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DI FERRARA
- EX LABORE FRUCTUS -

DEPARTMENT
OF ECONOMICS
& MANAGEMENT

Economics of Innovation

Basic concepts

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Technological change in standard economics

- Technology is exogenous to the production function
- Technical change represents a shift in the production function over time (not embodied in any particular input or group of inputs)
- A stable relationship between output, input and time (t) is presumed to exist: $y = f(x, t)$
- Technical change is measured by how output changes as time elapses with the input bundle held constant
- Strong restriction therefore unrealistic: change in technology may easily require new inputs
- Production function maintains the same basic form as time elapses
- Example: Cobb-Douglas

Technological change in standard economics

- Solow (1956): “Gross output per man hour doubled over the interval with 87.5% of the increase attributed to technological change and the remaining 12.5% to the increased use in K”
- Romer (1990): endogenous growth theory
- Atkinson and Stigliz (1969): localized technological change. The different points on the curve still represent different processes of production, and associated with each of these processes there will be certain technical knowledge specific to that technique. If one brings about a technological improvement in one of the blue-prints this may have little or no effect on the other blue-prints

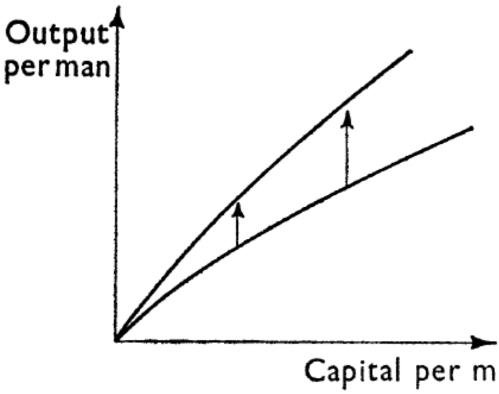


Fig. 1.

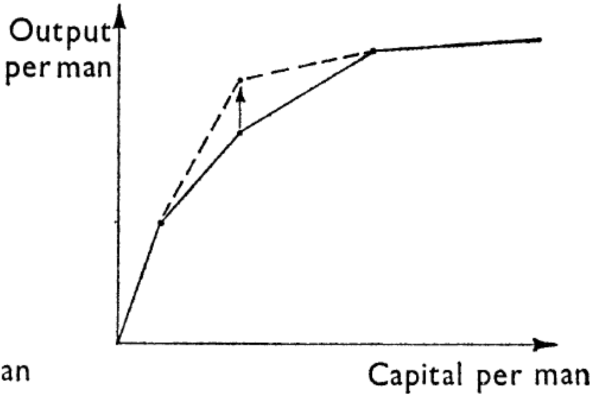
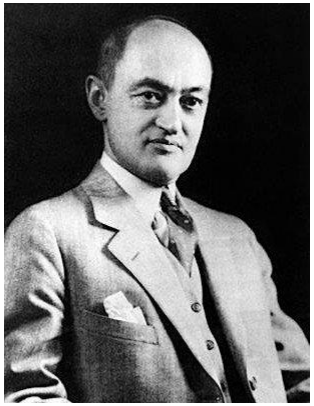


Fig. 2.

Joseph A. Schumpeter



Schumpeterian Economics (1883-1950)

- **Aim**: develop a theory of «evolutionary economics», different from the static neoclassical economics "[We shall designate by the term **Economic Evolution**] The changes in the economic process **brought about by innovation**, together with all their effects, and the response to them by the economic system" (Schumpeter, 1939, BC, Vol.I, p.86)
- "an **open-ended** process of **qualitative** change (driven by **innovation**)" (Fagerberg, 2003, JEE, p. 127)

- Schumpeter Mark I (1912 transl. 1934: The Theory of Economic Development: An inquiry into profits, capital, credit, interest and the business cycle)
  - Innovation happens in small firms and in perfect competition – central role for entrepreneur

- Schumpeter Mark II (1942: Capitalism, Socialism and Democracy)
  - Innovation in big firms and oligopoly:
    - Higher Investements for R&D
    - Higher credit access
    - Higher differentation (greater inventions)

Dynamic competition vs static equilibrium

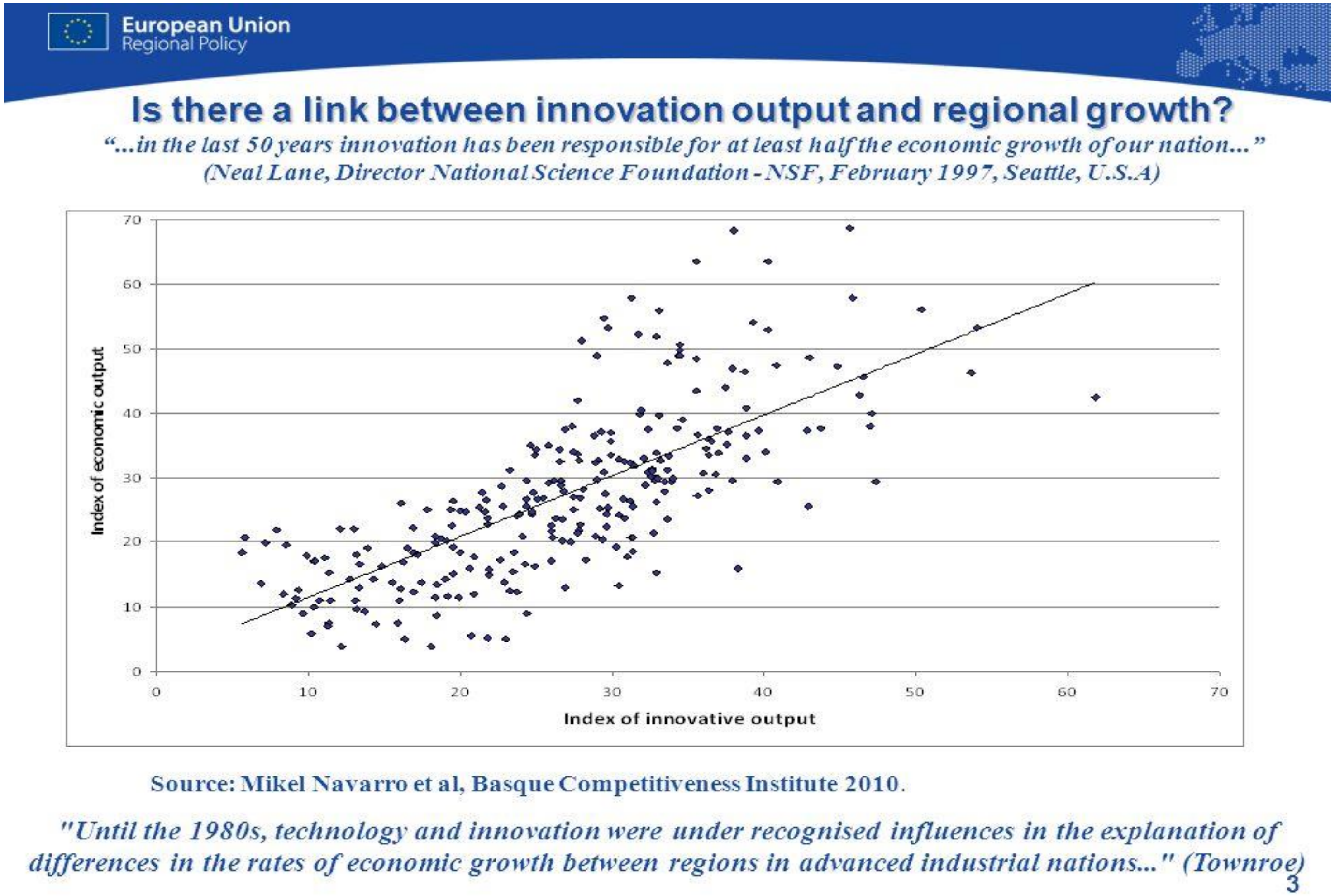
- “distinguished from its textbook picture … competition … which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives” (Schumpeter, 1943, p.84)
- Equilibrium not as a goal (static point to arrive at) rather as an attractive power
- “Schumpeter saw the neoclassical equilibrium theory as an …illustration of … equilibrating force [which], in the absence of innovation, force the economy into a stationary state. But in the real world, such a stationary state would never […] be reached because … disrupted by innovation”

So what is economics of Innovation about?

- The best definition I found is in Italian:

“economia dell'innovazione: intende esaminare natura, caratteristiche, determinanti e conseguenze dell'innovazione e della sua diffusione nel sistema economico; i soggetti e le istituzioni coinvolte nella dinamica innovativa, i processi di apprendimento, generazione di conoscenza, competizione, selezione ed interazione; gli aspetti cognitivi, comportamentali, organizzativi e istituzionali associati all'innovazione...” (Malerba 2001, Preface)

Why does it matter?



Is there a link between innovation output and regional growth?

"…in the last 50 years innovation has been responsible for at least half the economic growth of our nation…"
(Neal Lane, Director National Science Foundation - NSF, February 1997, Seattle, U.S.A)

Source: Mikel Navarro et al, Basque Competitiveness Institute 2010.

"Until the 1980s, technology and innovation were under recognised influences in the explanation of differences in the rates of economic growth between regions in advanced industrial nations…" (Townroe)

Defining innovation

“In an essential sense, innovation concerns the search for, and the discovery, experimentation, development, and adoption of new products, new production processes and new organizational set-ups” (Dosi, 1988, p.222)

Core concepts

- INNOVATION is different from INVENTION
- INNOVATION creates profit and a temporary monopolistic position
- INNOVATION is embedded in history
- INNOVATION as an uncertain process
- Entrepreneur is crucial but has bounded rationality
- TIME matters
- SECTORS matter
- SPACE and LOCATION matter
- INNOVATIONS are not randomly distributed in space and time
- … and they do affect the economic cycle

Innovation and technological change

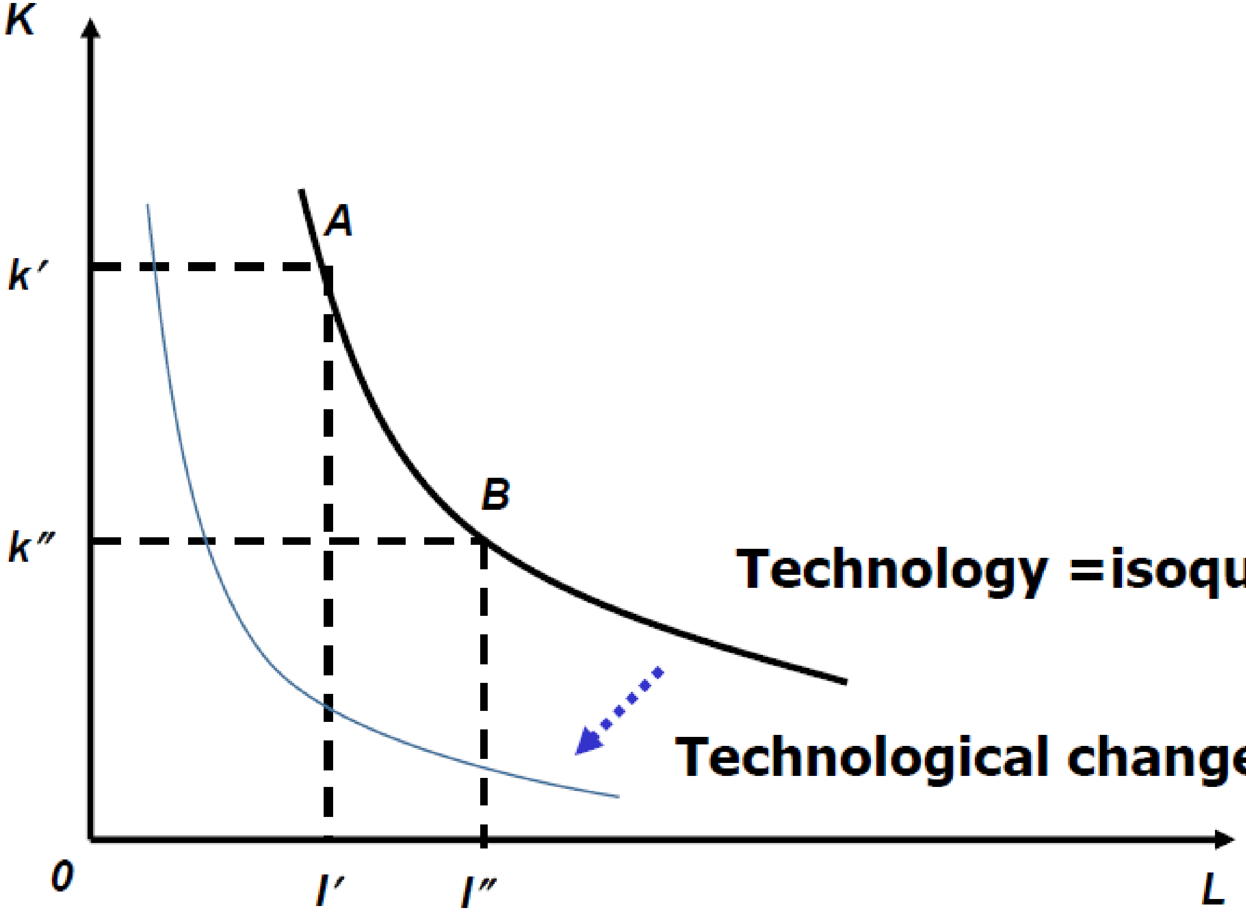
Innovation ≠ technological change

- Technological change is always an innovation

Whilst

- Innovation can also be *non technological*:
  - new organizational set-ups;
  - new products or production processes implemented with already existing technology

Technological Change



Technology =isoquant A- B

Technological change

The linear model and the chain model

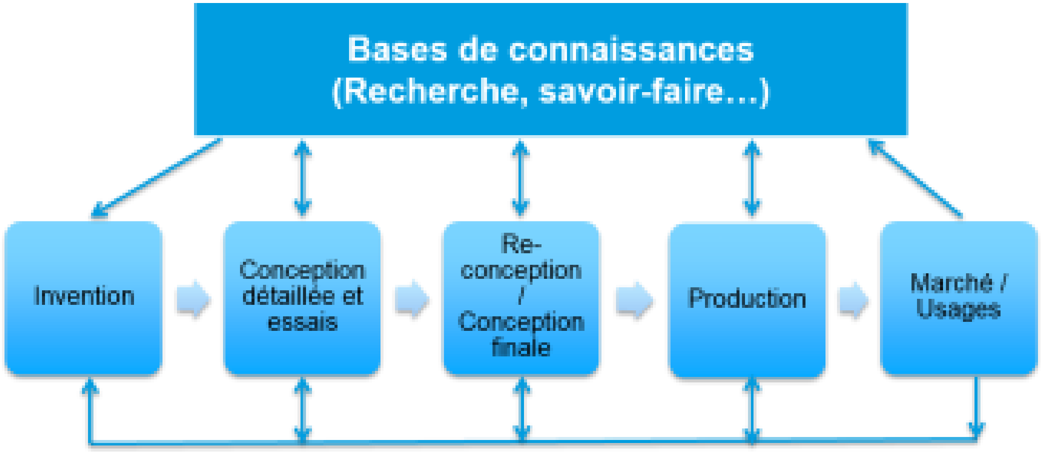
Linear model

Invention

Innovation

Diffusion

Chain-linked model (Kline and Rosenberg)



Bases de connaissances (Recherche, savoir-faire…)

Invention

Conception détaillée et essais

Re-conception / Conception finale

Production

Marché / Usages

Types of innovation

Product - Process

- Product: a new or improved product for sale, with the *same* production process. It includes:
  - Service innovations
  - Product proliferation
  - Innovative pricing
  - …

- Process: a new way to make the *same* product. It includes:
  - Organizational innovations;
  - Marketing innovations
  - …

- Note: The same innovation could be both

Types of innovation

Incremental - Radical

- Incremental: an improvement to a particular product or process which does not alters it fundamentally

- Radical: an improvement that alters the product or process fundamentally (disruption with the past)

- Note: Can the innovation be both?
  - “new with respect to what?”

Types of innovation
Modular - Architectural

- Modular: changes in the core design, leaving architectural knowledge unaltered

- Architectural: change in the way the components of a product are linked together, while leaving the components untouched

- Note: Limited to product innovations

Source: Henderson and Clark, 1990

Radical invention – a focus

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The division of labour between academia and industry for the generation of radical inventions

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Introduction

- Technology tends to evolve along predictable trajectories, characterized sometimes by discontinuities brought about by paradigm shifts (Dosi, 1982).
  - long-run economic growth (Ollson, 2000)
  - new industries formation (Arthur, 2007).
- Radical inventions are the base of these discontinuities

- Given this pivotal role, two main questions arise:
  - How do we identify radical inventions?
  - What are the sources of radical inventions?

Defining radical inventions

- Radical inventions are rare events and only a few develop successfully into viable innovation
- New technology that “depart[s] in some deep sense from what went before” (Arthur, 2007, p. 274)
- Differ from incremental inventions in the capability to promote the development of subsequent inventions (Ahuja and Lampert, 2001)

How do we identify radical inventions?

- Two approaches to identify radicalness:
  - Ex ante approach: radicalness conceptualized as a recombination process (Schumpeter, 1934)
  - Ex post approach: conceptualised for its impact on future technology development (Schoenmakers and Duysters, 2010)
- As Verhoeven et al. (2016, p. 708) note however, adopting an ex post assessment of radicalness overlooks unsuccessful short-term inventions
  - Especially true in empirical studies based on patent data
- We adopt an ex ante approach to identify radicalness

Ex ante approach

- Approach theoretically built on the conceptualization of inventive activity as a recombination process
- A radical invention needs to show some form of novelty: to emerge from a different recombination process from that characterizing the majority of inventions
- Most measures of radicalness tend to capture novelty in terms of the distance between new and old combinations
- A recent approach requires the invention to encompass some form of novel combination never observed before (Fleming, 2001; 2007; Verhoeven et al., 2016).
  - Fleming (2001): degree of radicalness as a function of the rareness of the combination of the same components prior to the focal invention

Recombination processes

- Inventive activity can emerge from two distinct, but non-exclusive, forms of recombination (e.g. Arthur, 2007; Fleming, 2001; Carnabuci and Operti, 2013).
  - Novelty in recombination: the generation of a new combination of components that gives rise to a new method of doing things
  - Novelty in technological origins: novel application of a phenomenon to some combinations of components

What are the sources of radical inventions?

- Investigating the sources of radical invention requires exploring the “innovative division of labour” (Arora and Gambardella, 1994) between public and private research (Trajtenberg et al., 1997; Popp, 2016)
  - Various radical inventions generated by public research (Rosenberg and Nelson, 1994; Rosenberg, 2004)

- RQ: While the relationship between technological development and public R&D has been largely investigated and proved, the link between public research and radical invention has not been examined

Public research and technological change

- Positive relationship (Jaffe, 1989; Mansfield, 1991; Salter & Martin, 2001)
- Mechanisms for the transfer of public science to industry have become increasingly complex (Gibbons et al., 1994)
  - Policies incentivised more direct and codified technology transfer activities (Henderson et al., 1998; Mowery et al., 2001; Geuna, 2001).
- Public research, even if patented, tend to be more basic, more general and less appropriable (Trajtenberg et al., 1997)

Public research and technological change (2)

- Heterogeneity of relationship across scientific or technological sectors.
  - Biomedicine and chemistry: patents developed by public research important share of the sector’s overall patenting activity (Mowery et al., 2001).
    - Most studies focus on these sectors
  - Applied science fields: the share of academic patents is much smaller (David, 1997)

- Codified public research usually proxied by two indicators in the literature: academic patenting and scientific literature in patent references

Empirical framework

- Patent data analysis based on the UK
- EPO patents in which at least one assignee based in UK
  - Focus only on public and private patents: sample of 113,910 patents (90% of total UK EPO population)
- Grouping patents into families (to avoid counting same invention more than once)
- Final dataset of 103,732 patent families
  - 6,710 include at least one public research institute as an assignee, corresponding to 6.47% of the sample.
- Relationship we investigate

$$Radicalness_{ijt} = \alpha + \beta PublicR\&D_{ijt} + \delta \boldsymbol{X}_{ijt} + \gamma_j + \tau_t + \varepsilon_{ijt}$$

Dependent variables: radical inventions

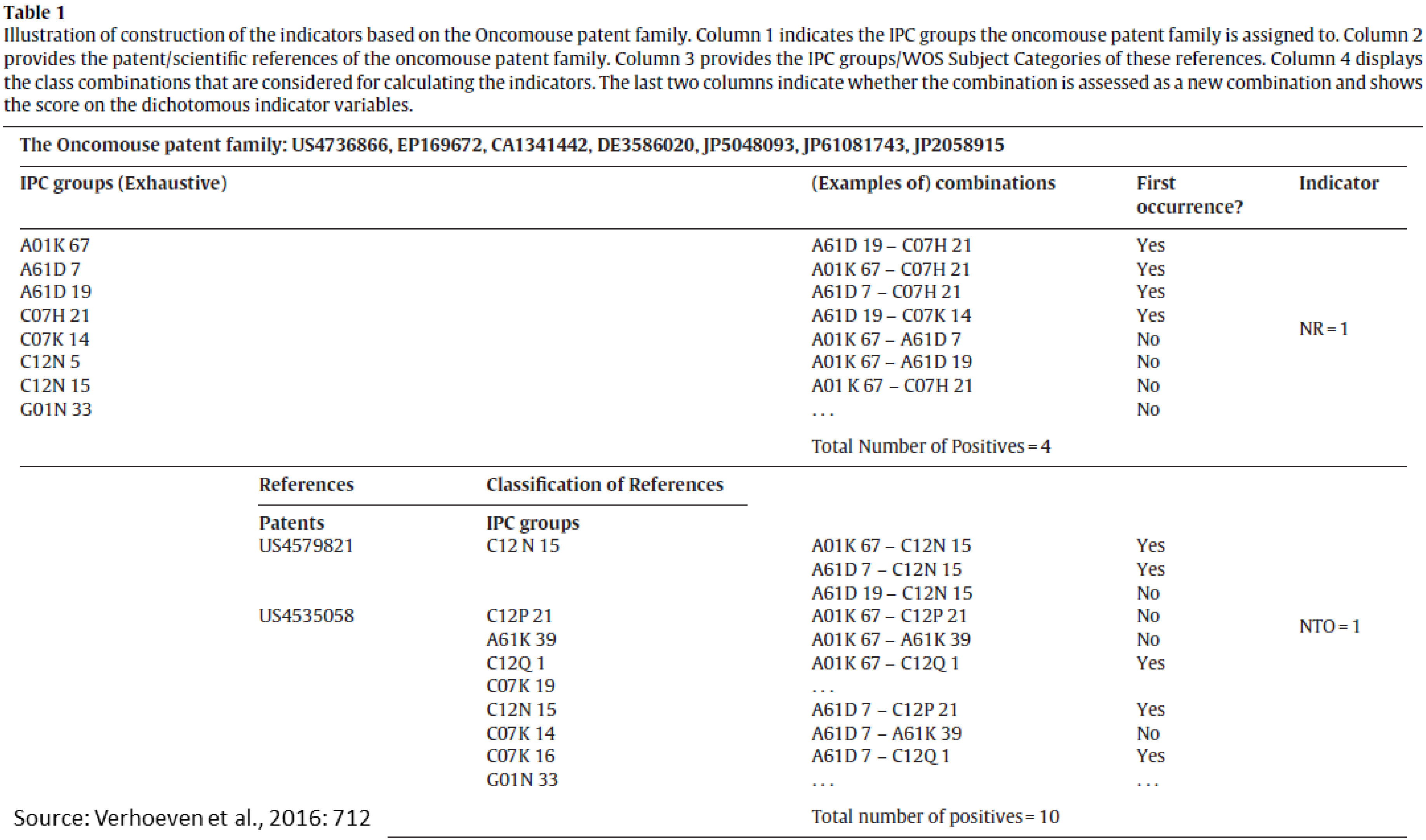

Table 1

Illustration of construction of the indicators based on the Oncomouse patent family. Column 1 indicates the IPC groups the oncomouse patent family is assigned to. Column 2 provides the patent/scientific references of the oncomouse patent family. Column 3 provides the IPC groups/WOS Subject Categories of these references. Column 4 displays the class combinations that are considered for calculating the indicators. The last two columns indicate whether the combination is assessed as a new combination and shows the score on the dichotomous indicator variables.

The Oncomouse patent family: US4736866, EP169672, CA1341442, DE3586020, JP5048093, JP61081743, JP2058915

IPC groups (Exhaustive)			(Examples of) combinations	First occurrence?	Indicator
A01K 67			A61D 19 – C07H 21	Yes	NR = 1
A61D 7			A01K 67 – C07H 21	Yes	
A61D 19			A61D 7 – C07H 21	Yes	
C07H 21			A61D 19 – C07K 14	Yes	
C07K 14			A01K 67 – A61D 7	No	
C12N 5			A01K 67 – A61D 19	No	
C12N 15			A01 K 67 – C07H 21	No	
G01N 33			. . .	No	
			Total Number of Positives = 4		
	References	**Classification of References**			
	Patents	**IPC groups**			
	US4579821	C12 N 15	A01K 67 – C12N 15	Yes	NTO = 1
			A61D 7 – C12N 15	Yes	
			A61D 19 – C12N 15	No	
	US4535058	C12P 21	A01K 67 – C12P 21	No	
		A61K 39	A01K 67 – A61K 39	No	
		C12Q 1	A01K 67 – C12Q 1	Yes	
		C07K 19	. . .		
		C12N 15	A61D 7 – C12P 21	Yes	
		C07K 14	A61D 7 – A61K 39	No	
		C07K 16	A61D 7 – C12Q 1	Yes	
		G01N 33	. . .	. . .	
			Total number of positives = 10		

Source: Verhoeven et al., 2016: 712

Independent variables

- Public: Dummy variable taking the value of 1 if the patent displays at least one public research institute as assignee, and 0 otherwise (only private companies)
- Npl: Dummy variable taking the value of 1 if at least one non-patent literature document is reported in the references of the patent, 0 otherwise
- Controls:
  - Bwd_pat: Number of patents referenced by the focal patent
  - N_ipc: Number of 8digit IPC codes of the patent
  - N_inv: Number of inventors of the patent
  - Time, technological field and geographical dummies

Method

- Logit regressions, due to the dichotomous nature of our dependent variables
  - Investigation of the relationship between a one-unit change in the predictor of interest, keeping the other predictors fixed, and the change in the log of odds ratio of the outcome, invention radicalness.

Frequencies and contingency tables

	Nr	*Nto*
Observed frequency	5,541	9,349
Percentage	5.34	9.01

	Nr=1 & Public=1	*Nto=1 & Public=1*	*Nr=1 & Npl=1*	*Nto=1 & Npl=1*
Observed frequency	417	567	1,982	3,270
Ratio between observed and expected frequency	1.16	0.94	1.00	0.98
Chi2(1)	10.91**	2.62	0.031	2.72

Logit regression, full sample

	Nr	*Nto*
Public	1.2% higher probs of being Nr if the patent is Public (3.6% vs 4.8%)	+ 1%
Npl	+ 0.5%	+ 1.5%
Bwd_pat	0.007*	0.094**
	[0.003]	[0.005]
N_ipc	0.163**	0.104**
	[0.005]	[0.004]
N_inv	-0.065**	-0.040**
	[0.012]	[0.009]
chi2	2836.468	4590.362
N	103,732	103,732

Robust standard errors in parentheses.
Time, technological field and geographical dummies included.
* p<0.05, ** p<0.01

Radicalness in different sectors

Sector	Obs	Radicalness	Frequencies	Percentage
Electrical Engineering	19,278	*Nr*	647	3.03
		Nto	927	4.34
Instruments	16,640	*Nr*	769	4.08
		Nto	1,261	6.69
Chemistry	34,281	*Nr*	2,368	6.57
		Nto	3,651	10.12
Mechanical Engineering	25,354	*Nr*	1,962	6.65
		Nto	3,609	12.24

Technological sectors are identified by PATSTAT and associated to patents by Squicciarini et al., 2013

Logit regression, different sectors

	Electrical Engineering		Instruments		Chemistry		Mechanical Engineering	
	Nr	*Nto*	*Nr*	*Nto*	*Nr*	*Nto*	*Nr*	*Nto*
Public	0.091	0.158	0.073	-0.24	+ 1.7% (fro 4,2% to 7%	+ 1.2%	0.229	+ 1.7%
	[0.211]	[0.175]	[0.137]	[0.1			[0.146]	
Npl	-0.209*	-0.005	-0.007	0.076	+ 0.7%	+ 1.9%	0.085	+ 1.5%
	[0.099]	[0.082]	[0.096]	[0.075]			[0.075]	
Bwd_pat	0.017	0.159**	0.010	0.138**	0.003	0.064**	-0.008	0.156**
	[0.016]	[0.013]	[0.009]	[0.020]	[0.004]	[0.005]	[0.009]	[0.007]
N_ipc	0.375**	0.199**	0.471**	0.315**	0.098**	0.064**	0.363**	0.212**
	[0.021]	[0.016]	[0.017]	[0.013]	[0.004]	[0.003]	[0.012]	[0.008]
N_inv	-0.033	-0.042	-0.058	-0.035	-0.066**	-0.035**	-0.026	-0.019
	[0.039]	[0.032]	[0.035]	[0.026]	[0.016]	[0.013]	[0.026]	[0.019]
chi2	565.905	677.502	939.112	993.124	1,262.72	1,764.15	1,283.18	1,786.90
N	19,278	19,278	16,640	16,640	34,281	34,281	25,354	25,354

Findings

- The proprietary output of public research – measured in terms of public ownership of patents – is related to a higher probability of producing a radical invention in terms of recombination of components
  - However small portion of publicly owned radical patents
- Conversely, open science – captured by non-patent references – is more likely to be related to the generation of radical inventions based on application of a new phenomenon to existing components
- This overall patterns is however consistently heterogeneous across sectors
  - Absence of a relationship does not imply a low level of influence of public research on industrial technological change. It might be interaction is not captured by patent related information (we are capturing only the proximity of the codified public research to radical invention generation)

Conclusions

- Public (codified) research is linked to the probability of an invention being radical in different ways, depending on the type of novelty on which the radical invention is built and the type of public research outcome
- The relationship is heterogeneous across sectors and is more prevalent in those sectors that patent more and produce a higher share of radical inventions
- The share of public patents is quite low; the lion's share of the inventive activity leading to patents, is confined to the private sector
- Pushing universities to patent would lead to an increase of only chemistry-related radical inventions

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Thanks for your attention