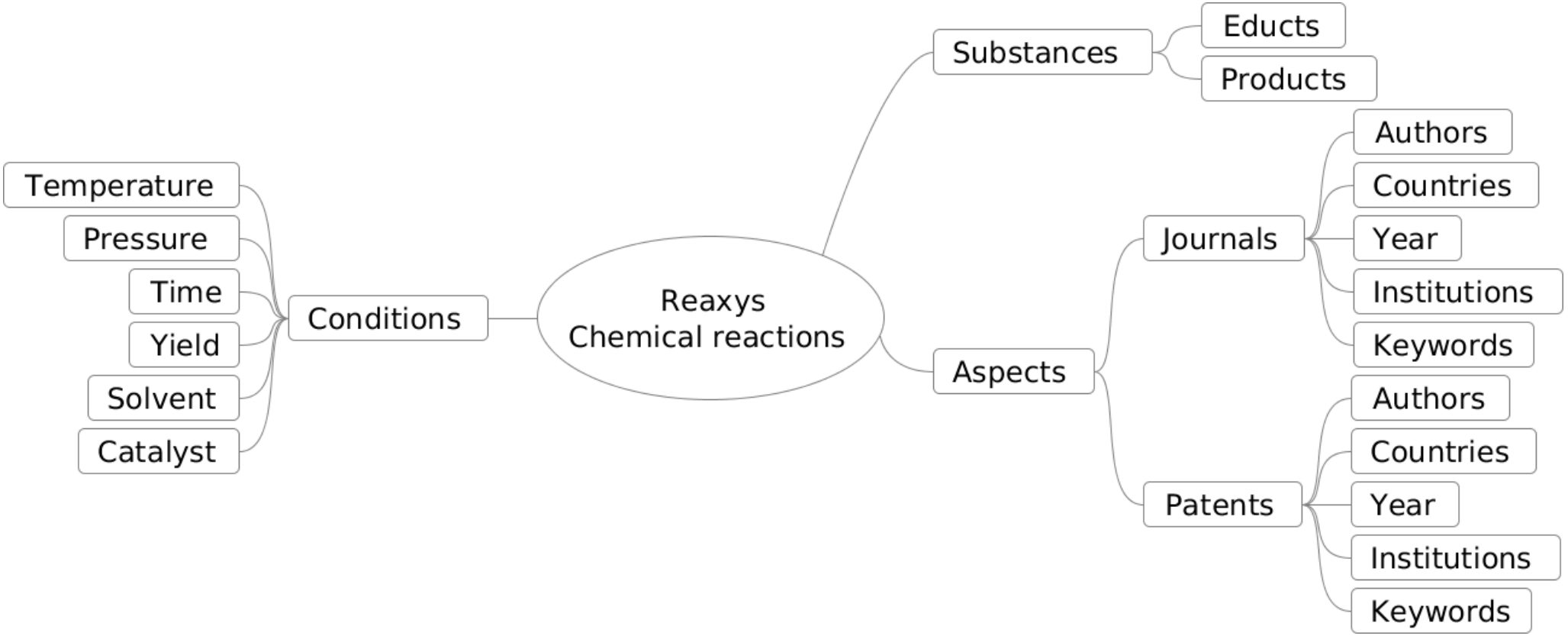
EINLEITUNG. — SPECIELLER THEIL: FETTREIHE.

HAMBURG UND LEIPZIG,
VERLAG VON LEOPOLD VOSS.
1886.

Einbanddecken, dauerhaft in Halbleder, sind zum Preise von M. 2.— durch jede Buchhandlung zu beziehen.

1881

Patent database (English)
1976



January 2017

Reactions
42,781,477

Full
36,834,852
Educts → → Products

Single-step
23,268,893
Educts → Products
Educts →
→ Products

Full & Single-step
16,684,776
Educts → Products

Issue 15, 2014

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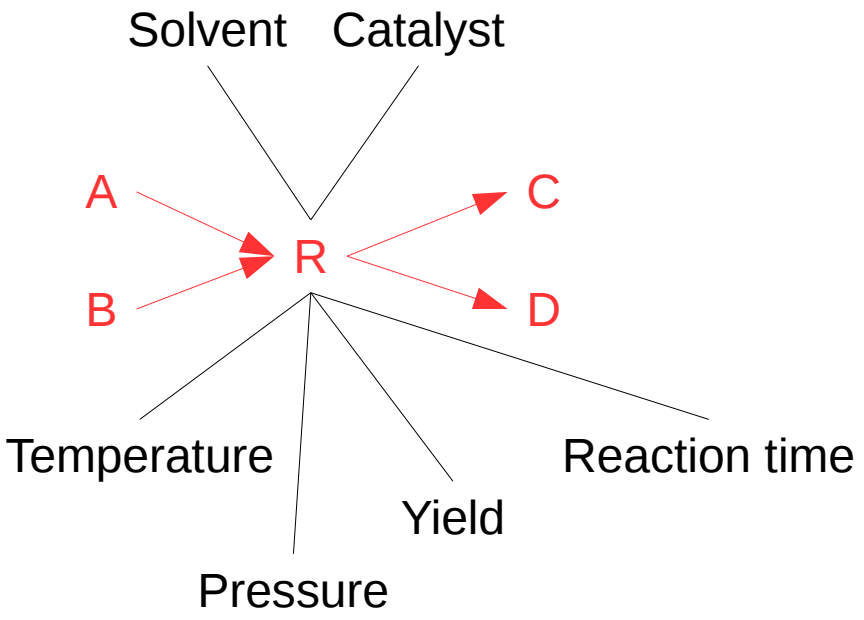
From the journal:
Chemical Society Reviews

Anthropogenic reaction parameters – the missing link between chemical intuition and the available chemical space

György M. Keserű,*[a] Tibor Soós*[a] and C. Oliver Kappe*[b]

- There are several anthropogenic factors that limit the reaction parameters and thus the scope of synthetic chemistry
- We argue that these are at least partly responsible for limited access to new chemistries

Model of chemical reactions



Substances & Reactions
Growth of substances and reactions

Angewandte International Edition Chemie
GDCh A Journal of the Gesellschaft Deutscher Chemiker
Explore this journal >

Communication

Architecture and Evolution of Organic Chemistry†

Marcin Fialkowski Dr., Kyle J. M. Bishop, Victor A. Chubukov, Christopher J. Campbell, Bartosz A. Grzybowski Prof. Dr.

First published: 8 November 2005 Full publication history

DOI: 10.1002/anie.200502272 View/save citation

Cited by: 32 articles Citation tools

Am score

Data from Beilstein (organic chemistry)
April 2004

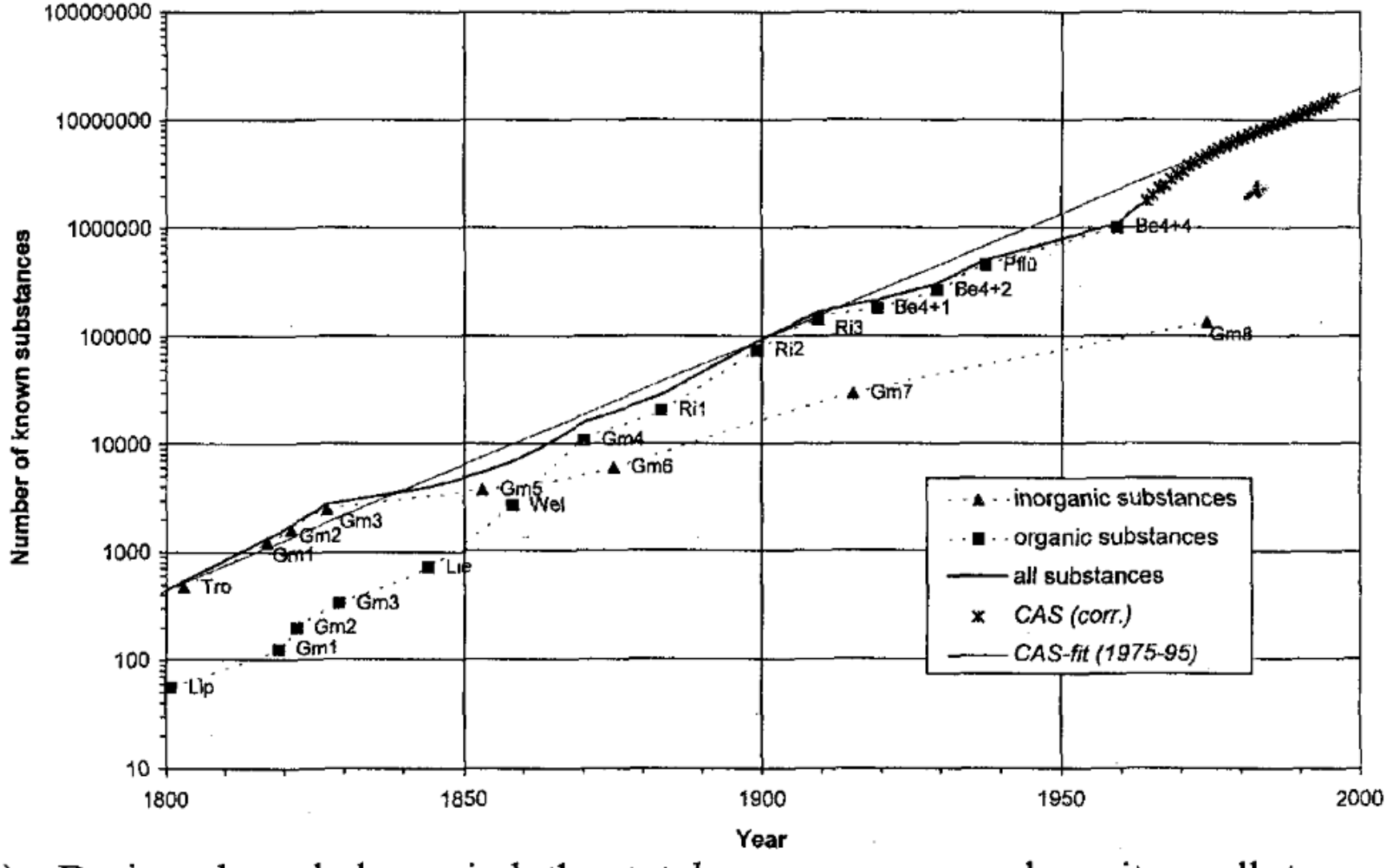
9,550,398 substances
9,293,250 reactions

The number of substances and the number of chemical reactions have increased exponentially

SCIENTOMETRIC STUDIES ON CHEMISTRY I: THE EXPONENTIAL GROWTH OF CHEMICAL SUBSTANCES, 1800–1995

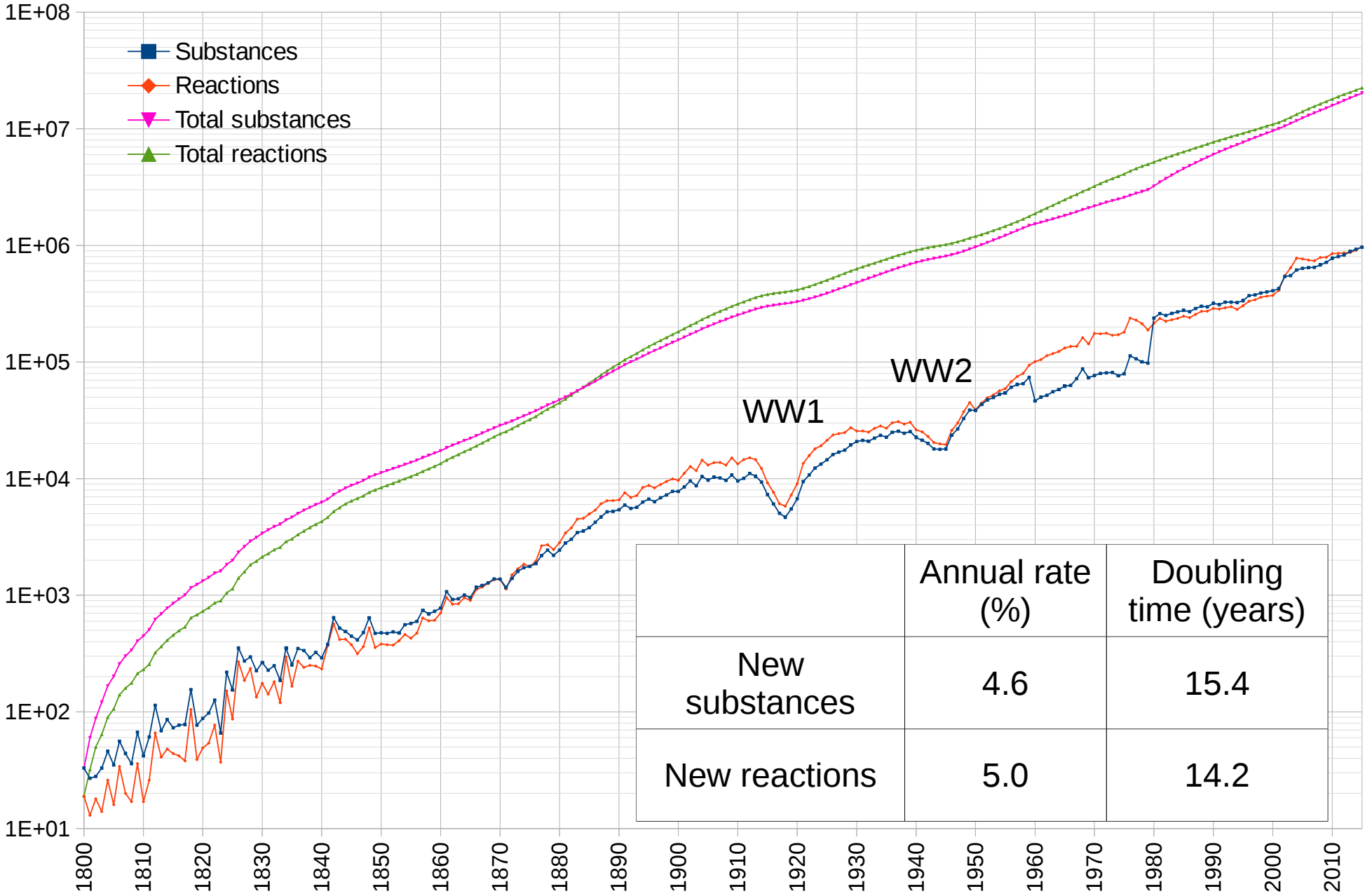
Scientometrics,
Vol. 39, No. 1 (1997) 107–123

J. SCHUMMER



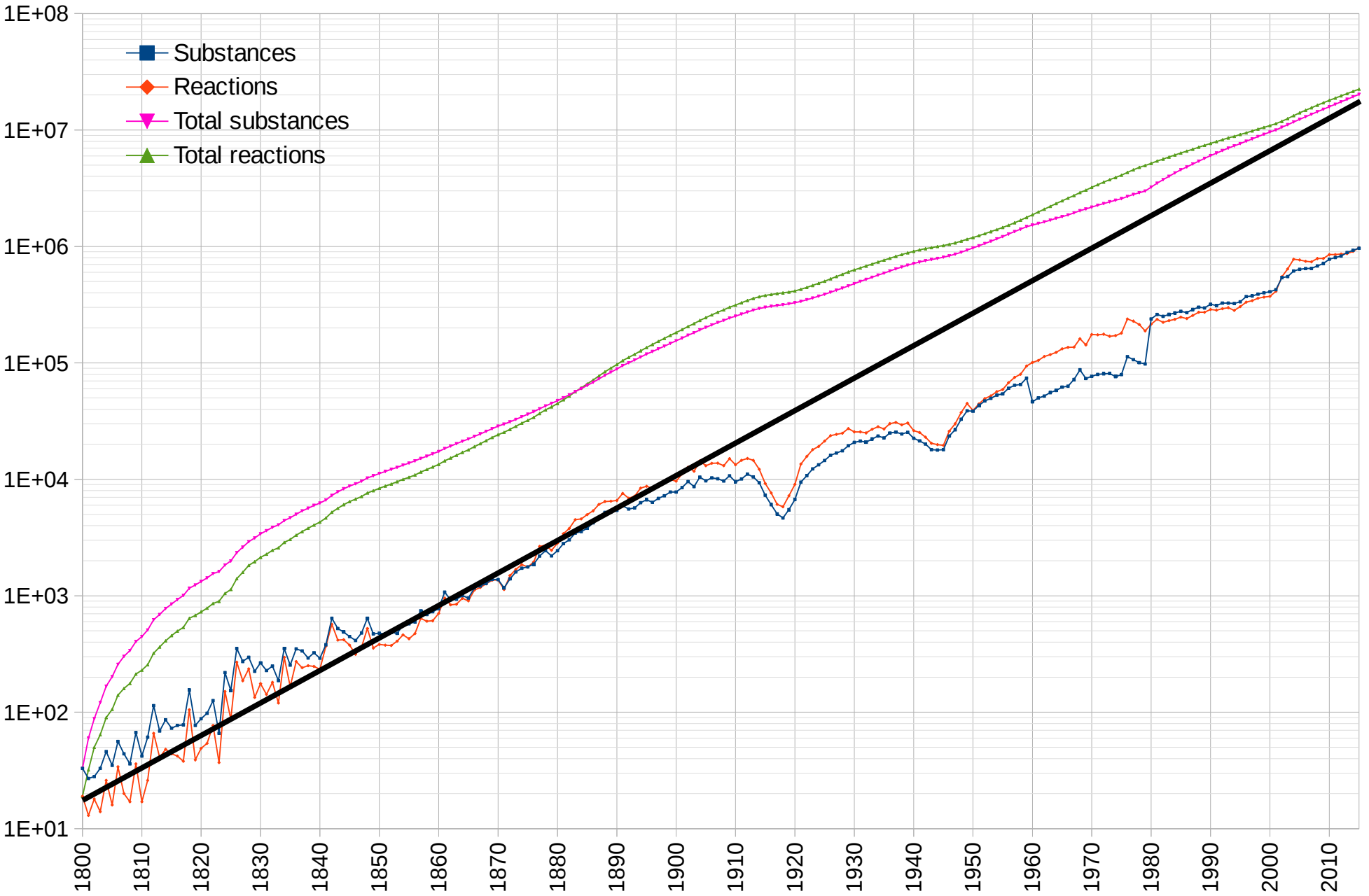
(1) During the whole period the *total curve* corresponds quite well to a stable exponential growth (i.e. a straight line in semi-logarithmic scale) with an annual rate of 5.5% and doubling time of 12.9 years.

Substances & Reactions - growth



	Annual rate (%)	Doubling time (years)
New substances	4.6	15.4
New reactions	5.0	14.2

What would have happened without wars?


Substances
Reactions
Total substances
Total reactions
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

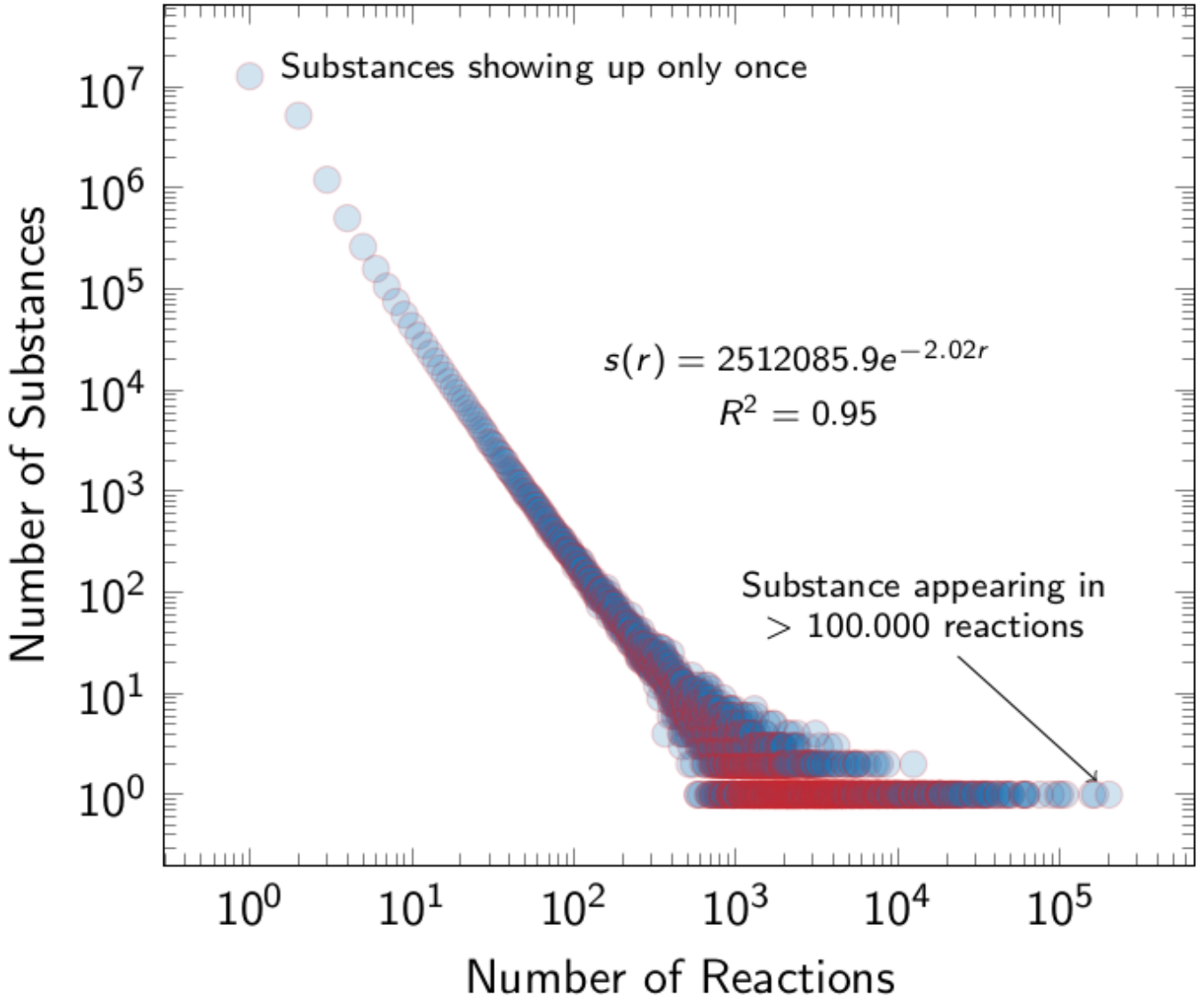
What would have happened without wars?

	Annual rate (%)	Doubling time (years)	Substances-reactions by 2015
New substances	4.6	15.4	966,965
Peaceful new substances	5.5	12.9	3,226,240
New reactions	5.0	14.2	977,233
Peaceful new reactions	6.6	10.8	18,161,557

We would have explored by far more chemical space!

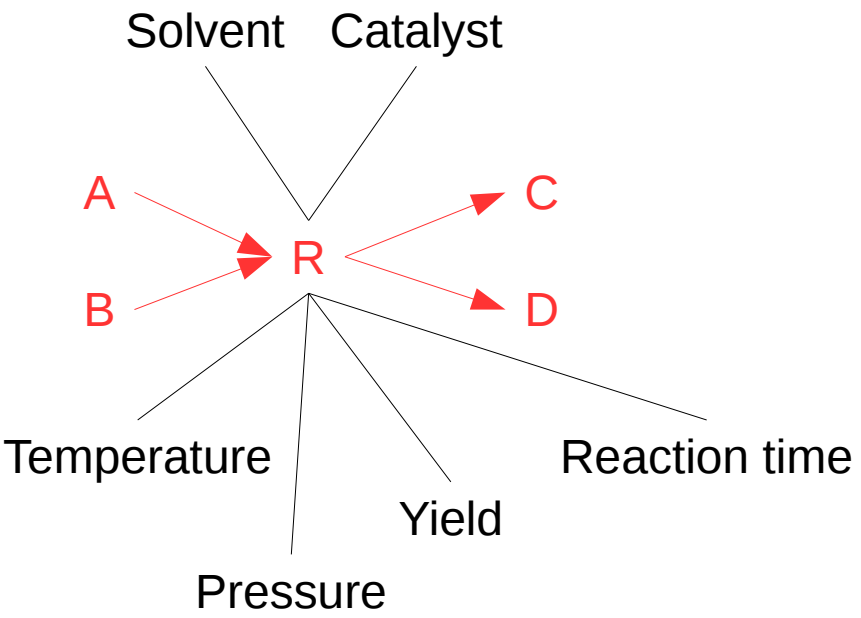
Substances

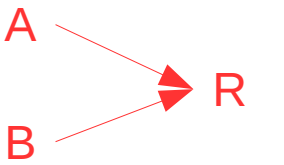
How chemists have explored the space of substances?



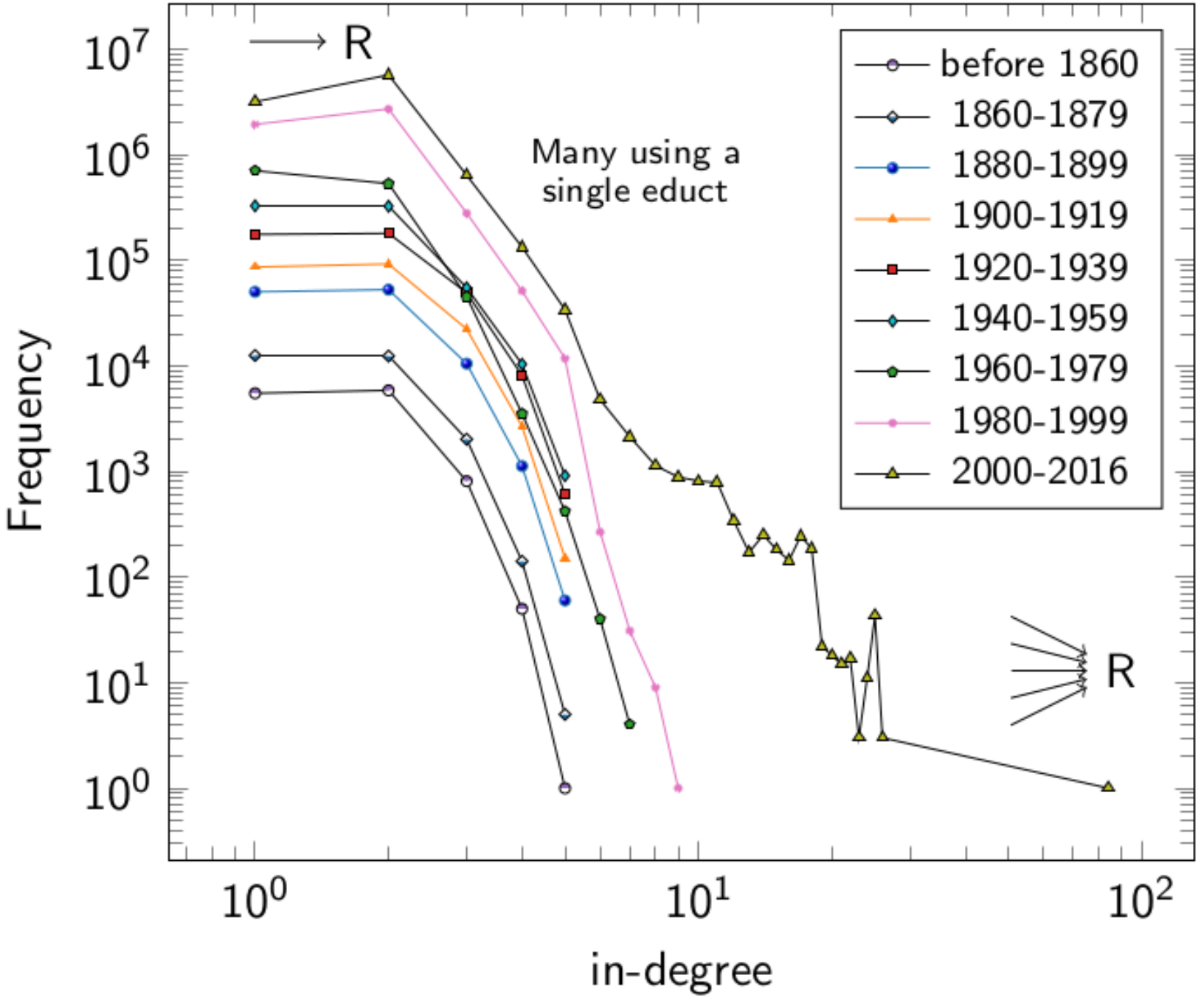
They concentrate on some few substances

Do chemists combine many reactants per reaction?

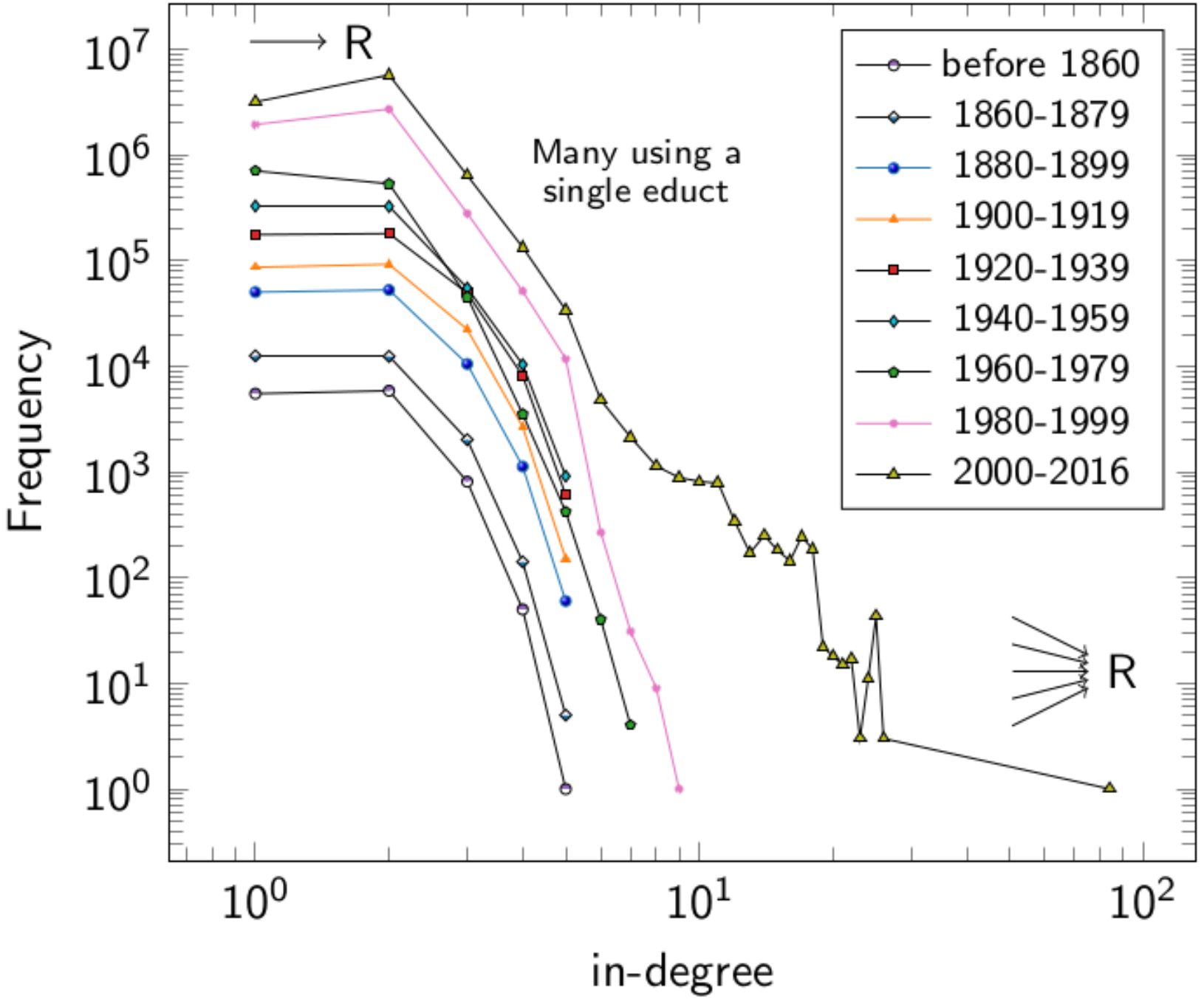




In-degree

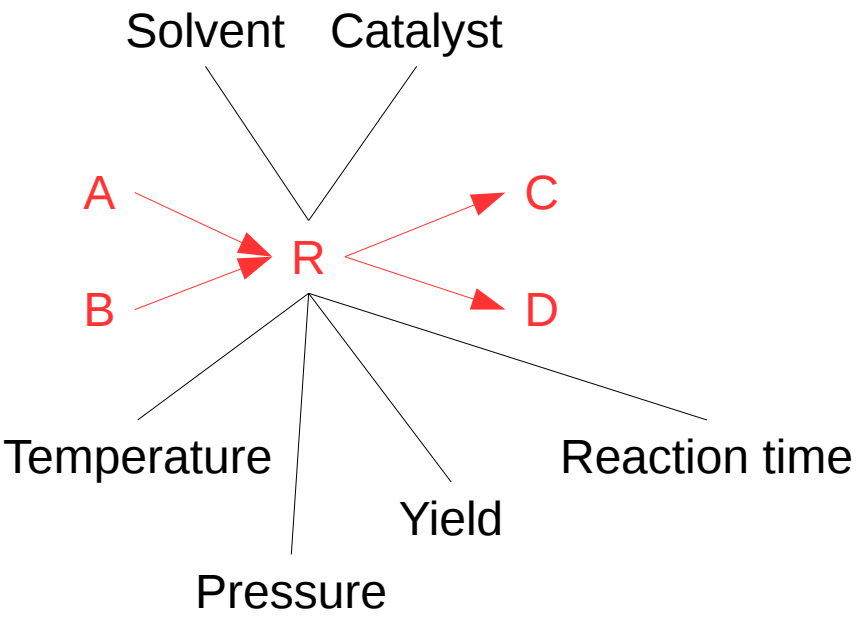


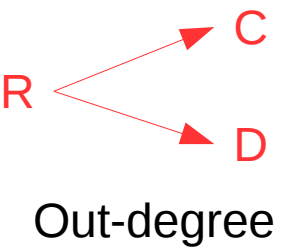
They combine few of them (1-2)



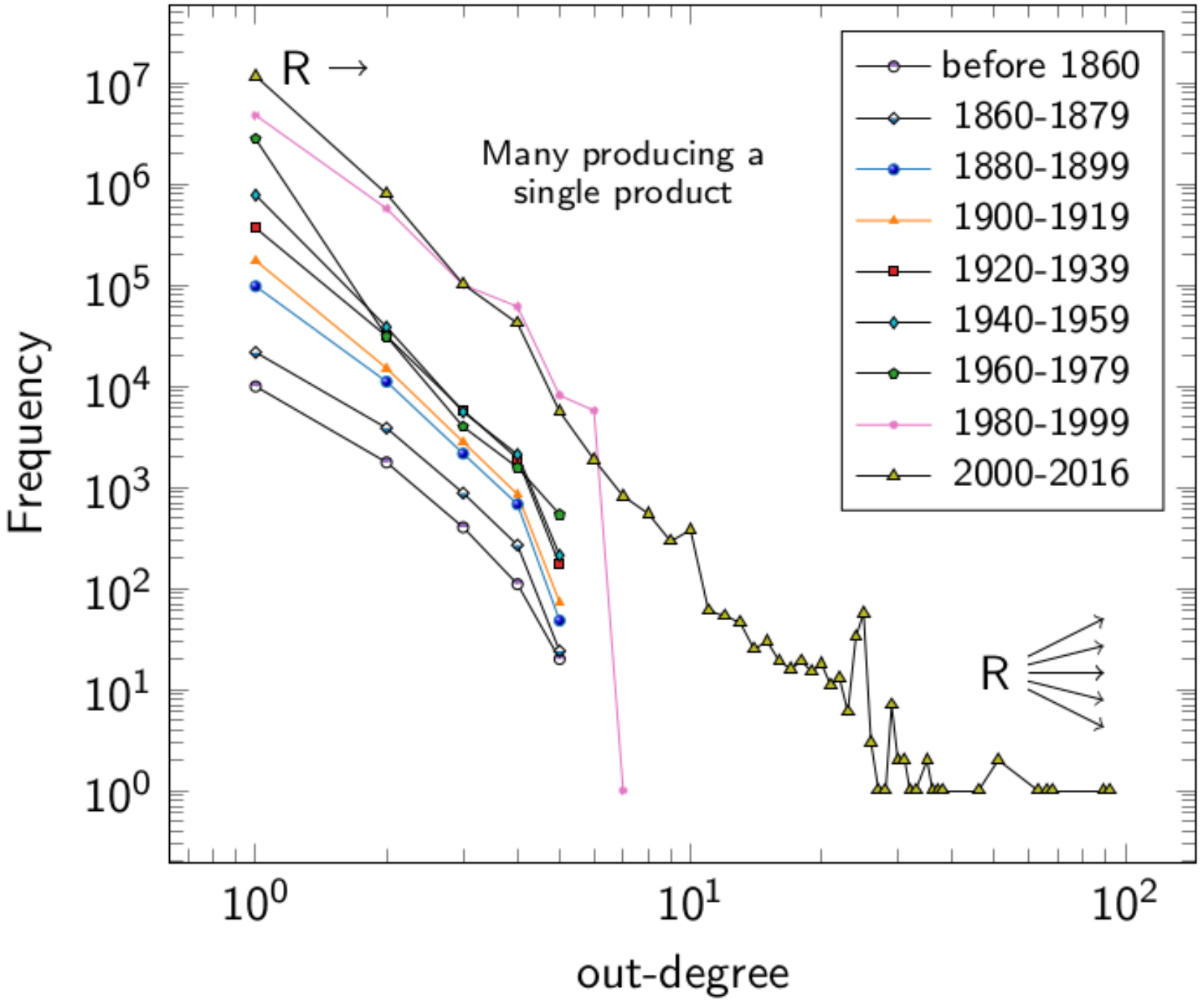
2000-2016: More reactants per reaction

Do chemists produce many substances per reaction?

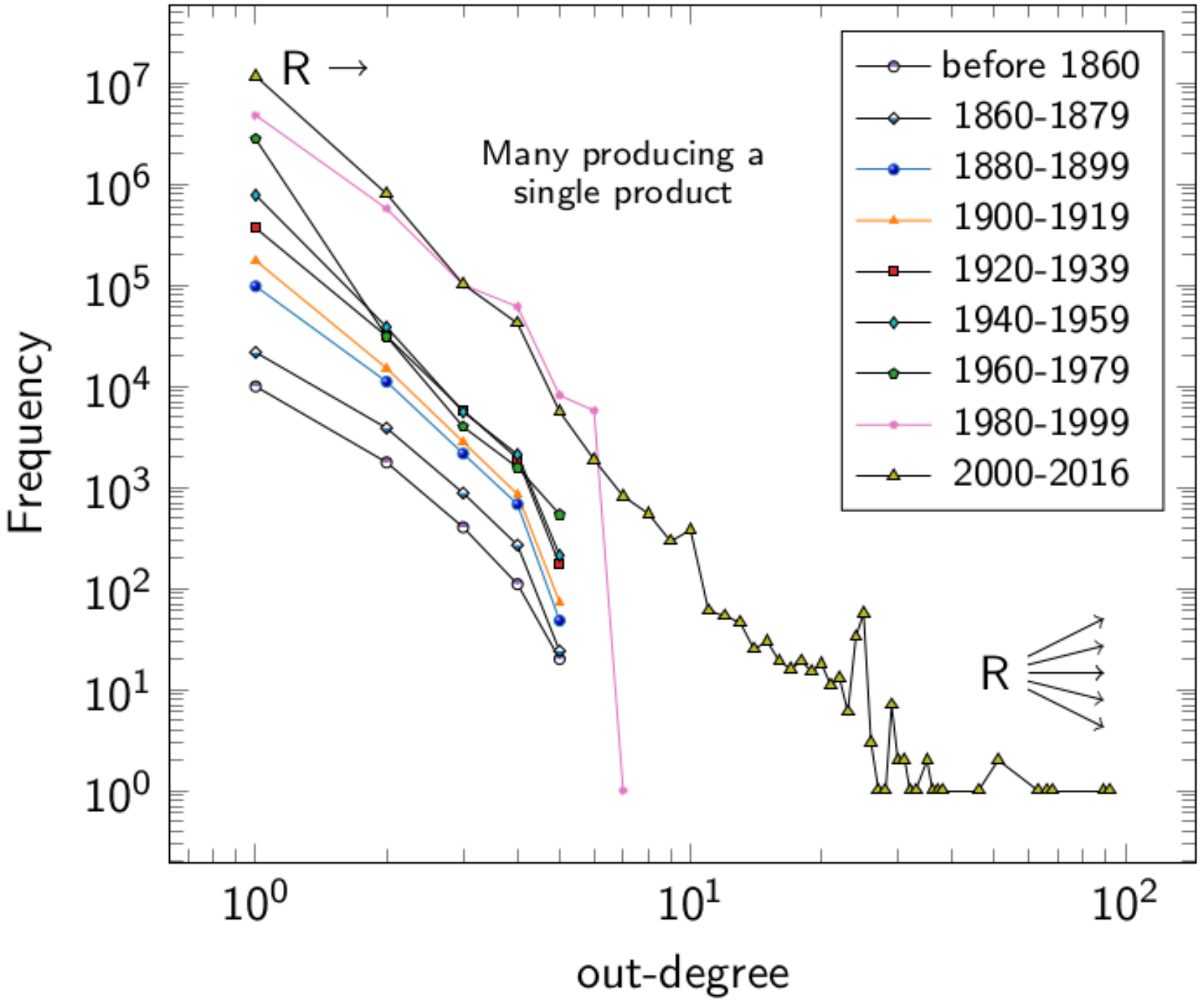




Out-degree

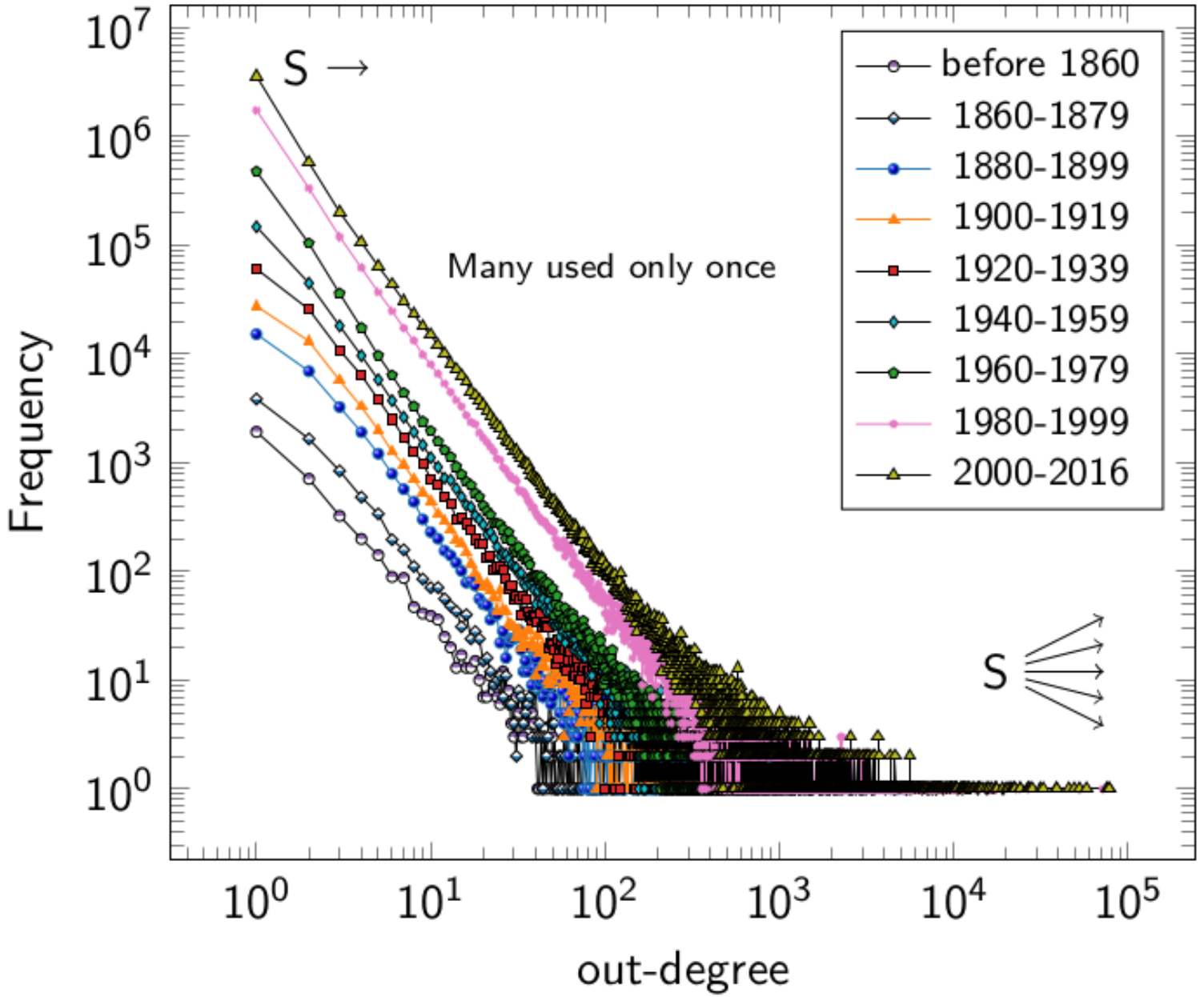


They produce few substances per reaction (1-2)



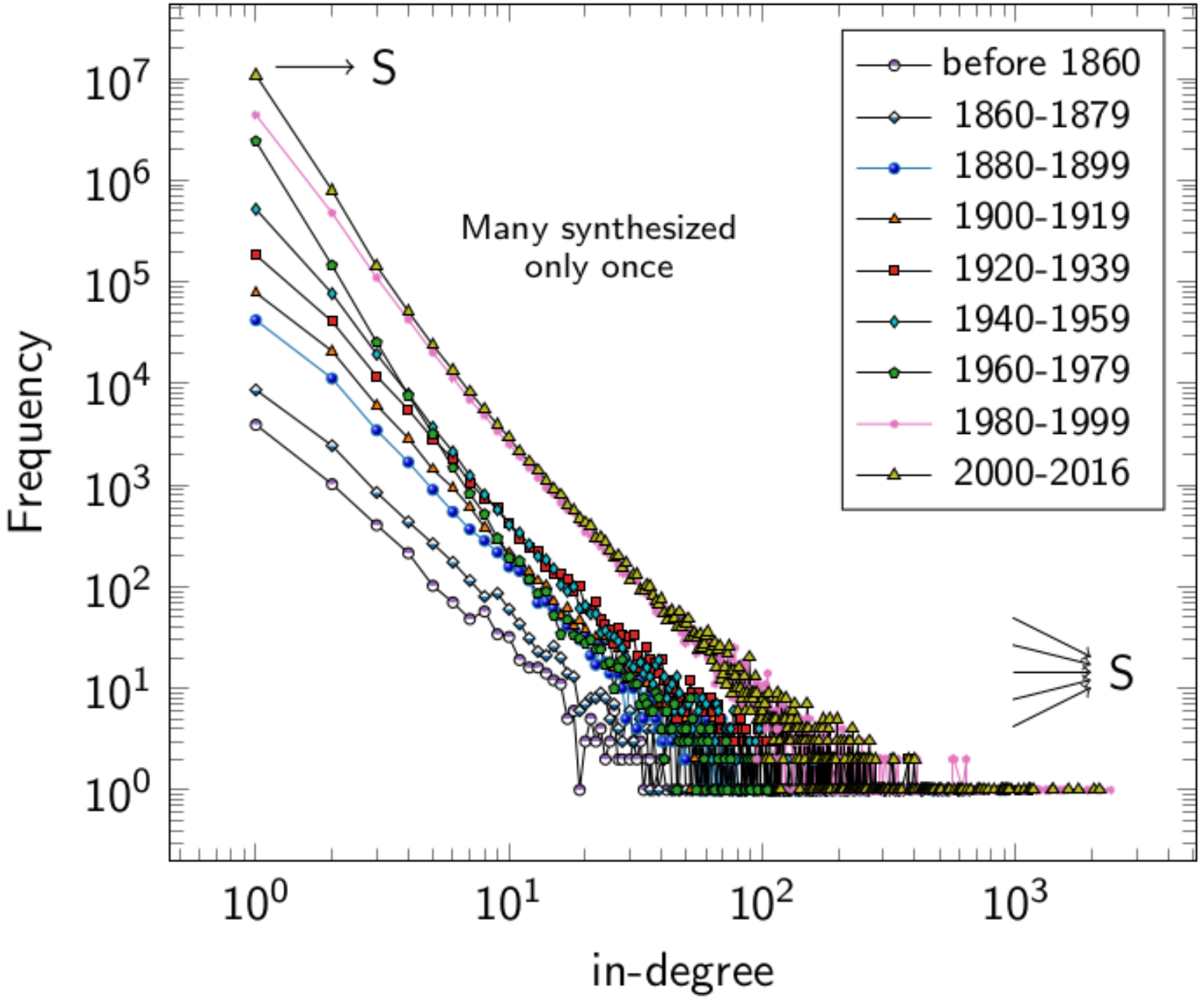
2000-2016: More products per reaction

Chemists combine few reactants, but are they well distributed?
Do chemists try to use homogeneously their reactants?



They concentrate on few substances and have done so historically

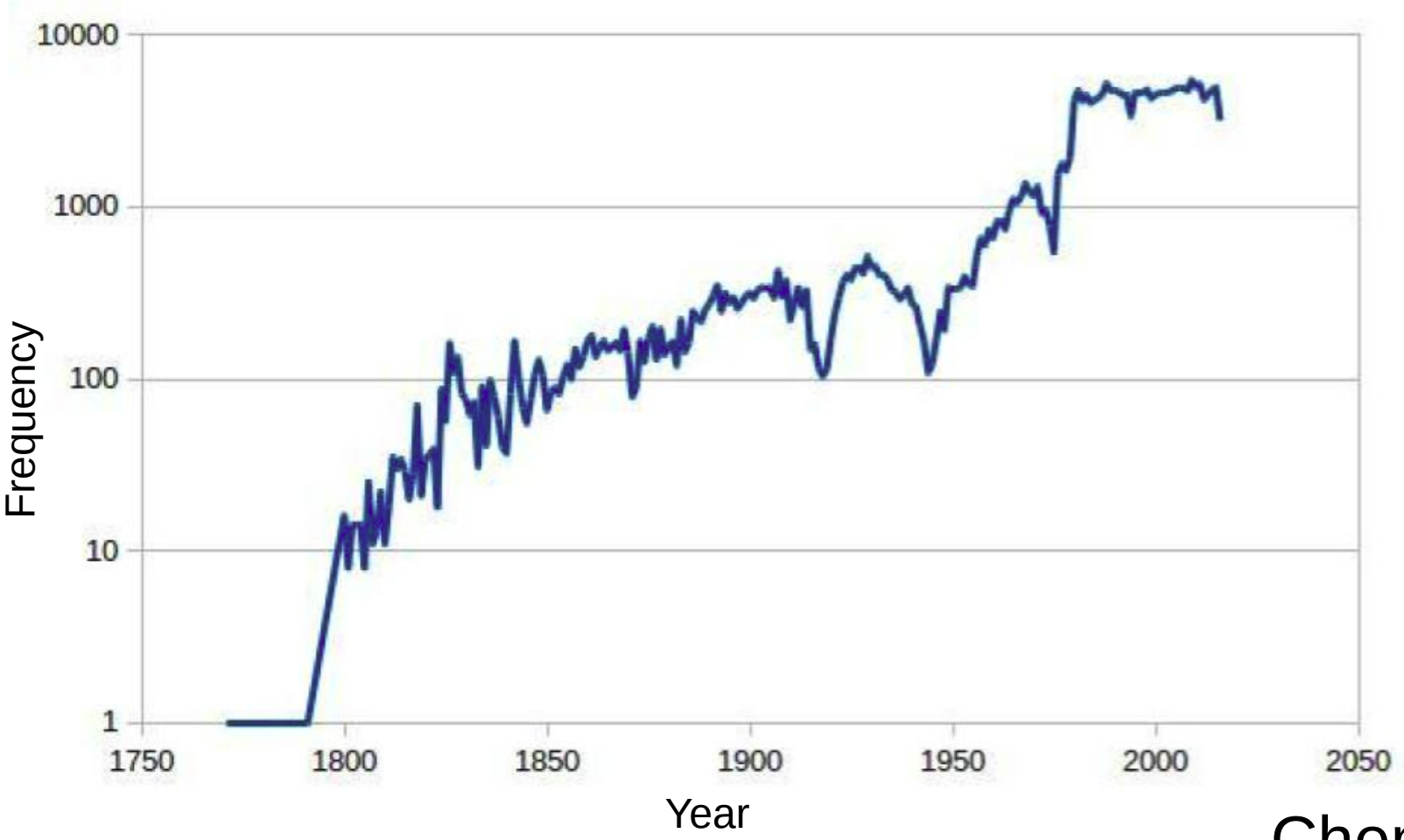
Chemists produce few substances per reaction, are they trying to populate the space of substances homogeneously?



Yes!

What about combinations of elements?
Are chemists exploring new combinations or do they keep exploring the traditional ones?

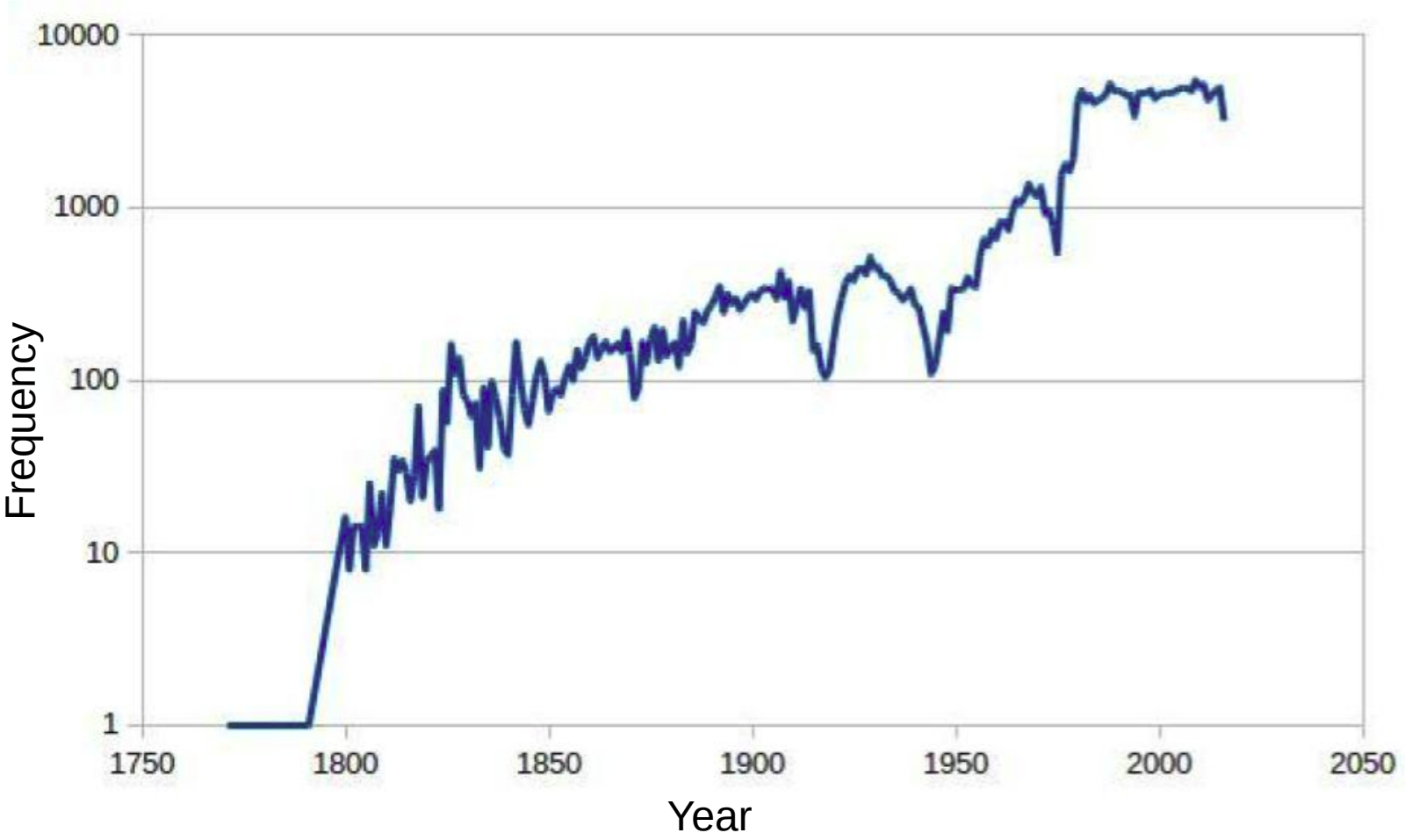
$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$ ➡ COH



Chemists explore new combinations

What about combinations of elements?
Are chemists exploring new combinations or do they keep exploring the traditional ones?

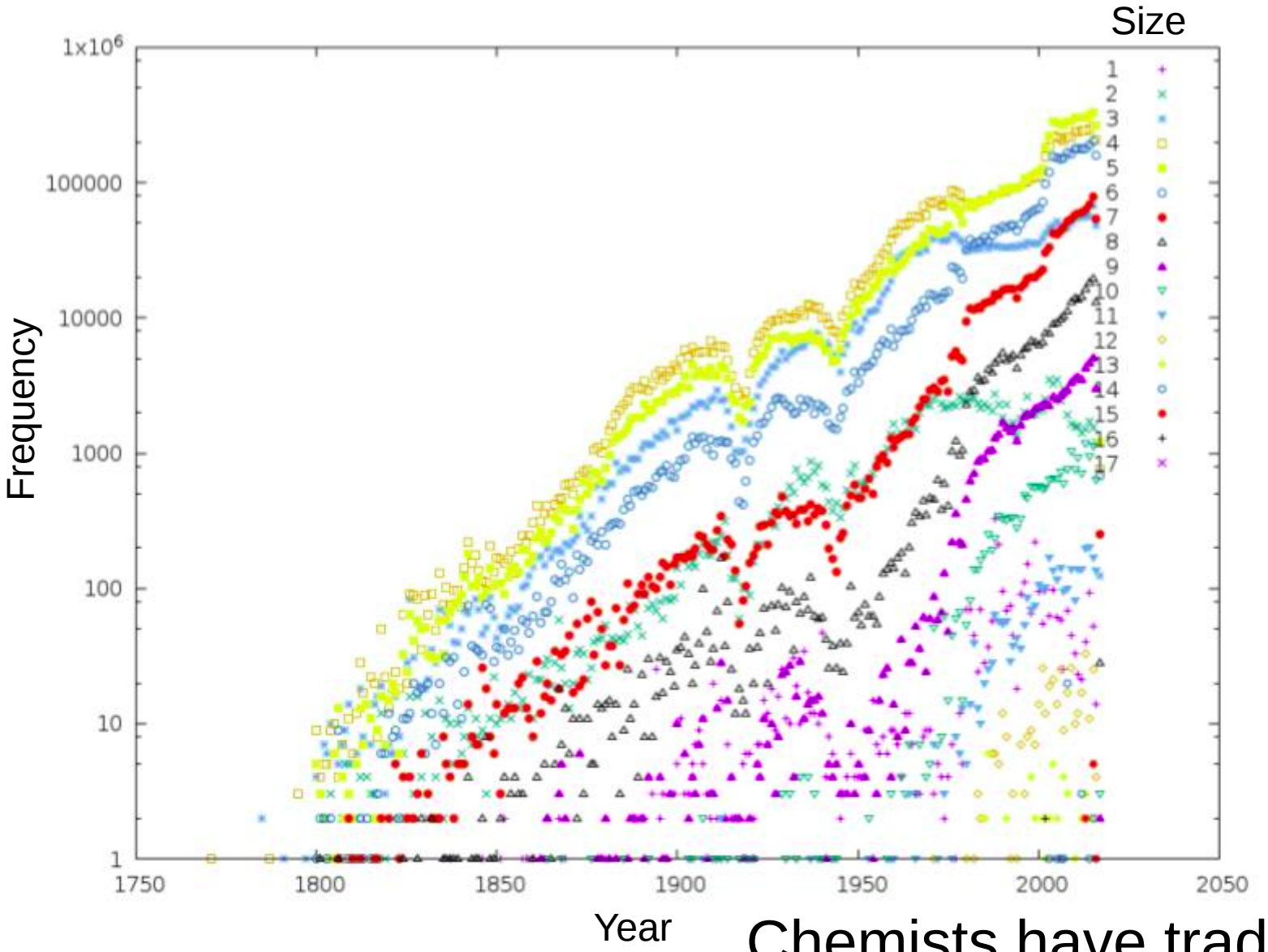
$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$ ⇨ COH



The rate of new combinations has slowed down since 1980.

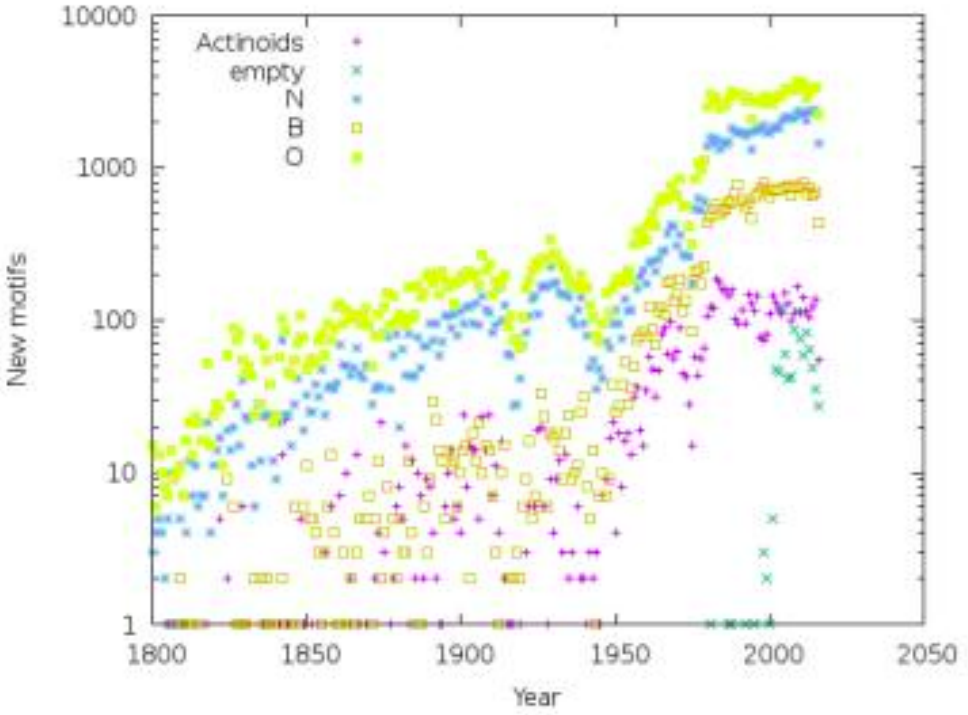
Are these new combinations large or small?

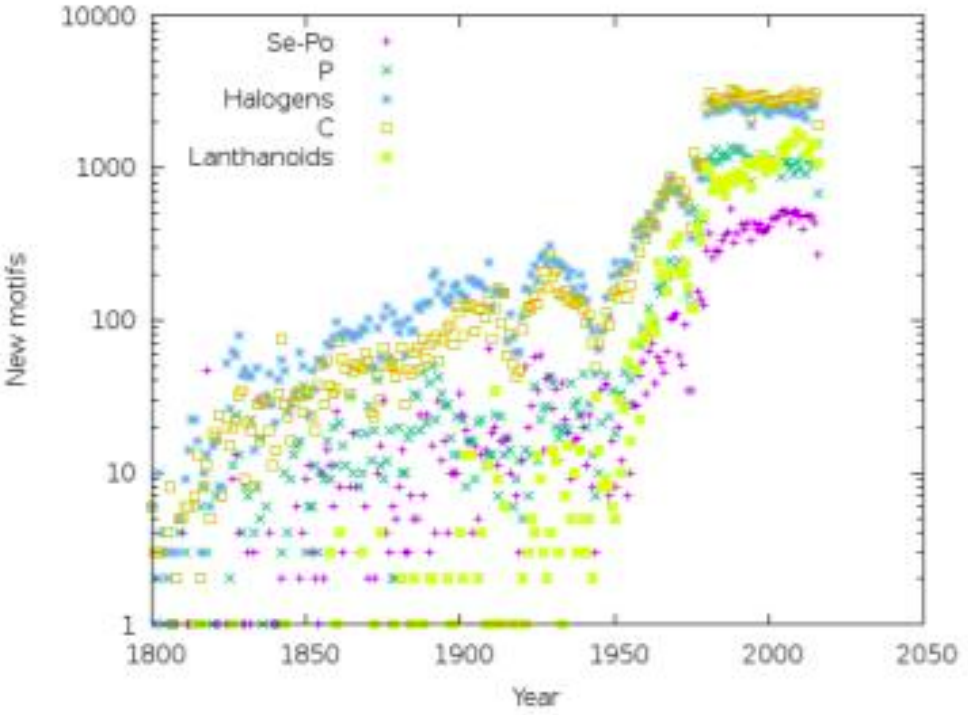
$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$ ➡ COH ➡ Size 3

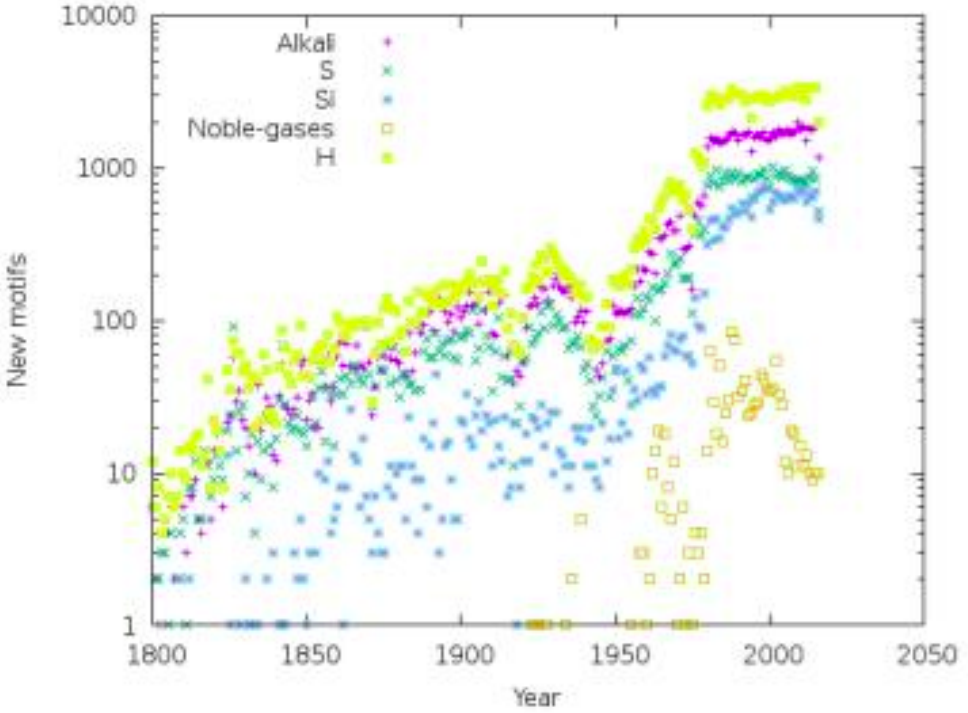


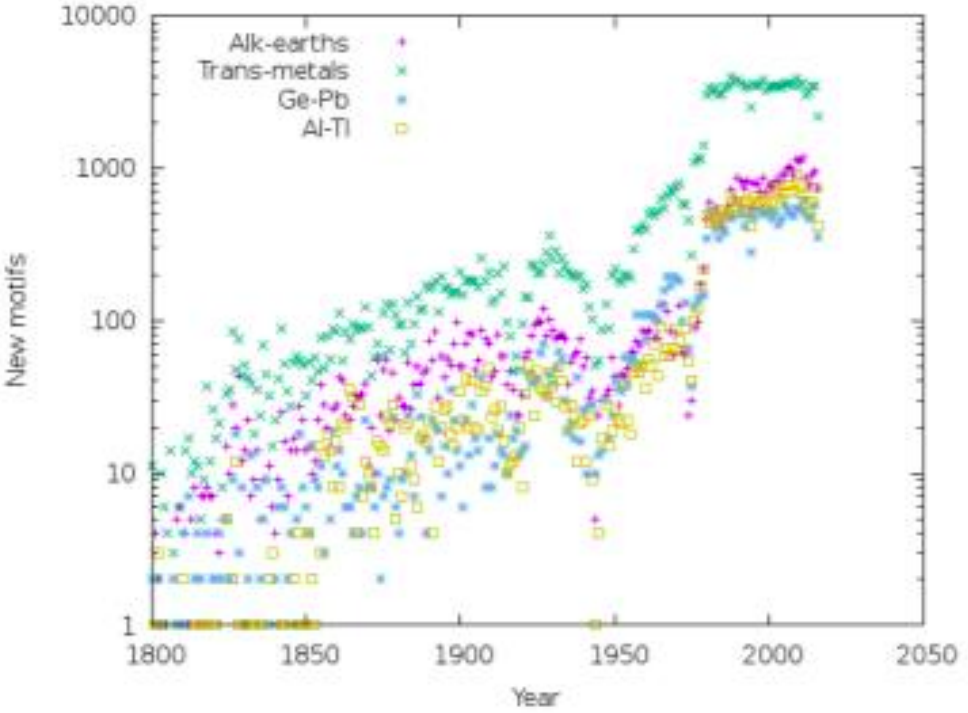
Chemists have traditionally played with combinations of 4 elements

Which elements?









Conclusions

- Chemists have historically used a small set of starting materials to produce a larger set of substances.
- The combined educts have been traditionally 2 to get 1 or 2 products.
- Since 2000 the exploration of the space has been carried out using more and more educts per reaction and reporting more and more products.
- They explore each time more combinations of elements but the sizes of the combinations are about 4 elements per combination
- Chemists have traditionally explored more combinations of elements, but the rate of innovation is slowing down since 1980.
- World wars (WWs) caused a drop in chemical novelty for substances & reactions. WW1 took production back around 30 years and WW2 around 15.

Open questions

- Modelling the evolution of the network
  - Random hypergraphs
  - Barabási-Albert model for hypergraphs
- To what extent chemical reactions & substances are novel?
- Are there preferred transformations (rewriting rules)?
- What is the meaning of chemical organisations here?
  - What is the meaning of closed sets of reactions for the industry?

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Hvala!