THESIS DECLARATION

The undersigned

SURNAME	Pero
NAME	Mickael
PhD Registration Number	1194885

Thesis title:

The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies

PhD in	Economics
Cycle	22
Candidate's tutor	Prof. Franco Malerba
Year of discussion	2013

DECLARES

Under his responsibility:

1) that, according to the President's decree of 28.12.2000, No. 445, mendacious declarations, falsifying records and the use of false records are punishable under the penal code and special laws, should any of these hypotheses prove true, all benefits included in this declaration and those of the temporary embargo are automatically forfeited from the beginning;

2) that the University has the obligation, according to art. 6, par. 11, Ministerial Decree of 30th April 1999 protocol no. 224/1999, to keep copy of the thesis on deposit at the Biblioteche Nazionali Centrali di Roma e Firenze, where consultation is permitted, unless there is a temporary embargo in order to protect the rights of external bodies and industrial/commercial exploitation of the thesis;

3) that the Servizio Biblioteca Bocconi will file the thesis in its 'Archivio istituzionale ad accesso aperto' and will permit on-line consultation of the complete text (except in cases of a temporary embargo);

4) that in order keep the thesis on file at Biblioteca Bocconi, the University requires

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

that the thesis be delivered by the candidate to Società NORMADEC (acting on behalf of the University) by online procedure the contents of which must be unalterable and that NORMADEC will indicate in each footnote the following information:

- thesis (thesis title) The Role and Importance of Instruments in the Scientific Process, and their Implication in the emergence of new technologies
- by (candidate's surname and first name) Pero Mickael;
- discussed at Università Commerciale Luigi Bocconi – Milano in (year of discussion) 2013 ;
- the thesis is protected by the regulations governing copyright (law of 22 April 1941, no. 633 and successive modifications). The exception is the right of Università Commerciale Luigi Bocconi to reproduce the same for research and teaching purposes, quoting the source;

5) that the copy of the thesis deposited with NORMADEC by online procedure is identical to those handed in/sent to the Examiners and to any other copy deposited in the University offices on paper or electronic copy and, as a consequence, the University is absolved from any responsibility regarding errors, inaccuracy or omissions in the contents of the thesis;

6) that the contents and organization of the thesis is an original work carried out by the undersigned and does not in any way compromise the rights of third parties (law of 22 April 1941, no. 633 and successive integrations and modifications), including those regarding security of personal details; therefore the University is in any case absolved from any responsibility whatsoever, civil, administrative or penal and shall be exempt from any requests or claims from third parties;

7) that the PhD thesis is not the result of work included in the regulations governing industrial property, it was not produced as part of projects financed by public or private bodies with restrictions on the diffusion of the results; it is not subject to

Date __31-10-2012_____

SURNAME	Pero	NAME	Mickael

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Abstract

The objective of this thesis is to assess the role and importance of instruments in the scientific process, and their implication for the emergence of new technologies. This topic is embedded within the field of Economics of Science, where the general aim is to investigate the role and effect of science and scientific actors on the economic system, acknowledging the strong evidence indicating a relationship between scientific performance and economic growth (Dasgupta & David, 1994; Stephan, 1996; Salter & Martin, 2001).

The first chapter aims at understanding the role at the micro level of instruments in material science by looking at the contribution of instrumentalities[1] to scientific outcomes. While research can be defined as the creative work of a research team based on the available data, instrumentalities concern the

[1]"The invention of new instrumentation or methods enabling the identification of new scientific phenomena", similarly defined as "an artifact (or system of artifacts) that is instrumental in accomplishing some end" (Princeton university definition inspired from Price DeSola's articles (Price D. J., 1984; Price D. J., 1963). Source: http://wordnet.princeton.edu/.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

improvement of existing instrumentation to deliver radically new observations. To explore the complementarity of the two elements in the scientific process, a theoretical model is proposed to describe how research teams set the time allocation between research and instrumentalities. Empirical evidence follows and shows that chemistry and biology depict a positive relation between time allocated to research and productivity whereas material sciences and physics and energy show the opposite pattern. An interesting finding is also the under-estimation of instrumental activity in the scientific process when using citation as a measure for scientific productivity.

The second chapter explores the systemic role and position of instrument institutions, namely Research Infrastructures (RIs), in the Italian material science field. Two questions are investigated. The first question concern the central position of RIs within the Italian material science network and whether they contribute towards connecting otherwise disconnected research organisations. The second question looks wether Italian research organisations which work with RIs increase their visibility by benefiting from enhanced

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

international collaborations. To answer these questions, a dataset of scientific articles in material science from the Scopus database is compiled for several time periods. Concerning the first question, a social network methodology is proposed and evidence point at the central and beneficial role of RI research towards specific clusters which is in line with the support and "cohesion" role of the initial objectives of RIs. In the second part of this chapter, the effect of RIs on Italian international scientific collaborations is investigated. In order to test the hypothesis of a positive effect, a modified gravity model is proposed. The tested regressions point at a positive and significant role of RIs on the probability to collaborate at the international level.

Finally, the third chapter explores the interaction between research and inventive activities as defining new and emerging technologies. Indeed, knowledge-based societies rely on research and innovative performance as condition for growth. This demands new methods to identify the most promising technologies at an early stage. Such tools provide an advantage in anticipating technological trajectories

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

which are crucial in elaborating S&T policies. This chapter develops a framework to identify emerging technologies based on their underlying research and inventive activities. To do so, the Sharpe ratio is used as a growth indicator (both in absolute and relative terms) to discriminate a sample of technologies and identify the ones that stand out. This method is tested within the field of nanoscience and nanotechnology. What is found first is that crossing the inventive Sharpe ratios for both growth indicators provide an adapted S curve framework that can be easily interpreted. Second, as argued in the conceptual framework a scientific dimension is introduced in the model. The new framework provides additional and complementary information to the S curve "baseline scenario", and in particular whether technologies are characterized by more basic and/or applied emerging dynamics.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Contents

Abstract 3
List of Figures 10
List of Tables 11
Acknowledgements 13
Chapter 1: the role and importance of instrumentalities in the scientific process: theoretical model and empirical evidence 16
Introduction 16
Literature background 17
Incentives 17
Physical capital 20
Research and Instrumentalities 24
Theoretical model 27
Empirical Evidence 34
Data and measures 35
Descriptive statistics 38
Results 40
Conclusion 45
Chapter 2: The Position and Role of Research Infrastructures in the Material Science Network 49
Introduction 49
Hypotheses 54
Hyp. 1: testing the centrality and brokerage role of RIs on the Italian material science network 55
Method: Social network analysis 55
Data 60
Results 62
Hyp.2: the effect of RI support on international collaborations 72
Empirical model 72
Data 77
Results 82
Robustness check 91

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Conclusion 94
Chapter 3: Identifying emerging technologies: an application to nanotechnologies 98
Introduction 98
Paper sections 105
Conceptual framework: emerging technologies and S&T dynamic 106
Methodology 116
Identifying emerging technologies 116
Measures for research and inventive activities 121
Data 122
Application field: nanoscience and nanotechnology 122
Technology dataset 125
Descriptive statistics 137
The nanoscience and nanotechnology field 137
Selected nanomaterials 139
Results 147
Adapted S curve concept (baseline case) 147
Applying the new framework 152
Comparing results 160
Exploring the data: partition results 163
Conclusion 171
Future research 173
General conclusion 177
References 179
Annexes 200
Annex chapter 1 200
RI Definitions 200
CES algebra 201
Cases and simulations 203
ISI WoS categories 206
Annex chapter 2 209
OLS results for the panel data 209
Poisson and negative binomial regressions for the cross section 210

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annex Chapter 3 211
Technology sample and search strategies 211
Between and within standard deviations formulas 220
Between and within standard deviations results 221
S curve partitions results 222
S curve framework applied to research dynamics .. 225
Sharpe results 226
Annex Short Case Study: European Research Infrastructures and their innovation effect as an "institutional" instrument 236
Abstract 236
Literature background 240
Direct effect from RIs: science & technology transfer 248
Indirect effect from RIs: the procurement market . 254
Conclusion 261
Annex: EPO-Scopus correspondence 265

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

List of Figures

Figure 1: Team average citations versus average articles 40
Figure 2: Team articles vs research time allocation 41
Figure 3: Team citations vs research time allocation 41
Figure 4: Team articles vs research time allocation by field 42
Figure 5: Team citations vs research time allocation by field 43
Figure 6: Cluster network evolution 66
Figure 7: RI brokerage roles 69
Figure 8: RI brokerage (proportion) 71
Figure 9: R&D expenditures by country 99
Figure 10: R&D expenditure vs. GDP 100
Figure 11: Science and Technology cycles 103
Figure 12: Conceptual framework 107
Figure 13: Nanoscience and nanotechnology field sizes 138
Figure 14: Total publications per material 141
Figure 15: Total patents per material 141
Figure 16: Total publications by material type 142
Figure 17: Total patents by material type 142
Figure 18: RI vs non-RI markets 258
Figure 19: Supply firms RI versus non-RI profits by NACE rev 2 sector 259
Figure 20: Average distance of RI suppliers 261

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

List of Tables

Table 1: Parameter simulations 31
Table 2: Descriptive statistics 38
Table 3: Descriptive statistics by scientific field 39
Table 4: Clusters and modularity per years 59
Table 5: Sample Nodes and Edges per Years 62
Table 6: Network indicators 63
Table 7: summary statistics: 81
Table 8: Poisson and Negative Binomial Regressions 84
Table 9: Zero inflated Poisson and Zero inflated Negative Binomial Regressions 89
Table 10: Zero inflated Poisson and Zero inflated Negative Binomial Regressions 93
Table 11: Emergence taxonomy 121
Table 12: Within and between year summary 144
Table 13: Publication correlation matrix for material type. (the statistics are expressed in percentage of the total number of double type publications. Source: own calculations based on selected search strategy.) 145
Table 14: Patent correlation matrix for material types (te statistics are expressed in percentage of the total number of double type patents. Source: own calculations based on selected search strategy.) 146
Table 15: S-curve typology 149
Table 16: Relative vs. Absolute patent growth 150
Table 17: Framework identifying material S&T dynamics 154
Table 18: Quadrant results, absolute growth 157
Table 19: Quadrant results, relative growth 159
Table 20: Absolute growth 1997-2002 165
Table 21: Absolute growth 2003-2008 166
Table 22: Relative growth 1997-2002 169
Table 23: Relative growth 2003-2008 169
Table 24: ISI WoS categories 208

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Table 25: OLS results 209
Table 26: Cross sectional Poisson & Negative binomial regressions 210
Table 27: Materials' description 219
Table 28: Summary statistics 221
Table 29: Relative vs Absolute Sharpe ratios (1997-2002 222
Table 30: S-curve Relative vs Absolute Sharpe ratios (2003-2008) 222
Table 31: Research S curve framework 225
Table 32: Sharpe results for absolute growth 226
Table 33: Sharpe results for relative growth 227
Table 34: Sharpe results for absolute growth 1997-2002 228
Table 35: Sharpe results for relative growth 1997-2002 229
Table 36: Sharpe results for absolute growth 2003-2008 230
Table 37: Sharpe results for relative growth 2003-2008 231
Table 38: Sharpe ratio results summary 232
Table 39: Quadrant material position by period in terms of absolute growth 234
Table 40: Quadrant material position by period in terms of relative growth 235

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Acknowledgements

I would like to thank the Bocconi University and in particular Prof. Battigalli and Prof. Ottaviano who have given me the opportunity and the support to be part of this great PhD programme in economics. From an interest in the Economics of Science and Innovation, I have been given the chance to meet my supervisor Prof. Malerba who has always shown me support and help when needed. In the same way, Prof. Lissoni and Lorenzo Zirulia have given me strong and positive advice to overcome several hurdles that I came across when working on this thesis, as welI as valuable feedback from Prof. Gambardella.

Also, I would like to thank all those who gave their comments during presentations, seminars (in particular Prof. Alesina's one) as well as workshops organised at Bocconi. The same applies for the Strasbourg University and in particular Prof Wolff and Frederique Lang for their interest in my thesis and their advices received during the doctoral days and Strasbourg Conseil for their prize.

In parallel, I would like to warmly thank Prof. Rizzuto and Dr. Rochow from Elettra Sincrotrone

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Trieste for their support and trust over the years. In particular, in giving me the opportunity to bridge the academic and policy-making approaches of this thesis' topic through Italian and European projects such as RIFI. I greatly appreciated their numerous feedbacks which nourished this thesis.

The same goes to colleagues and advisors at the Fraunhofer ISI in Karlsruhe namely Dr. Thomas Reiß and Dr. Axel Thielmann for their precious comments and guidance.

Finally, I would like to warmly thank my family for their encouragements, my father for providing his enlightened point of views and Lou for being by my side.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

"The real voyage of discovery consists not in seeking new landscapes but in having new eyes"

Marcel Proust (1871-1922)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Chapter 1: the role and importance of instrumentalities in the scientific process: theoretical model and empirical evidence

Introduction

The understanding of the mechanisms behind the scientific process has been subject to longstanding research. In particular, a key topic extensively studied concern scientists' incentives to conduct research. However, in the case of hard sciences an often underestimated element of this process is the time devoted to instrumentalities which are broadly speaking activities dedicated to the development and adaptation of new methods and instruments to research needs. Indeed, research activities only constitute a necessary but not sufficient condition for discoveries: understanding and improving the physical capital at hand is a key factor for successful and novel research.

This chapter investigates the interactions between time devoted to research and "instrumental" time (i.e. time devoted to understand, configure and improve methods and instruments). A theoretical model is

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

provided to illustrate the nature of the interaction between these two factors as well as parameters affecting it.

In particular, a closer look is given to the effect of a given research team's scientific productivity on the allocation of time between the two activities. For instance, based on the results of the model empirical evidence are provided to test the relation between research teams' productivity (scientific production / citations) and time allocated between research and instrumental activity. This enables to test the relative importance of instruments for research teams characterised by high productivity levels, hence illustrating some of the model predictions.

Literature background

Incentives

Several levels of analysis have been proposed to explain the underlying mechanisms behind the scientist's incentive for conducting scientific activities.

Organisational approaches explore the type of incentive schemes proposed by firms to scientists.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Lacetera & Zirulia (2008) model predicts that scientists' incentives are contingent on the interaction between the competition faced by a firm and the degree of knowledge spillovers: greater incentives – for both basic and applied research - occur when knowledge spillovers are high and competition is low. Lacetera (2008) highlights the differences of outcome from scientists conducting research in a corporate and university environment, coining the importance of project duration and broadness of research in explaining a firm's outsourcing decisions.

Individual approaches explain differences of effort and performances between scientists by looking at intrinsic - activity related - or extrinsic - environment related - motives. Many studies focus on scientists working in the private sectors, with empirical evidence that the trade-off between monetary benefits and freedom of research is an important feature (Stern, 2004); and that the intrinsic motives can appear more beneficial for innovation than extrinsic ones (Sauermann, 2008).

The present chapter sets the level of analysis at the research team level since it is sensible to consider the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

outcome of the scientific activity in hard science field as a collective product (Stephan, 1996), where each individual bring his own skill and approach (Jones, Uzzy, & Wuchty, 2008).

Also relevant for this chapter, the time allocation approaches focuses on the trade-off of the scientist between different activities with the objective to reach the optimum balance. This framework is based on the one developed by Becker (1965). An example of application is given by Cassiman (1998) who instead of focusing on the trade off between effort and monetary benefits highlights the importance of time allocation between lobbying and research activities.

Using a similar approach, this chapter focuses on a research team conducting fundamental research activities. Its main concern is the way in which it has to allocate time between performing research and improving the instrumentation at hand. Effort and monetary benefits are assumed to be given to the team before conducting the scientific activities suggesting that these two variables do not add information to the model. In other words, it is assumed that the team has an exogenous taste for science that is constrained by

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

instrumental limitation. The "free" motivation of the team and its members mentioned here is supported in the economic literature by articles exploring the reward system in science where the rule of priority applies. The competition in science, similar to a race, motivates scientists to be the first to reach significant new knowledge and diffusing it in the scientific community for reward such as promotions, scientific awards or general recognition (Dasgupta & David, 1994).

Physical capital

The second important element of this chapter lies in the interest given to the instrumentalities which support the scientists' research. Recall that the models mentioned above focus on factors that affect research performance without accounting for the instruments needed by the scientists, therefore disregarding the role of scientific equipments[2] in the knowledge creation process.

Several economists have introduced scientific

[2] Scientific Equipment is defined as "an instrumentality needed for an undertaking or to perform a scientific service". Source http://wordnet.princeton.edu/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

equipments in the picture, but often more to study the effect on the society of this under-studied outcome of research. Rosenberg (1992) highlights the commercial importance of scientific equipments provided by universities to industries, coining the importance of "university research as the source of a highly influential category of modern technology: instruments of observation and measurement (…). New instrumentation has thus often been an unintentional and, to a surprising extent, even an unacknowledged, product of scientific research"[3] . Von Hippel (1976; 2005)[4] explains the critical importance of the user community in developing scientific equipments alongside the manufacturer in view of commercial applications. Notice that in the case of a public environment, we can translate this exchange as the collaboration between engineers and scientists working on common research projects (Price D. J., 1984). However, this difference between environments is decreasingly true since evidence show that Public Research Organisations (PROs) collaborate more over

[3]Rosenberg 1994: Chapter 13, p 251

[4]Von Hippel 1995: Chapter 5, p 70

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

time with firms on basic research (Autio, Bianchi-Streit, & Hameri, 2003). More political, Dasgupta and David (1994) raise two interesting questions about scientific equipments: first the political choice for funding either few large scale equipments (particle accelerators, telescopes etc.) or many smaller ones; and second if the funding to university equipment is sufficient to keep pace with the instrumentation provided by the private sector.

Closer to the original topic, studies within the Economics of Science mention scientific equipments as a strategic element in research. Stephan (1996) recalls that physical resources in addition to human resources are an important component of research when assessing the large costs of scientific equipments needed in hard science fields. She adds that this aspect is understudied especially since it is not taken into account in the human capital model. Looking among other topics at the priority and secrecy in science related to scientific equipment, Dasgupta and David (1994) highlight that the prime users of cutting edge equipments experience a

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

competitive advantage in research[5] . They underline the following two contradicting forces: on the one side the increasing diffusion of knowledge thanks to communication technologies, and on the other the increasing tacit (know-how) knowledge related to the use, improvement and calibration of the necessary instruments and experimental techniques. Considering the last point, Price (1984) did advocate the use of a new term to define the invention of new instrumentation or methods enabling the identification of new scientific phenomena, namely "instrumentalities". He highlights their importance in generating both scientific and innovative advancement, shifting forward the existing scientific knowledge frontier: "The almost accidental generation of a newly invented instrumentality gives a means of doing something new in the laboratory and perhaps also conjointly in the world outside". Less into a serendipity explanation, Rosenberg (1994)[6] supports the view of "how instrumentation has selectively

[5]"Each may believe that some particular feature of their research design, say some special instrumentation or data analysis technique that has not been mastered by others, will give it a competitive edge, and all observe that winning a bigger race, in which there are a larger number of entrants, will do more for one's collegiate status" (Dasgupta & David, 1994).

[6]Rosenberg (1994, pp. 16-17 Ch. 12)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

distributed opportunities in ways that have pervasively affected both the rate and the direction of scientific progress". He also warns not to fall into the simplistic view of technological determinism since scientific equipments differ vastly in their specificity or generality, and that they obviously constitute a necessary but not sufficient condition for scientific progress. Regarding this last point, I should quickly mention that one school of thought from sociology of science approached the importance of physical capital in research through the actor-network theory (M. Callon[7] and B. Latour[8]). This theory claims that non-human inputs (such as scientific equipments) have as much a role in scientific progress as human inputs.

Research and Instrumentalities

The scientific activity of a research team in hard science fields both includes time in research and time improving instrumentation. The definition of Price (1984) describes any research as needing "(...) basic science, which uses its entire achieved repertoire of

[7] http://www.csi.ensmp.fr/index.php?page=EMembres&lang=en&IdM=2

[8] http://www.bruno-latour.fr/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

instrumentalities to study and understand the world of nature, but also (...) applied sciences, which use the same repertoire to examine the world of artefacts". Including and updating this definition, the Frascati manual (OECD, 2002) mentions that "research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" [9] . It comprises three elements: basic and applied research (Price D. J., 1963; Price D. J., 1984) as well as experimental (instrumental) development activities (OECD, 2002) [10] .

At this level of analysis, the research team performs two tasks: research which consists in creative work stemming from the available data and instrumental

[9]OECD Frascati Manual (2002, p. 30)

[10] OECD Frascati Manual (OECD, 2002, p. 17):"***Basic research*** *is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.* ***Applied research*** *is also original investigation undertaken in order to acquire new knowledge. It is, however,directed primarily towards a specific practical aim or objective.* ***Experimental development*** *is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed."*

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

development which corresponds to the activity of improving the tools to generate new data. Both activities have uncertain but important outcomes. To use the words of Foray (2004), the first consists in discoveries and the second one concern inventions[11] .

This introduction shows that researchers did focus on topics related to instrumentalities, but none proposed a micro-model describing the role of instrumentalities in the scientific process of a research team. Therefore, the added-value of this chapter is to show in which way research teams allocate time between research and instrumental development, and how the research productivity of a team affects this allocation.

The next part focuses on the theoretical model. It is then followed by the empirical part testing model's predictions concerning the relation between productivity of research and time allocation in the context of the Elettra laboratory operated by Sincrotrone Trieste[12] .

[11] Examples: understanding the properties of chemicals are discoveries, synchrotrons beamlines are the instrumentality that permitted it. A new observed planet is a discovery; the telescope that permitted that observation is the instrumentality.

[12] http://www.elettra.trieste.it/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Theoretical model

This model aims at maximizing the scientific outcome of a research team conducting research under scientific, instrumental and time constraints. The rational team maximizes the following production function:

$$P = (\alpha \cdot (\gamma \cdot t_r)^{\varepsilon} + (1-\alpha) \cdot (\delta \cdot Q)^{\varepsilon})^{\frac{1}{\varepsilon}}$$

where P is the outcome of the research team; the variables are t_r the time devoted to research and Q the instrumental component; the parameters are α the relative importance of research in the research outcome, γ the research productivity of the team in research, δ the affinity of the team with the instruments and ε the complementarity element. The production function is then maximized with respect to two constraints: namely an instrumental function and a time constraint. The parameters of interest in this model depart from the ones in models using wage or effort –extrinsic and intrinsic incentives (Sauermann, 2008)- and focus on time devoted to research and time in improving instruments as key variables.

Indeed, focusing on scientific and instrumental outcomes Foray (2004) states that new knowledge can

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

be of two types: "(...) inventions, that is, it does not exist as such in nature and is "produced" by man", and "(...) discoveries, that is, the accurate recognition of something which already existed but which was concealed" [13] . In turn the quality of the instrument achieved by the research team is the following:

$$Q = \bar{q} + t_q \cdot (q_{max} - \bar{q})$$

where $\bar{q}$ is the initial quality of the scientific instrument, t_q the time invested by the team in improving the instrument and q_{max} the optimal performance of the instrument. Indeed, the team has to invest time in improving the instrumentation in case the initial one does not fully satisfy the expectations.

Finally, the team has to decide in what way to allocate the available time between the two activities:

$$t_r + t_q = 1$$

The story is therefore the following: a team of scientists conducts a scientific project. As a first step, they assess the instrument configuration at disposal and estimate the effort needed to customize it for their research purpose, and then collectively decide the time

[13] Foray (2004, p. 14)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

to allocate between the research and instrumental tasks: on the one hand t_r for gathering, treating and analysing the data, and on the other hand t_q devoted to technological and methodological adaptation of the hardware for the needed observation[14] .

Coming back to the equations above, I replace Q and t_q in the production function:

$$P = \left(\alpha \cdot (\gamma \cdot t_r)^{\varepsilon} + (1-\alpha) \cdot \left(\delta \cdot \left(\bar{q} + (1-t_r) \cdot (q_{max} - \bar{q})\right)\right)^{\varepsilon}\right)^{\frac{1}{\varepsilon}}$$

This general equation can already give some interesting theoretical elements.

This theoretical equation representing the output of the scientific process of a team encompasses a large number of responses to a variation in time allocated to research. An overview of the possible cases can shed light on which conditions support the different scenarios from a variation in the allocation of both instrumental and research activities. Concerning the change of scientific output from parameters change,

[14]In the extreme case where the team invests all its time on research, the quality of the equipment will correspond to the initial quality level of the available instrument.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

simulations can be generated and give some preliminary information (details in annex). The outcome of a given scientific process depends on the model's parameters as follows: a higher research productivity, for example from a more experienced team (i.e. higher γ) will increase the output, just as the capacity to improve the instruments (i.e. higher δ), or the quality of the infrastructure (i.e. higher $\bar{q}$). Concerning the parameters that affect both research and instrumental activities, for instance α and ε, their effects are as follow. A higher outcome will be reached when a team will allocate more time into the activity which has a higher weight in the outcome of the research process, α for research activities and 1-α for instrumental activities; and as the substitutability parameter ε converges to minus infinite, the two factors of the research process will become increasingly complementary.

Coming back to the original maximization problem, what I am interested in is the effect of the team's research productivity on the time allocation decision between research and instruments. For example, would a team with experimented scientists (high productivity) differ in the time allocation from a less experimented

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

team?

Solving for the optimal t_r provides the following[15] :

$$t_r^* = \frac{q_{max}}{\frac{1}{\left(\frac{\delta}{\gamma}\right)^{\varepsilon/\varepsilon-1}\left(\frac{(1-\alpha)}{\alpha}\cdot(q_{max}-\bar{q})\right)^{1/\varepsilon-1}} + (q_{max}-\bar{q})}$$

Based on this equation, simulation can be conducted to assess the responses of the time devoted to research from a change in parameters.

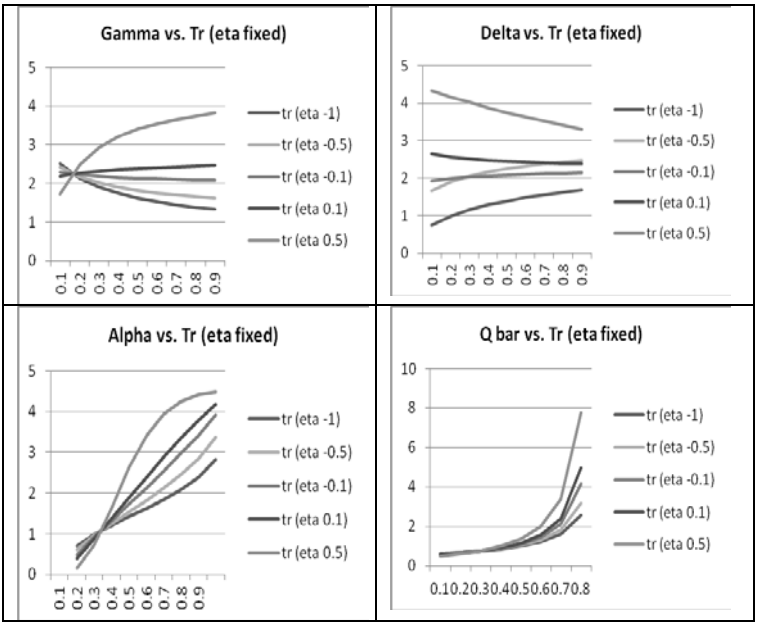


Table 1: Parameter simulations

The choice of time allocation in research as compared to instrumental activity will depend on several

[15] Algebra found in annex

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

parameters which are described below.

First, an increase in the share of research (as compared to instruments) in the output of the scientific process (i.e. higher α) will logically increase the time invested in research. Similarly, a higher $\bar{q}$ means that the quality of the instruments available to the team is higher and therefore the effort to improve the instruments to the need of the research project is lower. This simulation would suggest that by providing to a given research team instrumentation "close" to their needs or a specialized team that supports them, more time can be invested in the research activity and higher outcome can be reached. In short, the time invested in the research part of the process will be higher, the higher the $\bar{q}$.

Second, the skills of the team in one of the factor will also affect the relative time in one or the other activity, conditioned on the substitutability of factors (i.e ε). Here the behaviors of the research productivity (i.e. γ) and the instrumental productivity (i.e. δ) mirror each other. The main parameter of interest of this paper is the research productivity γ. When looking at the simulation, one can observe two potential scenarios. A

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

first scenario with $\varepsilon<0$ suggests an increasing complementarity of research and instrumental activities and therefore a lower investment of time devoted to research as the productivity of the team increases. The second scenario with $\varepsilon>0$ suggests an increasing substitutability of the two activities and therefore a higher investment in research when the research productivity of the team increases.

Intrinsically, research teams aim to push the boundaries of knowledge but to do so they need to collectively invest more time in the factor which is most valorised. Therefore, the output of research depends on the parameter ε.

In the next part, empirical evidence is provided to assess the relation between γ and t_r which will infer the sign of ε and therefore test the substitutability versus complementarity scenario. Therefore, indications should be provided whether or not high productivity teams invest more time in instrumental resources to maximise their research output.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Empirical Evidence

At a microeconomic level, evidence for the importance of instrumentalities can be illustrated by research teams that had access to the laboratory Elettra at Sincrotrone Trieste[16] . Among the many types of Research Infrastructures, the laboratory Elettra investigated here is a synchrotron[17] , a powerful light source used for scientific advancement in a large range of fields including biology, chemistry, material sciences, and physics. Sincrotrone Trieste, the organisation operating the laboratory Elettra, hosts a large number of scientists who need this type of infrastructure for their research. Data on the composition of 50 teams could be collected for this study.

A dataset was then built with the publication records of scientists composing those teams, in particular using

[16] Technically, this research laboratory provides synchrotron light: a type of very intense and coherent electromagnetic radiation which can penetrate even the densest materials. The spectrum of wavelength produced by the facility varies from radio waves to X-rays and can be set according to the employed experimental method. Experiments with synchrotron light contribute to new knowledge in many science and technology fields. Concerning the structure of the organisation, it is to note that the RIs can be managed by other organisations, for instance, Sincrotrone Trieste manages the RIs Elettra and Fermi@Elettra.

[17] http://en.wikipedia.org/wiki/Synchrotron

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the database ISI Web of Science[18]. Based on this individual information, team level information could be induced concerning the allocation of research and instrumental activities as well as research team productivity.

Data and measures

Two data sources were used to build the dataset.

First, a list of the 50 independent research teams which were granted access to the Elettra laboratory in 2010. These selected teams are categorised by the laboratory as conducting research with applications in three large research areas namely biology and chemistry, physics and energy, and material sciences. Individual information from the scientific database ISI Web of Science was added to the entries of all team members, namely the number of publications from peer reviewed journals as well as citation numbers.

The two following measures were then constructed.

18 http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Variable	*Theory*	*Proxy*
γ	*Research productivity factor of the team*	• *Average team's past yearly publications* • *Average team's past yearly citations*
tr *Similarly* *tq*	*Proportion of time invested in research* *Proportion of time spent in instrumental activities*	*Number of non-instrumental scientific articles over total number of publications* *Number of instrumental scientific articles over total number of publications*

Concerning the research productivity parameter, the two proxies above were used. Among the publications, only the scientific articles were retained in the computation of the measure in order to avoid possible bias. Observing large differences between a scientist's first and last published article, numbers were normalized with respect to the experience span of each researcher (in years).

Concerning t_r (and t_q) which represent the proportion of time invested in the two factors, a measure is built to differentiate between scientific articles which aim at improving the state of knowledge (i.e. facts), and the one aiming at improving know-how

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

(i.e. artefacts).

In order to achieve this, the official category description of WoS Science Citation Index Expanded categories is used. Each subject category is mapped to the research group, instrumental group, or both depending on its "instrumental" content. A category is fully defined as instrumental if the description contains one (or more) of the following search terms: methods, tools, techniques, technology, instruments or engineering and its content exclusively relate to instrumental activities (e.g. biochemical research methods, instrument and instrumentation etc.). However, in some cases subject categories encompass both research and instrumental activities of a given area (e.g. food science and technology, nanoscience and technology etc.). In that case, the subject category is assumed to contain half research half instrumental related content. The last group of categories is the one that only relate to discoveries in a given field and where instrumental search terms are absent (e.g. cell biology, organic chemistry etc.).

Based on this framework, the publications of all team members are then mapped into the two categories and

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

scores summed up: 1 unit for an article published in an instrumental subject category and 0.5 units for an article published in an ambiguous category[19] .

From the allocation of each member into both research and instrumental activities the proportion of articles in each categories was computed, and used as a proxy for research time tr (and tq).

Descriptive statistics

The sample is composed of 50 teams composed in total of 225 scientists that conducted scientific experiments in 2010 at the Elettra laboratory. The variables of interest show the following:

Variable	Obs	Mean	Std. Dev.	Min	Max
Team Alpha	50	**0.73**	0.15	0.4	1
Articles (norm)	50	2.59	1.21	0.67	6.7
Citations (norm)	50	25.3	20.5	1.29	112.43

Table 2: Descriptive statistics

Team Alpha is on average 0.73, meaning that 73% of

[19] The complete list of WoS subject per group is given in the annex of chapter 2.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the team's time is allocated to research and 27% to instrumentalities. It has a maximum of 1 (full time on research) and a minimum of 0.4 (majority of time spent on instrumentalities). Rounding up, on average 3 articles (normalized) per teams is published, and about 20 citations (normalized) per team are observed. Notice the large difference in the numbers of articles and citations among teams.

When breaking the data down in three main scientific disciplines, we observe the following:

Discipline	Team Alpha	Std. Dev.	Articles (norm)	Std. Dev.	Citations (norm)	Std. Dev.	Freq
Biology and Chemistry	**0.76**	0.17	2.27	1.14	24.79	24.68	20
Material Science	0.74	0.15	2.80	1.39	28.73	16.64	12
Physics and Energy	**0.68**	0.10	2.79	1.12	23.97	17.24	18
Mean	0.73	0.15	2.59	1.21	25.30	20.45	50

Table 3: Descriptive statistics by scientific field

The allocation of time in research appears more

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

important in biology and chemistry and material science than physics and energy, where instrumentation appears more important. In terms of performance, on average little disparities exist between scientific disciplines, but large heterogeneity exists within each categories.

Results

First, concerning the complementarity between research and instrumental activities depicted in the model, the following graph illustrates the positive relation using the two selected proxies.

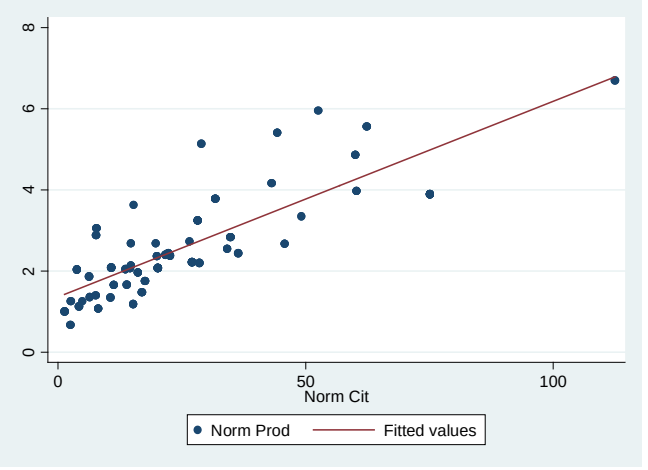


Figure 1: Team average citations versus average articles

Second, introducing the time allocation proxy, the relation between a research team's productivity and

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

time allocation can be illustrated as follows:

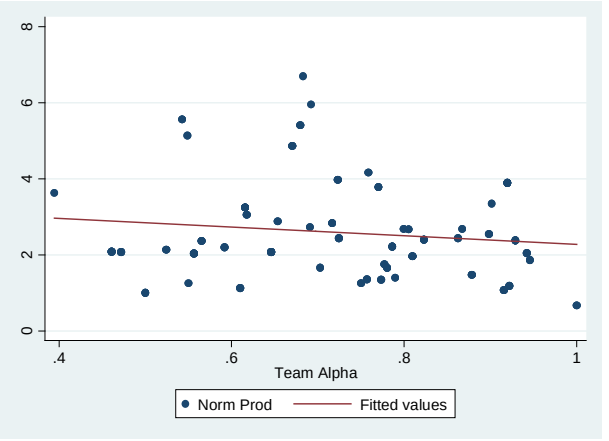


Figure 2: Team articles vs research time allocation

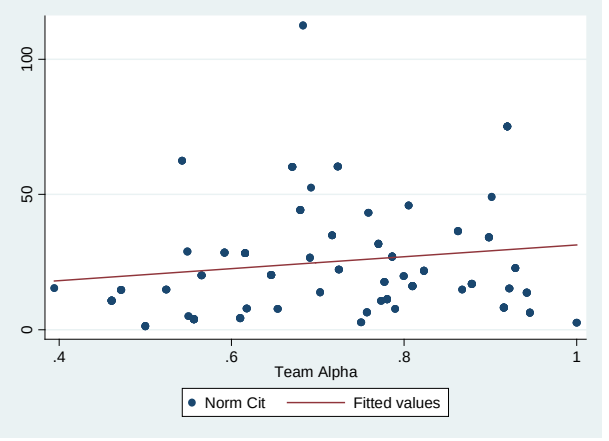


Figure 3: Team citations vs research time allocation

At first inspection, the relation is not clear. On the one hand taking published articles as proxy shows a slight complementarity story (correlation = -0.15, significant at the 5% level). However, taking citations as

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

a proxy shows the opposite, a slight substitutability story (correlation = 0.16, significant at the 5% level).

A reasonable explanation of this difference could be explained by the fact that instrumental articles are relatively less cited than research ones. Indeed, it might be that research related articles are more prone to be diffused since more explicit than instrumental articles, themselves more tacit.

If diffusion can explain this difference, then it should hold not only for the overall but also for the fields of science in which the scientific effort takes place. Indeed, the diversity of performance between the three main research fields can be observed.

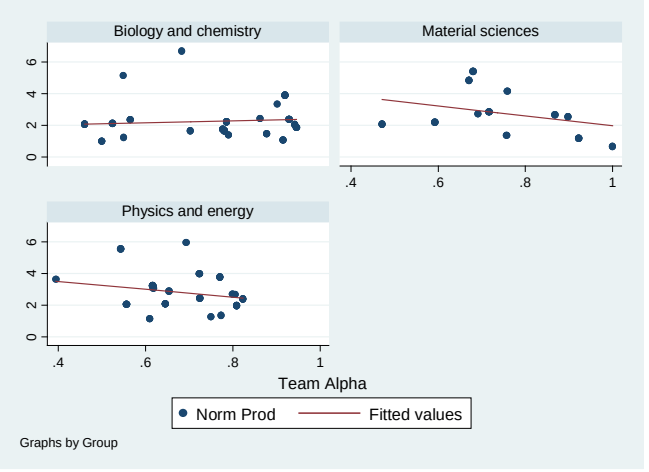


Figure 4: Team articles vs research time allocation by field

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

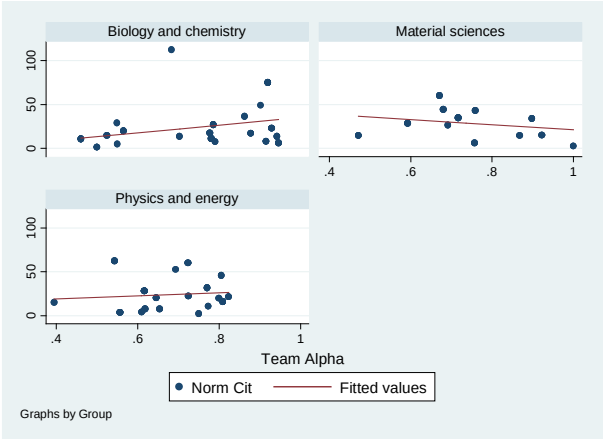


Figure 5: Team citations vs research time allocation by field

Breaking down the results by fields gives different relations between a team's productivity (articles and citations) and the team's alpha.

Biology and Chemistry: 0.09 (not significant) and 0.30 (significant 5%)

Material Science: -0.33 and -0.26 (both significant at 5%)

Physics and Energy = -0.22 (significant) and 0.10 (not significant)

By looking at these correlations, two cases take place.

In the field of biology and chemistry, there is a positive sign between both proxies of research productivity and the time allocated to research. This

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

consistency can be explained by the low instrumental nature of the field: biology and chemistry discoveries are evaluated on their capacity to bring new knowledge that does not primarily rely on know-how advancements.

Material sciences represent the second case and shows that the inverse from the previous fields is observed: a negative sign between the two proxies and research time allocation. Here the opposite explanation could hold: in material science, the know-how advancement is relatively more important and valued by the community in that field. This would suggest that teams in that discipline, in order to increase their research output, would tend to seek experience in instrumental know how as their research productivity increase. The same observation can be made for the field of physics and energy. That case follows the pattern of material sciences of a negative relation between productivity and research time allocation and suggests the importance of the instrumental factor in the field.

Looking at the three fields, it is to note that less negative or more positive correlations are systematically found for citations in the three fields under study. This

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

interesting finding suggests that using this measure favors research activities more than instrumental activities. In other words communities in a given field cite relatively more discoveries than instrumentalities. This suggests interesting hypothesis for this observation. A possible explanation would be the "taciteness" of methods and the difficulty to fully transmit the related knowledge (e.g. by a publication). Another one would be the fact that the instruments and methods used by the researchers are often omitted in publications; although themselves being the fruit of experimental research. This current flaws in the scientific reward system could therefore potentially lead to the under recognition of instrumental inputs and consequently under-investments in cutting edge tools which are key in the scientific process.

Conclusion

Rosenberg questioned in 1994 about "how much would the basic research thrust of the university science community have been impoverished if it had been deprived (...) of the stimulus to further research that was

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

provided to by the attempt to improve the performance of these instruments, once they appeared in their earliest, primitive forms? " [20].

This chapter investigates Rosenberg's question, providing first a theoretical model to simulate the possible parameters affecting the dependency between research and instrumental activities. And second, testing the model's predictions on how the "quality" of a scientific team affects the allocation of time between research and instrumental activities. Theoretically, what is found is that the relation between research and instrumental factors depend primarily on the value of the substitutability factor.

Based on this theoretical framework, empirical evidence test the possible scenarios proposed by the model concerning the effect of research productivity on time allocation; hence inferring the value of the substitutability parameter. To proceed, on the one hand teams' research productivity were proxied by both an article and citation related variable; and on the other hand the parameter assessing the time allocation was

[20] Rosenberg (1994, p. 263)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

measured by looking at published articles in research versus instrumental WoS subject categories.

From the empirical evidence, what is found is that the factors' substitutability depends on which research field is being looked at. Chemistry and biology depict a positive relation between time allocated to research and productivity whereas material sciences and physics and energy show the opposite pattern. An interesting finding is the under-estimation of instrumental activity in the scientific process when using citation as a measure for scientific productivity. A possible extension of this approach could be to test it in other contexts with larger datasets. Also, to apply this model in other field of social sciences or philosophy where new ideas in science need methods as tools to define and articulate them.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

"Progress comes from the diversity of cultures"

Pierre Joliot (1932-)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Chapter 2: The Position and Role of Research Infrastructures in the Material Science Network

Introduction

Since the launch of the 6th European framework programme, the importance of instrumental institutions called "Research Infrastructures" (RIs) has had an increasing role in the European Research Area until becoming one key pillar of the European Research Area[21] . These actors can be defined in short as "essential or unique facilities used by the (international) scientific community to conduct research in any field of science or technology[22] ". In other terms, a RI can be understood as an entity that provides access to cutting edge scientific equipments and research services to the scientific community, thus promoting the exchange and diffusion of both knowledge and know-how towards all types of research organisations.

The present chapter focuses on one research area

[21] http://ec.europa.eu/research/era/pdf/era_gp_final_en.pdf. World-class research infrastructures, integrated, networked and accessible to research teams from across Europe and the world, notably thanks to new generations of electronic communication infrastructures

[22] Definition retained by the EC funded RIFI project, 2010

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

where RIs are particularly important, namely material sciences. This field aims at exploring the fundamental properties and characteristics of materials, a type of research which has a very wide application scope, ranging from metallurgy to nanotechnology. The role of RIs within this field is mainly to support the research of scientific teams coming from a large number of organisations (national and international) to conduct experiments on top-class scientific instruments, managed by highly trained engineers and technicians.

To investigate the role and position of RIs in the material science domain, this chapter combines a social network analysis (SNA) as well as a statistical one, a mix which happens to be suited for the evaluation of an actor's position and role within a scientific system.

On the one hand, the SNA approach has the advantage to capture part of the complexity of inter-organisational research and deliver a static as well as dynamic view of the system. In addition, the reason why to experiment such a tool in this context is that the "traditional" economic method to evaluate the returns from science usually needs the pricing of scientific output, which in the case of fundamental science is

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

almost impossible to achieve. On the other hand, the statistical approach enables one to test the benefits of conducting research with an RI, and in particular concerning international collaborations.

Literature background

The topic of this study relates to the Economics of Science where the general aim is to investigate the role and effect of science on society, therefore acknowledging the strong evidence indicating a relationship between scientific performance and economic growth (Stephan, 1996; Dasgupta & David, 1994; Salter & Martin, 2001). Two branches of literature are shortly mentioned here: the one that measures the increase in scientific output resulting from a change in the technological / scientific environment, and the one evaluating the scientific performance of a research actor.

The first branch of literature focuses on the effect of technology on scientific performances. One way explores the scientific effects of the introduction of a new technology on scientific outcomes (Goldfarb & Agrawal, 2008; Ding, Levin, Stephan, & Winkler, 2010). Another approach, which is closely related to the RIs, is to measure the importance of scientific instruments

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

developed in fundamental scientific environments for both industrial innovations and scientific progress (Von Hippel E. , 1988; Rosenberg, 1992; Price D. J., 1984). One last approach that could be mentioned is the effect of public scientific investment on scientific performance (Lane & Bertuzzi, 2011).

The second branch of literature seen here focuses on the effect of a research institution on the scientific, technological and economic development. Well known studies of this type have been taken into consideration, such as the economic effect of an RI from S&T procurement contracts (Autio, Bianchi-Streit, & Hameri, 2003; Autio, Hameri, & Vuola, 2004). Other studies have measured spillovers by linking patented inventions to basic science (Meyer, 2000; Tijssen, 2002; Foray & Lissoni, 2009), patent-to-patent citations (Verspagen, 1999), scientific mobility between research institutions (Zellner, 2003), or the efficiency of the research itself (Arora, David, & Gambardella, 1998).

With regards to the network method, this chapter adopts a social network analysis that has already been used for evaluating research related phenomena such as the effect of a research programme on network

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

structures (Breschi, Cassi, Malerba, & Vonortas, 2009); or the position of academic inventors (Lissoni, Llerena, & Sanditov, 2011) as well as non-academic inventors (Balconi, Breschi, & Lissoni, 2004).

The statistical method is based on a modified gravity model. The latter has been used to identify determinants of collaborations mostly by testing the relevance of geographic proximity but also cognitive, institutional or social proximity (Boschma, 2005); as well as technological proximity (Montobbio & Sterzi, 2011). In my case, I introduce a RI proximity factor to test whether Italian research institutions having been supported by Italian RIs affects the probability to collaborate internationally.

Overall, this chapter focuses on RIs' scientific involvement and support of the Italian material science network. As mentioned already in the introduction, the reason for this approach is the lack of data related to RIs activities since most of the literature focuses on other types of research organisations such as universities.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Hypotheses

The following two hypotheses will be tested.

The first one concerns the position and role of the RI within its scientific network. The nature of the facility being to generate new data and technical knowledge for research, RIs in material science is expected to attract leading scientists within its field. In network terms, we would expect a central position of RI research. In addition, RIs are mostly located within scientific parks; thus their role would be expected to connect external actors to their own scientific cluster.

The second hypothesis that is tested concerns the expected effect on international visibility of local research institutions that collaborated with RIs. The idea is to see whether the presence of RIs in Italy enhances the number of international collaborations for Italian research organisations through common research projects. If that were true, RIs could be considered as "bridging" international scientists to local ones, and facilitating an increased knowledge and know-how exchange between partners (Bozeman & Corley, 2004).

As a preliminary comment, it is to note that for both datasets a group of Italian RIs is identified among the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

set of research organisations. It is composed of Elettra Sincrotrone Trieste (Elettra ST) as well as the National Institute for Nuclear Physics (INFN), which hosts the two large RIs of Legnaro and Frascatti. These RIs are defined as such by ESFRI[23] and the European Commission[24] .

Hyp. 1: testing the centrality and brokerage role of RIs on the Italian material science network

Method: Social network analysis

From the dataset, the available affiliation network (i.e. article * affiliation matrix) is converted to a one node network (i.e. article * article matrix): the network now relates two identical sets comprising nodes –which represent articles- and ties -which represent common authorship-. The reason why articles are used as a node instead of institutions is to permit institutional activities to overlap several network subsets, what I call

[23] European Strategic Forum for Research Infrastructures

[24] http://www.RIportal.eu

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

"clusters[25] " in accordance to the network theory. In addition, the advantage of this configuration is the focus on research, where articles' position and role in the network will indirectly assess the ones concerning research institutions and more particularly RIs. Indeed, by taking an institutional perspective, structural properties such as centrality of the RI would appear isolated due to the difference in size with institutions which central objective is to publish. Therefore, little information would be given on the actual role of RI related research in the network.

The conversion from affiliation to one node network only makes sense if the set of research institutions affiliated in articles are known to each other, giving an informative substance for each relation. Indeed, criticism arose from the observation of co-authorship one-node networks in scientific collaboration where articles can reach very large number of authors, therefore suggesting that there was no real contact between them, and therefore providing misleading structural properties of networks (Newman, 2001;

[25] "Clusters" are to be understood in the network theory jargon and not in an economic one: clusters consist in groups in which articles are assigned

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Newman, 2001).

Indeed, some tests using the dataset of this paper as a one-node network of scientists reveals features that are subject to the criticism here above. For instance, using the average number of authors per publication should provide evidence of the proximity between authors; it is found that scientific publications tend to be characterised by numerous authors with an average of 5 authors per article and 5% of articles having a team size above 10 members. These number question the accuracy of collaborations between scientists, and are largely above number usually accepted for inventor collaborations (Lissoni, Llerena, & Sanditov, 2011).

However, the present paper focuses on networks of organisations and investigates network measures that are only relevant to institutions instead of scientists. Using this level of analysis, the network depicts an average of 3 organisations per publications, with a standard deviation of one organisation, and only 1% of articles having more than 6 organisations as author's affiliations. With this number, it is reasonable to assume that close institutional contact exists between research organisations. One can observe that by using this level

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

of analysis enables to avoid "social co-authorship" internal to organisations which might be the cause of such a large number in the case of one node scientist's network.

Coming back to the applied methodology, one goal is the categorisation of articles into clusters. In order to achieve this, we apply to the article*article dataset an algorithm called the "Louvain method" which is a community detection approach that maximises the "modularity[26] " of the partition (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). In simple terms, this (iterative) two steps method identifies firstly small communities that are well connected together and secondly communities as nodes to build up the network. As a result, for each year under study, a certain number of clusters with their related modularity are generated[27] .

[26]The modularity of a partition is a scalar value between *−1 and 1* that measures the density of links inside communities as compared to links between communities

[27] Use of the open source application GEPHI (http://wiki.gephi.org)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

	1984	1989	1994	1999	2004
Clusters	6	4	6	5	4
Modularity	0.074	0.144	0.173	0.281	0.213

Table 4: Clusters and modularity per years

From the above table, one can notice the relatively limited number of clusters and the increasing level of modularity over the years. These elements show that the diversity of the Italian network of material sciences appears to be quite limited, but with clusters which tend to concentrate relatively more over time. Each article of the network data can now be associated to a cluster. In that way, all the present research institutions can be tracked with respect to their research involvement.

An additional feature of the network that is investigated concerns the "brokerage" roles of institutions, and in particular Research Infrastructures' ones. The information delivered enables to understand the types of relations a RI plays between as well as within clusters. Based on the seminal paper by Gould and Fernandez (1989) and the application of the concept in Pajek by de Nooy, Mrvar, & Batagelj (2005) the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

brokerage roles / structural positions are applied in the context of the flow or exchange of scientific information.

Data

The data originates from the Scopus[28] database and consists of a list of scientific articles from thirty peer-reviewed journals[29] in material sciences over five years (1984, 1989, 1994, 1999, and 2004). In order to limit the variations of articles in the selected sample and to avoid the general increase in scientific production, the journals are filtered with respect to two main conditions: the presence of articles in each of the five years under scrutiny (1984, 1989, 1994, 1999 and 2004) and a maximum standard deviation of 500 articles per journals in the five-year periods. An additional condition is to retain articles which have had at least

[28] http://www.scopus.com

[29] Inorganica Chimica Acta, Journal of Organometallic Chemistry, Solid State Communications, Macromolecules, Thin Solid Films, Journal of Non-Crystalline Solids, Journal of Materials Science, Applied Surface Science, Polyhedron, Journal of Nuclear Materials, Solid State Ionics, Cryogenics, Journal of Fluorine Chemistry, Polymer Degradation and Stability, Corro- sion Science, European Polymer Journal, Journal of Power Sources, Journal of Membrane Science, Physics and Chemistry of Minerals, Journal of Elasticity, Materials Chemistry and Physics, Materials Letters, Oxidation of Metals, Polymer Bulletin, Cement and Concrete Research, Solar Energy, Journal of Physics and Chemistry of Solids, Materials Research Bulletin, Journal of Electrostatics and Ultramicroscopy.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

one Italian author since the focus of this chapter is on Italian related networks. Note that the first year (1984) under scrutiny is related to the first year with complete information for the 30 selected journals. This raw dataset consisting of a list of articles with additional characteristics – such as the list of the author's affiliations as well as the number of citations- is then converted into an article * affiliations matrix. From this new format, articles with incomplete information or a single author are dropped since the interest lies in the network. Also, the latter operation should not affect the study of the network since connections are represented by common authors and isolates would be disregarded in any case. In addition, in the field of material sciences, single authors appear to be scarce (Jones, Uzzy, & Wuchty, 2008). As a result of the process, a dataset composed of 702 articles from 72 Italian research institutions is produced (mostly universities but also private and PROs and, of course, RIs). The dataset is then broken down by years, and additional cleaning is performed to remove isolates from every period.

Out of these operations, variation of data over the whole five year period remains small: affiliations vary

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

very little (standard deviation of 3) just like the number of publications (standard deviation of 12).

Results

The evolution of the article * article network can be illustrated by the following table

	Year				
	1984	**1989**	**1994**	**1999**	**2004**
Nodes (articles)	140	147	154	134	123
Edges (authorship link)	5320	7440	7302	5906	6194

Table 5: Sample Nodes and Edges per Years

The number of articles over the years is relatively constant, therefore limiting the number of journals controls for the increasing trend in article production. Additional indicators from table 3 can be looked at to analyse this evolution:

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

	Year				
	1984	**1989**	**1994**	**1999**	**2004**
Network density	0.55	0.34	0.31	0.33	0.41
Network closeness centralisation	0.3	0.18	0.37	0.47	0.39
Network betweenness centralisation	0.046	0.048	0.036	0.04	0.032

Table 6: Network indicators

The density[30] of the network follows a U-curve, showing that in the case of the field of material science, the number of co-authorship goes down until 1994 and then goes back up. Over the period, about 40% of all possible connections are present, depicting a well connected network.

Closeness centralisation[31] measures the variation between the nodes closeness centrality. The latter is defined by its closeness to all other nodes. In this case, the indicator increases until reaching a peak in 1999 and

[30] The density of a network is the proportion of edges that are present out of all the edges that could be there.

[31] Closeness centralisation is the variation in the closeness centrality of vertices divided by the maximum variation in closeness centrality scores possible in a network of the same size.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

stays at a relatively high level in 2004. This means that some key articles –as is usually found in science- are very central in this network, meaning a clear core-periphery structure.

On the other hand, the betweenness centralisation reaches very low levels. This indicator measures the variation between nodes' betweenness centrality. The latter is defined by how present the node is between all other nodes. Overall, the meaning of this low figure is a low variation between nodes that depicts a high degree of collaboration and few isolated articles.

Research Infrastructures and research centrality

The first indication of the relative position of RIs is their overall research output compared to other types of institutions. Summing up the five years, the RI related group publishes 131 articles which are cited 1207 times while the non-RI group publishes 567 articles which get 6671 citations. When comparing statistically the two groups, a significant difference can be noticed, meaning that the group involving RIs seems to have a lower performance than the other group. This is mostly due to the difference in members composing the two groups

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

(20 fewer actors for the RI group). However, no significant differences can be found when comparing both groups' citations per publications figures (t-test at the 0.05 level).

Refining the data, it is interesting to see that even though absolute difference exists on overall performances, RI research happens to be central in the network. Once again, the two centrality measures are used, but this time at the article level. The comparison of the RI group and non-RI group leads to two main results. First, research involving RIs have a similar closeness centrality than research not involving RIs, showing a similar level of connectedness. Second, research with RI involvement depicts a higher betweenness centrality than when RIs are not involved, a higher figure which shows on average a stronger influence of this type of research. This evidence would therefore support the first hypothesis of the chapter concerning the central position of the RIs in the network.

Research Infrastructures and clusters

The role of the RIs within the material science

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

network can be seen by applying a cluster analysis to the network. This would give evidence for hypothesis 1 about the role of RIs towards other organisations. The following illustration summarizes the clusters' evolution[32] .

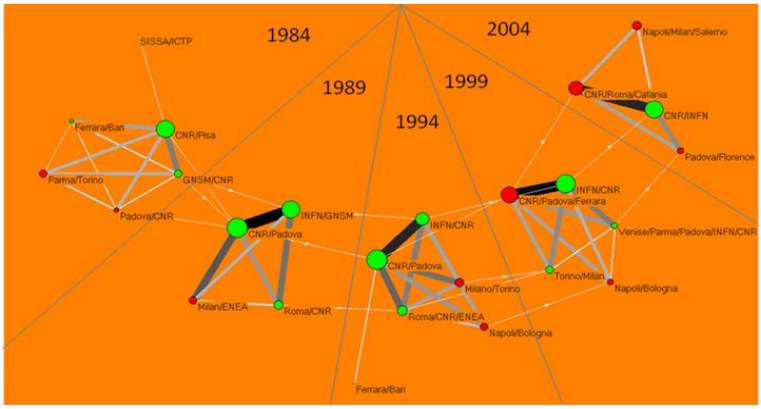


Figure 6: Cluster network evolution

Thanks to this new configuration it is possible to investigate the cluster position of RIs; and several cluster based indicators to be developed. The cluster diversity indicator measures the proportion of clusters

[32] The figure was created from a supermatrix containing both intra-period and inter-period cluster information. As before, green –lighter- dots represent clusters with at least one RI involvement and red –darker- dots represent clusters without any RI involvement and their size represents the number of members composing them. The darkness of the ties between clusters indicates the intensity of co-authorship. The name of the clusters relates to the two largest research contributors and finally the thin white arrows show the inter-period cluster similarity as measured by the Pearson correlation indicator. Concerning the latter, a score of at least 0.5 was retained for a link to exist between periods.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

where RIs are directly involved[33] . The indicator appears constant through the five periods with on average a presence of RIs in 26% of clusters whereas on average non-RI research institutions are present in 40% of clusters. RI research appears to focus on specific clusters. The cluster publication indicator measures the average number of cluster publications for RI and non-RI research. The RI related figure is smaller every year with an average difference of about 25 articles, indicating a lower scientific production in those clusters.

In a similar fashion, a cluster citation indicator measures the average number of cluster citations for RI and non-RI research. In this case, the difference is important with non-RI exceeding RI related research every year with a difference on average over the whole period of about 400 citations. Thus, the figure tends to show an involvement of RI research in lower knowledge diffusion clusters. In addition, the cluster members' diversity indicator was measured and captures the average number of cluster members RI and

[33] Many scientists, unfortunately, do not acknowledge the use of the RIs' in their publications. The current study, therefore, analyses publications where RI-based scientists are directly involved

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

non-RI groups interacted with. This indicator shows a systematic smaller figure for RI related research meaning that RIs tend to be concentrated in selected clusters.

From the evidence above, RIs appear to have their own particular position which is not similar to non-RIs actors, and more involved towards specialized clusters.

Research Infrastructures and research brokerage role

From the previous sections, the position of the RI research within the material science network has been investigated, but it would be useful to know, within or between clusters, what is its role. To identify this, four categories of brokerage roles from research collaborations between institutions are proposed as inspired and adapted from Gould and Fernandez (1989).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Brokerage role	Brokerage role from Gould and Fernandez (1989)
Coordinating research: research which takes place within a cluster:	Coordinator
Itinerant research: research involving the support of two actors from a foreign cluster	Itinerant broker
Representative or gatekeeping research: links between its own cluster to a foreign cluster	Representative broker or gatekeeper. Different roles when directed network.
Liaison research: connect two foreign clusters	Coordinator

The position of articles with at least one author from a RI can be translated into one of the role defined above. Out of this operation, the total number of articles which satisfy a role's condition is computed.

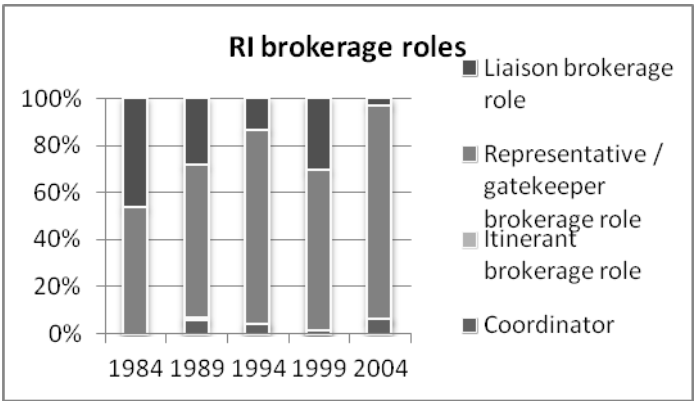


Figure 7: RI brokerage roles

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

From the result, the following statements can be made: the research performed by RIs will, in very few occasions, be connected with two other research projects neither belonging to the same cluster nor connecting two projects from another cluster. In decreasing cases over time the RI research will link two different research projects from two different groups. On the contrary, in most cases, RI research main role, from 1984 to 2004, has been to connect its cluster to other research organisations from a different cluster. This means that RI research has been embedded during that period into familiar clusters aimed at representing them towards other clusters. However, when looking at the brokerage of non-RI research, we find a similar pattern, which means that overall, the distribution of brokerage roles between RI and non-RI research tends to be similar. This would mean that brokerage roles at the article level tend to be governed by the same reasons above mentioned and are not structures specific to RI related research. Therefore, relating the absolute brokerage roles of RI research to the total of brokerage roles of all institutions might provide additional insight.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

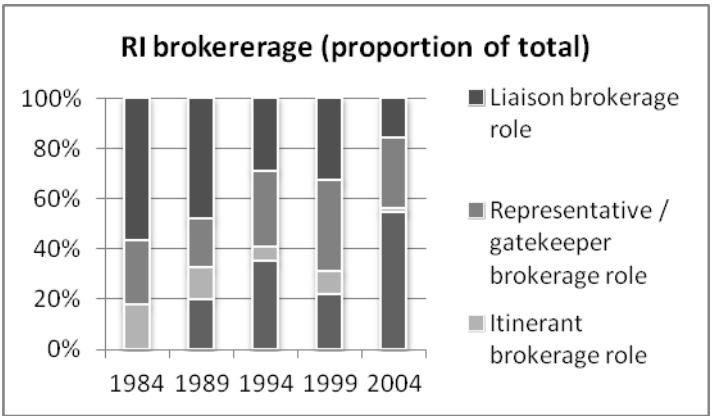


Figure 8: RI brokerage (proportion)

Indeed, what we find is that within the Italian material science network, the role of coordinator of RI research is growing overtime controlling for total brokerage roles until reaching about 50% of the total brokerage role for RI research role and more than 90% of coordinator role across institutional types (RI and non-RIs). This result suggest that RIs tend to have strong coordinator role, meaning extensive interaction within their cluster, hence supporting the idea of RIs embedded to longstanding relations with a given set of actors. Logically, the results also show the marginal existence of itinerant research bridging two "foreign" clusters. One explanation is that less clusters emerge over time due to an increasingly integration of research

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

communities and thus, enhancing the coordinator role of the RIs in Italy.

Hyp.2: the effect of RI support on international collaborations

Empirical model

In order to test this second hypothesis, the statistical empirical model used here is a modified gravity model. Gravity models applied to economics has become increasingly popular in various topics. Although subject to criticism for the lack of micro foundations, the validity of this family of models was re-established by Anderson (1979) and Anderson and Van Wincoop (2003) in studies concerning international trade. In this section this framework will be applied on international research collaborations between Italian and non-Italian research institutions. Related topics have been applied to identify determinants of collaborations, testing geographic proximity but also cognitive, institutional and social proximity (Boschma, 2005); or also technological proximity (Montobbio & Sterzi, 2011).

This method is used here to test the second

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

hypothesis of the chapter whether an "instrumental" factor (i.e. RI proximity) could explain part of the international collaborations between Italian and foreign institutions. In other words, if having collaborated with an (Italian) RI leads to a higher chance of common research projects between domestic and foreign research institutions. Other "classic" proximity measures are being tested in the model such as geographic, institutional and social[34] .

The gravity model is built at the city level. Drawing on the literature applying this model to international collaboration (Montobbio & Sterzi, 2011; Plotnikova & Rake, 2011), I enounce the basic gravity model form:

$$C_{ij} = C_0 * \frac{M_i * M_j}{d_{ij}}$$

Where C_{ij} represents the collaboration intensity between Italian city i and non-Italian city j; C_0 a proportional constant; $M_{i(j)}$ is the mass of city i (j) measured in terms of publication count; and d_{ij} is the proximity between the two cities. Note that d_{ij} comprise the several measures of proximity mentioned above.

[34] One of them, namely cognitive proximity –usually measured by scientific field- is not present as a factor since the paper focuses on one homogenous field of physics: material science

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

The "unconstrained" gravity model is:

$$\ln C_{ij} = \ln C_0 + \beta_1 \ln M_i + \beta_2 \ln M_j - \beta_3 \ln d_{ij} + \epsilon_{ij}$$

where ϵ_{ij} is assumed to be independent and identically distributed.

In order to test the second hypothesis, the above equation needs to be adequately estimated. However, the type of regression used for this equation depends on the nature of the dependant variable collaboration. Indeed, the data behind the variable collaboration has several characteristics that have to be taken into account.

First, it is a count model and as such depicts highly non-normal distribution which makes OLS an improper estimation due to the failure of the homoscedasticity assumption. A usual way to deal with this problem is the use of the Poisson regression (Santos Silva & Tenreyro, 2011) that can be stated as the following:

$$PR[C_{ij}] = \frac{\exp(-\mu_{ij})\mu_{ij}^{C_{ij}}}{C_{ij}!}, (C_{ij} = 0,1, \dots)$$

where the conditional mean is linked to an exponential function of the set of independent variable (Burger, Van Oort, & Linders, 2009; Plotnikova & Rake, 2011; Flowerdew & Aitkin, 1982):

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

$$\mu_{ij} = E(C_{ij}) = e^{\beta_0 + \beta_1 \ln M_i + \beta_2 \ln M_j - \beta_3 \ln d_{ij}}$$

Last but not least the dependant variable is overdispersed with a variance significantly larger than the mean, around three times larger. In order to overcome this problem a suitable candidate is the negative binomial as proposed by Burger, Van Oort and Linders (2009). The use of this regression instead of the Poisson regression is confirmed by obtaining a dispersion parameter (i.e. alpha) significantly different from zero for all tested regressions. Integrating this above parameter in the negative binomial distribution as well as the dispersion parameter alpha delivers (Greene, 2002):

$$P[C_{ij}] = \frac{\Gamma(\alpha^{-1} + C_{ij})}{\Gamma(C_{ij}+1)\Gamma(\alpha^{-1})} \left(\frac{\mu_{ij}}{\mu_{ij}+\alpha^{-1}}\right)^{C_{ij}} \left(\frac{\alpha^{-1}}{\mu_{ij}+\alpha^{-1}}\right)^{\alpha^{-1}}$$

One last problem faced by the dependant variable is the excess number of zeros which discards the use of an ordinary count models such as the negative binomial regressions (Greene, 2002; Santos Silva & Tenreyro, 2011). Indeed, data shows that over a total of 12848 potential collaborations, only 3532 are present (about 27%). It is also to note that significant Vuong tests favour the use of the ZINB over the standard negative

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

binomial. Thus the inspection of the data would suggest the use of the zero inflated negative binomial models (with robust errors).

Coming back to the "inflated" part of the model, an observed zero could be due either to no contact between organisations (true zero) or contact but no outcome (uncertain zero):

$$\mathrm{P}[C_{ij}] = \begin{cases} \varphi_{ij} + (1-\varphi_{ij})\left(\frac{\alpha^{-1}}{\mu_{ij}+\alpha^{-1}}\right)^{\alpha^{-1}} & \text{if } C_{ij} = 0 \\ (1-\varphi_{ij})\frac{\Gamma(\alpha^{-1}+C_{ij})}{\Gamma(C_{ij}+1)\Gamma(\alpha^{-1})}\left(\frac{\mu_{ij}}{\mu_{ij}+\alpha^{-1}}\right)^{C_{ij}}\left(\frac{\alpha^{-1}}{\mu_{ij}+\alpha^{-1}}\right)^{\alpha^{-1}} & \text{if } C_{ij} > 0 \end{cases}$$

The zero inflated negative binomial aims at differentiating between certain and uncertain zeros. Certain zeros are defined by a situation where two institutions have never been in contact due to their lack of visibility, resources or scientists not being connected to the scientific community. Uncertain zeros are defined by the situation where two institutions are in contact and visible but no common article (but possibly another outcome) was written. In this situation, inflated zeros could be explained among other explanatory variables by the institutional mass because of the importance of

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the visibility provided by the size of a research institution.

Data

The publications' dataset is extracted from the Scopus database and concern more than two thousands publications in the material science subject category. The data is used at the city level and comprises all collaboration pairs as measured by scientific co-authorship. The period under scrutiny spans from 2003 to 2005. Setting the level of analysis at the city level appears most adequate for the topic since it reveals more fined grained information, a clear advantage compared to a regional level of analysis.

The list of dyadic collaborations (i.e. collab) between Italian and non Italian cities is then generated (i.e. 12848 undirected pairs) along with gravity model inspired variables capturing masses and commonly integrated proximity measures (Boschma, 2005), and controls.

The first "classic" determinant of the attraction between two cities is their masses (lnMassI for Italian cities and lnMassNI for non-Italian cities). These are measured by the number publications originating in

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

that city in 2004 in the material sciences' subject category. This information is retrieved for each Italian and non-Italian partner cities.

The first proximity measure is the distance (i.e. lnDist), which is the "as the crow flies" geographic distance between collaborating Italian and non-Italian cities It is computed with the Haversine formula[35] with coordinates from the Getty Research Institute. For this factor a negative sign is expected (Audretsch & Feldman, 1996). From the evidence in the literature, it is tested whether this factor holds as affecting international collaboration in material research.

The institutional proximity representing the similarity between the types of institutions involved, namely universities, firms and PROs is calculated by a similarity indicator[36]. This measure (i.e. lnInstProx) captures the types of institutions present for each city and tests their importance for collaboration. Therefore if one city hosts two different research organisations, the

[35] Roger W. Sinnot, "Virtues of the Haversine", Sky Telescope, 68, 159 (1984)

[36] As measure by a modified Hamming distance which sums the institutional similarity between pairs of cities

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

city is given the aggregated mass and given multiple institutional attributes. A positive effect on collaborations is expected here due to institutional proximity. For instance, an institution in Italy would relate more easily to an institution outside of Italy if they belong to the same type (ex. Universities belonging to the same network or community).

The fourth measure, namely social proximity (i.e. lnSocProx), is also built to identify the importance of past collaborations on current collaborations. This variable is measured by collaborations that took place in 2002 (one year before our sample to avoid endogeneity issues) for each city pairs. Here, a positive sign is expected. The argument behind this is that past collaborations increase trust and stronger commitments between partners and therefore future collaborations (Boschma, 2005). Since we are measuring the log of previous collaboration and in many cases there are no previous collaborations, one unit is added to the social proximity measure before taking the log.

It is to note that the RI category is not included in these indicators since they act as support for other research organisations. However, RIs' implication in

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

scientific collaborations is introduced via a RI proximity variable that accounts for the number of common projects two cities had with an RI during the year just before the period under scrutiny, in 2002. In networking terms, it accounts for a triad between a dyadic collaboration and an RI. Note that the social proximity variable lnSocProx previously mentioned contains both dyads as well as triads since all triangular collaboration are present as dual collaboration. Therefore to disentangle the two types of information and reveal the contribution of triads for the probability to collaborate, the two non overlapping variables lnDyad and lnTriad are generated from lnSocProx. For computational purpose, in case of no previous triad, one is added to the measure before taking the log. A positive sign of the coefficient capturing the role of RIs on Italian international collaborations is expected due to the "instrumental" attraction of RIs towards foreign institutions.

Finally, controls are added. Geographic ones at the continental level are added to cover possible scientific agreements factors (Europe, Americas, Asia and Australia, and Africa). Dummies for the three years are

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

included to control for period fixed effects.

The table of summary statistics gives us a first impression of those variables.

	mean	sd	min	max
collab	.2749066	.9369901	0	15
lnmassi	3.230861	.9914591	1.098612	5.003946
lnmassni	3.63447	1.350538	0	6.862758
lndist	7.650737	1.030888	4.754905	9.723029
lninstprox	.5363248	.3196004	0	1.098612
lnsocprox	.0416302	.1911942	0	2.302585
lndyad	.0269202	.1470629	0	1.791759
lntriad	.0147101	.1115745	0	2.197225
europe	.6438356	.4788832	0	1
americas	.1541096	.3610678	0	1
asia	.1712329	.376727	0	1
africa	.0308219	.1728417	0	1

Table 7: summary statistics:

As mentioned above, only 27% of city pairs have occurred with a high standard deviation as compared to the mean, mostly due to the one / zero pattern of the dependent variable. This confirms the use of the use of negative binomial instead of the Poisson for the regression. Italian and non Italian city masses are similar with an average of 25 and 40 published articles. On average about 2100 km separates each dyad, the low end being due to European collaborations, close to the borders; whereas the high end being due to very distant intercontinental collaborations (Cagliari – Menai in new

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

south wales / Australia with more than 16,000 kms). Concerning institutional proximity, cities share between one and two research institutions. Social proximity variable depicts an average of 4,3% of dyads with existing previous collaborations. This number is then differentiated between dyads (collaboration without RIs) and triads (collaboration with an RI). The first represents 2,7% of previous collaborations and the latter 1,4%. Also, these figures have to be carefully interpreted due to relatively high standard deviation. The same care has to be taken for the RI proximity variable: both variables depict skewed patterns. Finally, most international collaborations of Italian research institutions take place with European partners (64%), the lower partner continent being Africa with only 3% of collaborations.

Results

The first results of the tested regressions start by accounting for the count nature of the dependent variable collaboration. Based on the above discussion, the next table depicts Poisson and negative binomial

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

regressions[37].

Regressions (1) to (3) depict Poisson estimates. The first regression concerns the "core" variables of the gravity model. As expected, the mass of Italian as well as international partners are positive and significant. Similarly, the distance coefficient is negative and significant, in line with previous finding. Note the high negative number for the intercept is due to the evaluation of the three other variables at 0 which is out of the range of possible observations. In the second regression the social proximity measured by previous collaboration between cities (i.e. in 2002) is introduced. The coefficient is positive and significant: for each additional unit of previous collaboration, the probability to collaborate increase by a factor of 3.5[38] . This strongly suggests the existence of a trust factor between dyads which increases the chance for future collaborations.

[37] OLS regressions can be found in annex.
[38] Exp(1.499)-1=3.477

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

		(1)	(2)	(3)	(4)	(5)	(6)
EQUATION	VARIABLES						
collab	lnmassi	1.051***	0.830***	0.804***	1.026***	0.841***	0.822***
		(0.0299)	(0.0303)	(0.0311)	(0.0262)	(0.0256)	(0.0264)
	lnmassni	0.400***	0.273***	0.261***	0.358***	0.274***	0.258***
		(0.0253)	(0.0235)	(0.0249)	(0.0181)	(0.0177)	(0.0184)
	lndist	-0.204***	-0.123***	-0.120***	-0.176***	-0.138***	-0.172***
		(0.0242)	(0.0226)	(0.0427)	(0.0207)	(0.0204)	(0.0421)
	lndyad			1.598***			1.907***
				(0.0705)			(0.0754)
	lntriad			1.374***			1.707***
				(0.0708)			(0.0953)
	lninstprox			0.249***			0.201***
				(0.0797)			(0.0731)
	europe			0.214			0.116
				(0.182)			(0.168)
	americas			0.391**			0.441**
				(0.188)			(0.172)
	asia			-0.0816			-0.135
				(0.196)			(0.174)
	lnsocprox		1.499***			1.839***	
			(0.0535)			(0.0598)	
	Constant	-6.376***	-5.856***	-6.091***	-6.332***	-5.877***	-5.742***
		(0.213)	(0.199)	(0.402)	(0.197)	(0.193)	(0.389)
lnalpha	Constant				1.202***	0.706***	0.696***
					(0.0531)	(0.0618)	(0.0618)
	Time fixed effects	yes	yes	yes	yes	yes	yes
	Observations	38,544	38,544	38,544	38,544	38,544	38,544
	stataaic	22022	20554	20472	20647	19673	19614
	statabic	22074	20614	20575	20706	19741	19725
	ll	-11005	-10270	-10224	-10316	-9828	-9794
	LR test				1377.77***	883.14***	860.45***

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8: Poisson and Negative Binomial Regressions

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

In regression (3) the social proximity variable is divided in two independent groups[39]. Indeed, this variable contains two pieces of information: previous collaborations which involved a Research Infrastructure (lntriad) and those that did not (lndyad). By replacing these two variables in the regression, I can test whether the relevance of triad collaboration while taking into account pre-existing dyadic links between partners. What is found is that both explanatory variables are positive and significant and both increase the probability to collaborate; by a factor of 3.9 for previous dyadic collaborations and by a factor of 3 for previous triadic collaboration involving an RI. This is a first empirical evidence of the importance of RIs in affecting collaborations between Italian research organisations and international partners.

However, as explained previously, a negative binomial regression is more adequate than a Poisson based on the over dispersion of the dependant variable. This can be deduced from a likelihood test which describes alpha as significantly different from 0.

[39] Correlation between the two variables close to 0 (0.0744)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Regressions from (4) to (6) provide the related estimates. The coefficients show similar results than the Poisson regression. However, it can be noticed that the variables of interest dyad and triad depict higher positive coefficients, raising the probability to collaborate from a unit of previous dyads by a factor of 6.7 and triads by a factor of 4.5.

One limitation of these two models is the excessive amount of zeros which are not taken into account. Differentiating between certain and uncertain zeros as explained before can be introduced in the models by proposing both zero inflated Poisson and negative binomial regressions. Starting by the zero inflated Poisson regression (ZIP) from column (1) to (3), what is found is lower coefficients which are due to the introduction of a logit process to explain the excessive zeros. Concerning the excessive zeros, the city masses as well as the distance are significant in explaining the certain zero group. It can be recalled that the certain zero group is defined by a situation where two research organisations have no collaboration due to impossibility (i.e. lack of visibility, budget, or absence in key. scientific communities), whereas the uncertain zero

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

group is defined by two organisations being in contact but not having written an article together. Concerning the certain zero group, the inflated part of the estimation shows that, the higher the city masses, the lower the odds of belonging to the certain zero group. Indeed, the larger the city the lower the chance of zero collaborations due to a lack of visibility, resources or network. Also, the higher the distance between institutions, the higher the odds to belong to the certain zero group.

Concerning the estimates, consistent results are being found with the previous regressions. For instance, the social measures increase the probability to collaborate with a factor of 1.2 for dyads and 1.1 for triads (in column 3) although to a much lower extent than previously. The introduction of dyads and triads in explaining inflated zeros is highly significant. A new result is the significance of the institutional proximity which increases the probability to collaborate by 35%. However, as mentioned before the ZIP regressions suffer from the over dispersion of the dependant variable. This can be seen from the likelihood test giving alpha significantly different from 0 for regressions (4) to

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

(6) suggesting that the ZINB model is preferred to the ZIP model. In addition, the relative goodness of fit of the ZINB statistical model as compared to the ZIP model can be measured by the Akaike Information Criterion (AIC) which constitutes a trade off between the number of included parameters and the maximised value of the likelihood function of the estimated model. In simple terms, the model with the lowest AIC figures the better. To accompany that criterion, another one called the Bayesian Information Criterion (BIC) is computed which is very similar to the AIC criterion but penalises more the inclusion of additional parameters. Again, the model with the lowest figure shows a better "efficiency" between the quantity and quality of included variables.

Based on the results in the following table, the ZINB models appear as fitting better the ZIP for testing the hypothesis. Coefficients are relatively similar to the zero inflated Poisson regression with some exceptions, and they tend to depict higher figures by taking care of the over dispersion problem.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

		(1)	(2)	(3)	(4)	(5)	(6)
EQUATION	VARIABLES						
collab	lnmassi	0.396***	0.262***	0.230***	0.492***	0.342***	0.316***
		(0.0430)	(0.0413)	(0.0423)	(0.0523)	(0.0452)	(0.0470)
	lnmassni	0.188***	0.114***	0.0816***	0.232***	0.131***	0.0948***
		(0.0275)	(0.0262)	(0.0277)	(0.0318)	(0.0266)	(0.0281)
	lndist	-0.0425	-0.0132	-0.0578	-0.0588*	-0.0496*	-0.111**
		(0.0277)	(0.0270)	(0.0427)	(0.0335)	(0.0290)	(0.0464)
	lndyad			0.779***			0.981***
				(0.0672)			(0.0816)
	lntriad			0.731***			1.000***
				(0.0675)			(0.0931)
	lninstprox			0.297***			0.274***
				(0.102)			(0.106)
	americas			0.193**			0.284***
				(0.0951)			(0.102)
	asia			-0.185*			-0.190*
				(0.0984)			(0.103)
	africa			-0.106			-0.0857
				(0.169)			(0.173)
	lnsocprox		0.737***			0.946***	
			(0.0499)			(0.0668)	
	Constant	-2.568***	-2.224***	-1.856***	-3.608***	-2.862***	-2.394***
		(0.300)	(0.293)	(0.374)	(0.390)	(0.319)	(0.410)
inflate	lnmassi	-0.811***	-0.764***	-0.784***	-0.856***	-0.812***	-0.842***
		(0.0499)	(0.0521)	(0.0542)	(0.0658)	(0.0625)	(0.0659)
	lnmassni	-0.252***	-0.226***	-0.251***	-0.232***	-0.249***	-0.288***
		(0.0330)	(0.0343)	(0.0364)	(0.0429)	(0.0399)	(0.0432)
	lndist	0.198***	0.186***	0.145***	0.216***	0.171***	0.125**
		(0.0348)	(0.0389)	(0.0404)	(0.0494)	(0.0479)	(0.0502)
	lninstprox			0.111			0.0918
				(0.146)			(0.178)
	lndyad			-2.086***			-3.680***
				(0.188)			(0.699)
	lntriad			-2.078***			-2.821***
				(0.235)			(0.621)
	lnsocprox		-2.128***			-3.390***	
			(0.142)			(0.465)	
	Constant	4.006***	3.871***	4.253***	3.092***	3.558***	4.041***
		(0.354)	(0.390)	(0.400)	(0.517)	(0.469)	(0.488)
lnalpha	Constant				0.00462	-0.348**	-0.297**
					(0.161)	(0.139)	(0.135)
	Year fixed effects	yes	yes	yes	yes	yes	yes
	Observations	38,544	38,544	38,544	38,544	38,544	38,544
	stataaic	20687	19508	19483	20546	19389	19355
	statabic	20773	19611	19646	20640	19500	19526
	ll	-10334	-9742	-9723	-10262	-9681	-9657
	Overdispersion (LR test)				143.09***	121.40***	130.65***
	Vuong test	10.99***	10.90***	10.66***	3.93***	8.02***	7.57***

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 9: Zero inflated Poisson and Zero inflated Negative Binomial Regressions

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

The original variables of masses of research organisations and distance are significant and behave in the same way as previous regressions. The mass of Italian cities appears to be more important than the non-Italian partner cities. As could be expected from the previous findings, the sign of the distance coefficient is negative and significant: the higher the distance, the lower the probability of having international collaborations.

The variable of interest measuring the impact of triads on the probability to collaborate is important and almost equal to the dyad variable with a factor of 1.66 against 1.71. This result confirms the hypothesis that Italian cities which perform research together with RIs increase the probability of international collaboration in addition to previous bilateral collaborations. Previous dyads affecting collaboration probabilities can be explained by the importance for partnerships to build trust over time and when trust is established, it will positively affect future collaborations. As explained before, triads comprise an additional actor: Research Infrastructures. There are some clear indications of their positive influence on the probability to collaborate

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

alongside dyads. A relevant interpretation is that the objective of triad research is not the same as dyad research. More precisely, the presence of an RI denotes a common need from two research institutions to use specialised infrastructure necessary for the advancement of research that is not available in-house. Dyads on the other hand denote collaborations which are more related to data treatment for a given topic than data generation.

Institutional proximity is slightly positive and significant. Therefore similarities between cities hosting institutions of the same type (mostly universities) has a positive effect on the expected number of collaborations -bearing in mind the low value of the coefficient-. Lastly, it can be noted from the continental geographic dummies that a city in the Americas has significantly more bilateral international collaborations than a non-Italian European city. This result which appears surprising at first can be explained by the concentration of American cities collaborating with Italian ones.

Robustness check

The section above has been looking at the city-pairs

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

collaborations over time, in this section a look is given on the measures affecting international collaborations over the entire 2003-2005 period. Only the zero inflated Poisson and zero inflated negative binomial results will be shown here[40] .

Some coefficients decrease such as the institutional proximity shows lower importance over the whole period. Pre-existing dyads is another variable which become insignificant and hence do not differentiate anymore between certain and uncertain zeros.

However, in general the cross sectional regressions show higher estimates. This is due to the fact the numbers show aggregates for the three periods under scrutiny. For example, the probability to collaborate internationally increase by a factor of 1.6 instead of 1.2 for previous dyads and from 1.1 to 1.5 for previous triads. Similar results are found in the case of ZINB estimates with a respective change from 1.7 to 2.6 and 1.7 to 2.6. Overall, the cross sectional results show consistency with the panel results.

[40] Poisson and negative binomial regressions can be found in annex

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

		(1)	(2)	(3)	(4)	(5)	(6)
EQUATION	VARIABLES						
collab	lnmassi	0.462***	0.325***	0.312***	0.590***	0.428***	0.422***
		(0.0322)	(0.0322)	(0.0325)	(0.0483)	(0.0442)	(0.0433)
	lnmassni	0.183***	0.115***	0.0948***	0.226***	0.137***	0.103***
		(0.0205)	(0.0200)	(0.0213)	(0.0289)	(0.0264)	(0.0280)
	lndist	-0.0575***	-0.0128	-0.0292	-0.0607*	-0.0451	-0.122**
		(0.0211)	(0.0210)	(0.0392)	(0.0334)	(0.0306)	(0.0522)
	lndyad			0.982***			1.290***
				(0.0511)			(0.0955)
	lntriad			0.917***			1.268***
				(0.0573)			(0.116)
	lninstprox			0.226***			0.209*
				(0.0789)			(0.111)
	americas			0.102			0.352***
				(0.0949)			(0.121)
	asia			-0.147			-0.173
				(0.100)			(0.121)
	africa			-0.0463			-0.00414
				(0.178)			(0.203)
	lnsocprox		0.926***			1.227***	
			(0.0396)			(0.0771)	
	Constant	-1.845***	-1.647***	-1.546***	-3.169***	-2.438***	-1.910***
		(0.219)	(0.219)	(0.322)	(0.360)	(0.315)	(0.429)
inflate	lnmassi	-0.791***	-0.754***	-0.755***	-0.906***	-0.841***	-0.856***
		(0.0435)	(0.0465)	(0.0477)	(0.0744)	(0.0693)	(0.0721)
	lnmassni	-0.289***	-0.267***	-0.277***	-0.300***	-0.313***	-0.357***
		(0.0294)	(0.0309)	(0.0322)	(0.0462)	(0.0452)	(0.0475)
	lndist	0.199***	0.211***	0.190***	0.262***	0.229***	0.183***
		(0.0325)	(0.0358)	(0.0368)	(0.0596)	(0.0552)	(0.0584)
	lninstprox			0.0336			0.0120
				(0.132)			(0.207)
	lndyad			-2.077***			-77.51
				(0.186)			(53,897)
	lntriad			-2.097***			-3.570**
				(0.262)			(1.716)
	lnsocprox		-2.121***			-5.049**	
			(0.150)			(2.279)	
	Constant	3.631***	3.340***	3.498***	2.409***	2.824***	3.302***
		(0.311)	(0.338)	(0.347)	(0.572)	(0.516)	(0.541)
lnalpha	Constant				0.438***	-0.0648	-0.0161
					(0.109)	(0.111)	(0.0925)
	Observations	12,848	12,848	12,848	12,848	12,848	12,848
	stataaic	14431	13492	13483	13858	13134	13110
	statabic	14490	13567	13610	13925	13216	13244
	ll	-7207	-6736	-6724	-6920	-6556	-6537
	Overdispersion (LR test)				574.52***	360.29***	375.24***
	Vuong test	12.07***	11.32***	11.11***	3.84***	6.86***	6.37***

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Zero inflated Poisson and Zero inflated Negative Binomial Regressions

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Conclusion

The aim of this second chapter has been to test two hypothesis; on the one hand the central and cluster position of RIs, as well as the role of Italian RIs in the material science network and on the other the effect of being connected to an RI for conducting international collaborations.

Concerning the first question, a social network methodology was proposed and evidence show that RI research in material science is central, which means that it is involved in key research, and is therefore influential over the network. In addition, within the group of articles involving RIs, several articles show high centrality, meaning an important role of few but key articles. From these general centrality aspects, a complementary cluster analysis is conducted. Results show that RI research is on average involved in a lower number of clusters compared to the non-RI group. However, if we take RI research independently from the cluster division, we find that RI related research has a similar performance in terms of citations per publication performance with respect to the non-RI group (t-test at

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the .05 level). These two observations suggest a beneficial role of RI research towards specific clusters which is in line with the support and "cohesion" role of the initial objectives of the RIs. The way in which RIs conduct their "cohesive" role can be understood by analysing the brokerage position of their research. The results obtained indicate that RIs research increasingly coordinate research projects within their own cluster as opposed to research projects outside their cluster.

In the second part of this chapter, the effect of RIs on Italian international scientific collaborations has been investigated. In order to test the hypothesis of a positive effect, a modified gravity model was proposed. Setting collaborations as dependant variable, a series of variables and proximity measures were introduced in the model. The tested variable of interest concerned a RI proximity variable which described a triadic relation between an Italian and non-Italian research organisations, and a research infrastructure. This variable was interpreted as how the presence of a research infrastructure in city-pairs collaborations (and their respective institutions) affects the probability to collaborate. The tested regressions point at a positive

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

and significant role of triads on the probability to collaborate at the international level. It is to note that alongside the triad factor, the dyad factor defined by previous bilateral collaboration also affects –to a slightly higher degree- the international collaboration. The two variables can be interpreted as positively affecting the probability to collaborate from both trust being built between partners as well as common need in using cutting edge instruments.

To conclude, it appears that RI research generally fulfils its inherent objectives: RIs appear central and support a large number of research organisations in the network. Also, they are involved in the creation of central knowledge and know-how towards more specialised and not necessarily central clusters. They affect the scientific network of Italian research organisations by increasing the probability of international collaborations to connected cities. This result suggests the role of RIs in improving visibility of local research organisations in the global material science field.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

"Science can amuse and fascinate us all,
but it is engineering that changes the world"
Isaac Asimov (1919-1992)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Chapter 3: Identifying emerging technologies: an application to nanotechnologies

Introduction

World history and in particular the two last centuries provide examples of regions and countries that gained comparative advantage from early investments in science and technology. For instance, significant and well documented cases from the 20th century are general purpose technologies (GPTs) such as the steam engine, internal combustion, electricity or IT. These provided tremendous effects on economic growth (Bresnahan & Trajtenberg, 1995; Jovanovic & Rousseau, 2005). These exemplary cases affected countries' investment strategies which led to a transition described by Derek De Solla Price (1963) as the passage from "little" to "big" science. This observation made in the beginning of the 20th century happened to be a first signal of the significant increase in funding of science and technology development across the world.

The first investment strategy promoted by governments was the linear view, which sees scientific

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

activity as determining technological performance. This view still leads as a dominant rationale today. This strategy was put into practice by active science oriented policies and considered as a key channel for growth. This trend can be observed by world's increasing investments in R&D, a reliable source of growth and more generally progress[41]. An expectation which can be seen as true on the ground that countries with a high level of R&D tend also to have a higher GDP; but correlation does not mean causality.

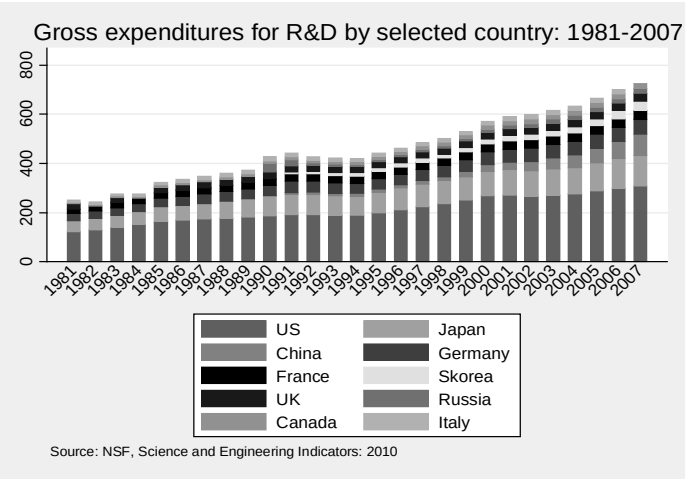


Figure 9: R&D expenditures by country

[41] The relation between R&D and Innovations is also well accounted in the literature (Smith, 2005).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

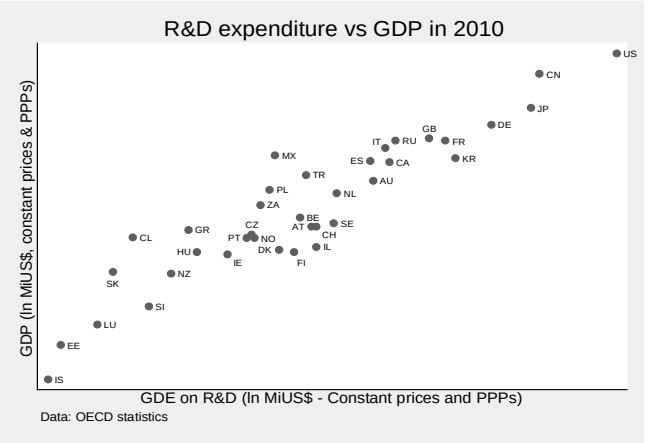


Figure 10: R&D expenditure vs. GDP

Indeed, other scholars explain that this "science" push view only gives a partial picture explaining the emergence of technologies (Rosenberg, 1982). It is argued that technology, in turn, can also lead to new knowledge and scientific activities. For instance, evidence suggests that new knowledge resulting from technology to science flows might have actually been the main direction of discoveries (Price D. d., 1984). Therefore, interactions between science and technology have to be considered as complex and non-linear in nature and it is by accounting for these complex interactions that promising technologies can be identified at an early stage.

However, participating to the S&T competition is

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

costly for states. This call for innovative tools to identify which technologies will benefit the most to society on the medium to long run. In particular, developing an identification strategy concerning emerging technologies is required. Emerging technologies are generally intended by policy makers to qualify technologies which have the greatest potential among all fields to bring radical improvements, overcome challenges, take over established technologies, or create comparative advantages. Today, a common given example are NBIC technologies: nanotechnology, biotechnology, Information technology and Cognitive science (Roco & Bainbridge, 2003).

In the literature, the technology life cycle (TLC) framework integrates an emerging phase and provides a good starting point to understand the evolution of technologies over time. The TLC framework describes the stages of technology evolution namely: introduction, growth, maturity, and decline (Popper & Buskirk, 1992) or emerging, rapid growth, maturity, decline (Roper, Cunnigham, Porter, Mason, Rossini, & Banks, 2011). In theory, this sequence can be illustrated by an S-curve which depicts the evolutionary path of a technology

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

over time (Andersen, 1999)[42] .

This model has been extended by introducing the case of double S curves explained by the double boom theory (Schmoch U. , 2007; Andersen, 1998) that can be observed in fields like chemistry (Haupt, Kloyer, & Lange, 2007). It is argued that a second emerging phase takes place after a temporary decline due to market pull response from the new technology (i.e. consolidation phase). However, with respect to the TLC framework, this paper only focuses on the emerging stage of science based technologies.

A nuance has to be given concerning the difference between a new and emerging technology. They both share a novelty attribute where no information exists yet over their future path or "success", however the difference is in the static (new) versus dynamic (emerging) perspective (i.e. all emerging technologies have been new at one point, but not all new technologies will emerge). Thus, emerging technologies have to be observed in a framework that accounts for

[42] Numbers of articles have proposed explanation for this pattern such as the heterogeneity model (different benefits from the invention) or the epidemic model (people are slowly informed about the invention).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

alternative future paths. The following sketch can be shown to delineate emerging from non emerging technologies.

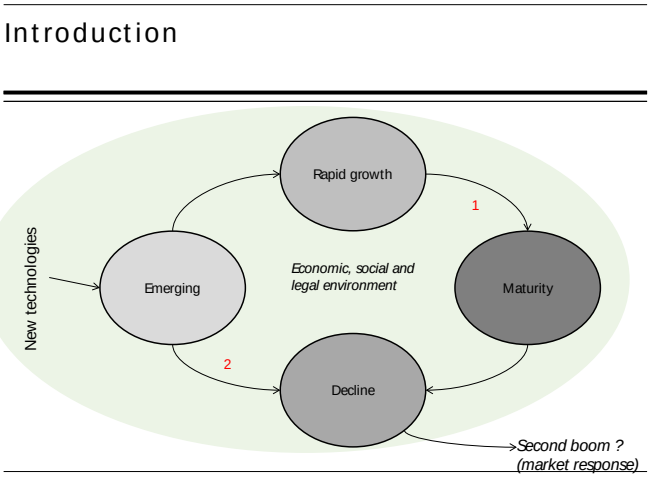


Figure 11: Science and Technology cycles

The complexity of factors under work behind the transition from emerging to established technology must be kept in mind. According to Pavitt (2005), those factors can be determined by many variables such as technological trajectories and scientific theories, government-funded R&D programs, systems integration, and techniques and approaches to managing uncertainty. Also, technologies in decline are either technologies being replaced by superior, more

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

competitive technology or ones in consolidation phase. The sketch above tries to summarize the possible evolution paths over time from an emerging technology perspective. Two cycles are illustrated:

Complete cycle: Emerging, Rapid growth, Maturity, Decline (second boom?)

Incomplete cycle: Emerging, Decline

The first bullet point describes a full cycle where a technology is introduced, emerges, is competitive enough to mature on scientific and technological grounds, and then possibly enters a double boom phase as response to market forces. This suggests a "complete" technological cycle. One should bear in mind the frictions in these transitions such as the competition usually taking place within the set of emerging technologies to challenge and replace established technologies in a closer to longer horizon. These competing emerging technologies are among other things very heterogeneous in the technological advance they might lead to, where the progress proposed is generally inversely proportional to the uncertainty they incorporate (Kline & Rosenberg, 1986). One should keep in mind that this "complete" cycle is rare and depicts a

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

best case scenario as compared to the other cycle.

Indeed, the second bullet point describes the incomplete case representing new technologies which potential is not proven and which did not experience a rise in research and inventive dynamic. For example, this subset could be the case when a technology did not happen to be on the dominant technological paradigm and got isolated.

The goal of this paper is to identify emerging technologies at an early stage, from an ex-ante perspective. As will be explained, the key identification dimensions are the measurement of research alongside technological dynamics. The claim of this paper is that better anticipations can be achieved by observing both S&T dynamics behind a given technology.

Paper sections

This study has the objective to provide a novel way to identify emerging technologies. In other words, the focus is primarily on detecting disruptive technologies at an early stage. The next section describes the scientific and technological model at work behind technology development, and its use in identifying emerging

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

technologies.

The section that follows provides the identification strategy adopted in this paper.

The data section then selects a relevant set of technologies in nanoscience and nanotechnology to test the proposed framework.

The result section starts by showing how the S curve concept can be interpreted in relation to the selected indicators. Second, it shows how the framework proposed in this paper adds on this information and provides a way to discriminate between emerging, emerging basic, emerging applied and non-emerging technologies.

The last section concludes and enounces further possible research paths.

Conceptual framework: emerging technologies and S&T dynamic

The central claim of this study is the existence of intrinsic scientific and technological differences between emerging and non-emerging technologies' dynamics.

The model proposed here describes the "engine" behind the emergence of technologies characterized by

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the continuous interaction between scientific and technological activities. The understanding of this black box (Rosenberg, 1994; Rosenberg, 1982) is central to identify the subset of emerging technologies.

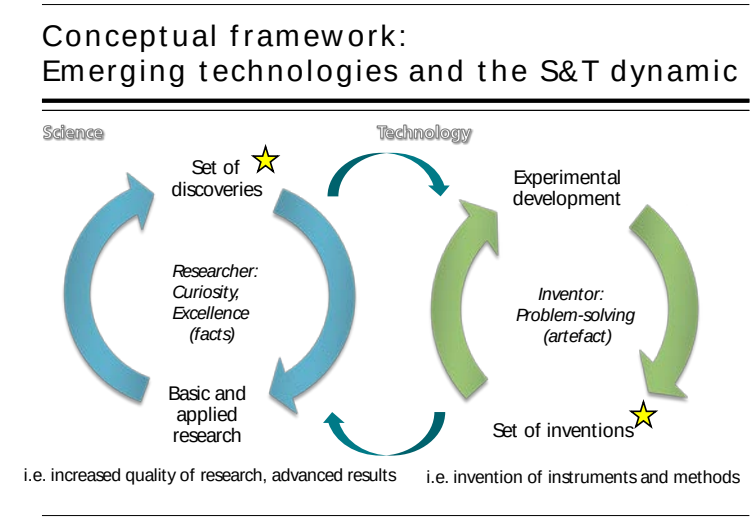


Figure 12: Conceptual framework

The model has two main characteristics. First, it captures the continuous process behind research and inventive activities (the TLC only looks at the inventive dynamic for instance). Second, it is non-linear to integrate the numerous feedback loops and interaction that take place between scientific and technological

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

activities. Note that in this paper only the part of technology related to inventions will be investigated (and not innovations).

Thus two parallel and interacting dimensions constitute the basis of this model: science[43] and technology[44] .

In this paper, the scientific process consists in fundamental and applied science activities carried out by researchers. Their activities continuously feed the set of discoveries (the R in R&D). The nature of their

[43]The definition retained is taken from the Frascati manual from the OECD **Invalid source specified.**: *"**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. **Applied research** is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. **Experimental development** is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed".*

[44] From Greek etymology, technology is defined by the combination of *tekhno-* "art, skill, craft, method, system" and *–logy* "a speaking, discourse, treatise, doctrine, theory, science". The current interpretation of technology draws on its etymon but do not perfectly map. Indeed, the term was subject to much in-depth refinement following increasing importance of technology in society. For instance, according to the OECD **Invalid source specified.**, technology "*refers to the state of knowledge concerning ways of converting resources into outputs*" or less economic, Wikipedia defines it as "*the making, usage, and knowledge of tools, machines, techniques, crafts, systems, or methods of organisation in order to solve a problem of perform a specific function*". Note that the specific function mentioned can have a large scope of applications, may they be commercial, scientific or else. So technology here is a picture which defines the technological state of the art.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

discoveries is usually information which can be quickly transmitted and shared with the scientific community. As described by Day, Schoemaker & Gunther (2000): "weak signals of technological emergence are those more subtle indicators that a discovery (i.e. from research) has commercial potential and that independent analysis has recognized this potential and a following has formed" [45] . Indeed, the pool of created knowledge (i.e. discoveries) interacts with experimental developments which can ultimately lead to the development of prototypes, new methods or more generally inventions (the D in R&D).

The transition from scientific experimental development to technology occurs when an idea is concretized into an artifact or invention. A "(…) first occurrence of an idea for a new product or process" (Fagerberg, 2005, S. 4) which is both strongly science related and depends on the skills and talents of inventors.

These developments can then follow two different

[45] Strong signals. According to (Day, Schoemaker, & Gunther, 2000), "*strong signals of technological emergence are those that clearly reveal commercial investment in the candidate technology and signal its technical feasibility to serve target market needs*".

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

objectives. First, provide artifacts or instrumentalities (Price D. d., 1984) for the advancement of science. According to Glanzel and Meyer (2003): „one of the possible explanations for the outstanding strong technology science transaction link could be found in the importance of specific processes and instruments relevant in scientific research". Also, from Price (1984, S. 15): "a high proportion of the world's most cited scientific and technical papers come under the category of "method papers", which act as a surrogate for some particular instrumentality[46] ". This phase accounts for intermediary inputs which "take the form of new materials, new machines, new components, or technical processes that never show up in conventional measures of final product for the simple reason that they are not final products" (Rosenberg, 1982, S. 71-72). Second, inventions can be directed to solving technical challenges. These types of inventions can be very valuable to the commercial market since they represent possible solutions for challenges faced by a very broad public with various degrees of complexity, from

[46] Instrumentality is defined by Price as „(…) a laboratory method for doing something to nature or to the data at hand"

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

everyday customers to high tech specialized firms. One of the main difficulties in this phase is matching and adapting problems with solutions, a search process that can be very costly. This task is the role of "retrievers" [47], more commonly known as "innovators" which role is to find and adapt solutions (innovate[48]) from existing inventions to overcome a given challenge and performing "the first attempt to carry the idea of a new product or process out into practice[49]".

The emergence of new science based technologies is therefore driven by a constant interaction between scientific and technological developments which has long been recognized in the economic literature: "science often is dependent, in an absolute sense, on technological products and processes for its advances. Over the course of history thus far, it is moot whether science has depended more on technological processes

[47] Term coined by Prof. Carlo Rizzuto at the ERF conference "Socio economic evaluations of Research Infrastructures" in may 2012, Hamburg.

[48] in Latin *innovare* "to renew, restore, to change" and invention relates to *invenire* "to come upon; devise; discover"

[49] Indeed, it should be stressed that there is a clear nature difference between those two terms in the distance-to-market attribute; invention being the result from development activities whereas innovations being the commercialization of such developments. The innovators carrying this transition process take into consideration different parameters than the inventors in their decision to adapt a new product or process to the market.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

and products than innovation has depended on science“ (Kline & Rosenberg, 1986, S. 287). This non linear process has been conceptualized by Kline and Rosenberg’s chain-linked model which scientific and technological component is particularly relevant for emerging technologies (Kline & Rosenberg, 1986, S. 303): on the one hand “potentiation of wholly new devices or processes from research”; and on the other hand “much essential support of science itself from the products of innovative activities, i.e. through the tools and instruments made available by technology”.

Therefore, the emergence of a given –successful- technology should both be signaled by underlying scientific and technological activities, and also subject to the acceleration of these or using the web vocabulary the observation of a “buzz” which would significantly differentiate a given technology at an early stage compared to other technologies.

One way of looking at it is through the pace at which a given idea or tool is adopted. The identification of emerging technologies by looking at their adoption has mostly been studied within the innovation literature where different theories are proposed to explain how

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

innovations "take off" (Young, 2009) from an "adopter" perspective [50]. However, the interest of this paper lies in provide supply oriented identification of emerging technologies in terms of science and technological dynamic.

Indeed, this paper claims that the parallel occurrence of scientific and technological dynamics is particularly true in the case of emerging technologies. In other words, it adds to the TLC a scientific dynamic which is crucial for emerging science based technologies[51] .

[50] Firstly, the heterogeneity model where agents adopt scientific facts or technological artifacts at different times due to their idiosyncratic differences; secondly, the social influence model where agents adopt as soon as enough other agents in their community have adopted it (i.e. via workshops, conferences, or publications). This adoption channel can be seen as the "first user" community. And finally, the contagion model where people adopt when they are informed about like in the case of "schools" of thought. Note how these different models have been subject to dramatic changes with the evolution of ITC capacity and exchange platforms. The theories from Rogers **Invalid source specified.** can also be helpful to understand characteristics affecting the diffusion of ideas or instrumentation advancements. These are their *relative advantage*; their *compatibility* with the potential adopter's current way of doing things and social norms; the *complexity* of the advancement in question; *trialability*, the ease with which an idea or instrument can be tested by a potential adopter; and *observability*, the ease with which the scientific fact or technological artifact can be evaluated after trial.

[51] Although the focus of this paper is on S&T dynamics, additional "environmental" factors have been looked at in the literature. Indeed, technologies are not independent from the context in which they evolve. This dimension covers a large number of factors and framework conditions which can have dramatic effects at all stages of the technology cycles. Environmental factors have a very wide scope comprising the state of market demand, technology policy and the influence of governments, legal and institutional settings, the state of the innovation system, or the level of capital formation or resources directed in

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Indeed, modern S&T fields such as biotechnology or nanotechnology tend to be more closely linked to science than traditional fields (Mansfield, 1990; Schmoch U. , 1997). This is due to the fact that a large part of today's bottlenecks could be solved at an infinitely small level where both science and technological activity become increasingly intertwined. As such, the object of a research (potential discovery) and its observation (potential invention) happen closely together in the emerging process. One way of observing this trend is the increase in scope of patentable areas to include scientific advancements in the case of genes or new materials. Therefore this study, by focusing on "science based" technologies will concentrate on the first boom (Schmoch U. , 2007) where those technologies emerge rather than the second boom governed by market demand forces.

This paper provides a method to identify those technologies which are indeed emerging according to the arguments developed in the conceptual framework. The model described in this section provided the

education among other factors. However, in this paper, these aspects will only be parsimoniously mentioned.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

theoretical foundation behind the use of science and technological dynamics to identify emerging technologies. Therefore, based on this theoretical model and previous literature, two main conditions for the emergence of technologies will be proposed.

First, and in line with the TLC literature, emerging technologies are subject to a growth phase of inventive activity (Andersen, 1999). Second, inspired from the observation of new technologies and the conceptual framework, emerging technologies should also be subject to a growth phase of research activity. By adding this "science" related condition no emerging technologies such as the one which remain as a new technology (little to no inventive activity but high research activity) or those which are applied and not suggesting discovery breakthrough (little to no scientific activity but high patent activity) will be accounted as emerging technology but respectively as emerging basic and applied technology. In other words, the identification method identifies emerging technology by the co-occurrence of research activity alongside inventive activity for a given period as compared to a set of technologies. Note that the parallel observation of

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

science and technology activity is mentioned in the literature as a good practice to identify emerging technologies (Schmoch U. , 1997; Hullmann & Meyer, 2003).

Methodology

Identifying emerging technologies

Several possibilities exist in trying to identify emerging topics. One of the first choices to be made is whether the emerging stage is identified in absolute or in relative terms. The advantage of absolute terms is to see the size of activities whereas the one of relative terms is to capture the relative importance within the framed set. The last approach will be adopted in this paper. For instance, the emergence of a technology will be detected by the relative increase in scientific and technological activity of a given technology as compared to all the other selected technologies. In addition, the performance of a given technology will be measure by the average over a given time period. Indeed, when the size of the activities are limited –as in the case of emerging technologies-, relying on year to year growth faces the limitation to be deeply affected by

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

"noise" due to exogenous event or mistakes coming from the database or data treatment.

It is therefore safer to rely on longer periods to assess the growth of activities, and a good indicator for that is the Sharpe ratio (Reiß, Hartig, & Schmoch, 2009; Sharpe, 1994).

$Sharpe_Ratio$ (when $\sigma_\alpha > 0, I_\alpha \neq 0$)	$S_\alpha = \frac{(\overline{I_\alpha} - \overline{I})}{\sigma_\alpha}$

Where:

-$\overline{I_\alpha}$: mean of technology a growth over the given period

-$\overline{I}$: mean of all technologies' growth over the given period

-σ_α: standard deviation of technology a growth over the given period

The use of Sharpe ratio has characteristics that suit the identification strategy. Looking at the numerator, it compares the average growth of a given technology to the overall average growth of technologies. A positive numerator would depict a relatively higher growth and vice versa for a negative numerator. This difference is

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

normalized by the standard deviation of the annual technology growth over the period under scrutiny. This accounts for the variability of the growth rates in the way that technologies showing stability in their growth rates are less penalized in their score than more volatile fields (which also tend to be smaller in size).

Two growth measures can be used to identify emerging technologies using the research and inventive activities related to each technology.

A first proposed measure for growth concerns the year to year absolute growth (i.e. the Sharpe ratio would be the average of those year to year growths). In that case, no advantage is given for starting during the period under study. What is advantaged is the absolute growth and therefore this proxy would identify technologies experiencing a more sustained growth, which would be a possible next sequence for a successful technology in terms of relative growth rate. It is to mention that this measure would face computational difficulties when:

If $\overline{I_\alpha} - \overline{I} \neq 0$ *and* $\sigma_\alpha = 0$	$S_\alpha = \pm$ *infinite*
If $\overline{I_\alpha} - \overline{I} = 0$ *and* $\sigma_\alpha = 0$	S_α *is indeterminate*

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

In order to correct for this singularity, I discard cases where the Sharpe indicator is not computable and impose:

$$\sigma_\alpha > 0$$

The second proposed measure is a year to year relative growth rate. This measure advantages technologies which are starting to show some activities during the observed period (i.e higher growth rates). However, since the year to year growth is being looked at, this proxy is non-measurable when research or inventive activity faces null data points. Therefore additional non-computable and disregarded cases are:

If $I_\alpha^{\,t} = 0$ *and* $I_\alpha^{\,t+1} > 0$	$I_\alpha^{\,t+1,t} =$ *infinite*
If $I_\alpha^{\,t} = 0$ *and* $I_\alpha^{\,t+1} = 0$	$I_\alpha^{\,t+1,t} =$ *indeterminate*
If $I_\alpha^{\,t} > 0$ *and* $I_\alpha^{\,t+1} = 0$	*since not consistent with firs*

In those cases what occurs is the lack of data for computing the relative growth values for a given technology. For example, this problem will occur when the number of entries among the period is only one (indefinite standard deviation), or the data is constant over time (0 standard deviation). In the data there are also series with 0's and 1's. In that case, the problem

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

faced is that the growth from 0 to 1 is infinite, whereas the passage from 1 to 0 is -1. This may lead to biases in the results. In order to solve this limitation, I disregard the un-measurable cases mentioned in that table and replace the mentioned growth rates with missing values.

Lastly, I impose the condition that both S&T Sharpe indicators by technology should be computable in order to be accounted in the analysis. In the case one "scientific" Sharpe indicator is not computable for a given year; the "technology" Sharpe indicator is not included to avoid bias.

Correcting for the above, the Sharpe ratios will then be computed both for scientific as well as technological activity. This provides the following taxonomy:

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Technology status during period p		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Emerging* *Strong growth of publications; strong growth of patents*	*Emerging application* *Weak growth of publications; strong growth of patents*
	Negative	*Emerging research* *Strong growth of publications; Weak growth of patents*	*Maturing* *Weak growth / decline of publications; weak growth / decline of patents*

Table 11: Emergence taxonomy

Measures for research and inventive activities

Research activity

The measure used for scientific activity, and more precisely discoveries made from research activities are publications in journals, trade journals, book series and conference material that have an ISSN (International Standard Serial Number) assigned to them, as well as conference papers. All these serial publications are taken into account as a measure for research activity in

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

order not to disregard emerging topics which might be exploratory and therefore not necessarily present in scientific articles on a short term base.

Inventive activity

Reliable and often used proxies of inventions are patents which describe the technological inventive dynamic of the model. Patent data describe the technology side of the conceptual framework in that they are an "indicator of invention rather than innovation: they mark the emergence of a new technical principle, not a commercial innovation" (Smith, 2005, S. 160). Technically, patents are defined as "a right granted by a government to an inventor in exchange for the publication of the invention; it entitles the inventor to prevent any third party from using the invention in any way, for an agreed period" (OECD, 1993). There are several patent offices where the main ones usually cited are the EPO, USPTO and JPO.

Data

Application field: nanoscience and nanotechnology

The empirical part of this paper focuses on

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

nanotechnologies, which represents a new and promising science based field strongly subject to both scientific and technological activities.

Current private and public bodies such as the National Science Foundation in US estimate the nanotechnology market to reach 1 trillion dollars by 2015. In addition, from its position at the crossroad between science, technology and markets (Schmoch U. , 2007) nanotechnology generates strong scientific, technological and societal expectations (though not unanimously shared). This translates into current active public policies and initiatives such as the National Nanotechnology Initiative in US or the NMP[52] initiative within the 6th and 7th Framework Programme in the EU.

Technically, nanoscience can be defined as the study of nanostructures and nanotechnology as the discipline which uses nanostructures to create useful nanoscale devices. Nanotechnology have size (1nm<n<100 nm or a billionth meter) and novelty characteristics. Any definition of nanotechnology should include: the size of the structure, the ability to work at that scale, and

[52] Nanoscience, nanotechnology, materials and new production technologies

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

exploitation of properties and functions specific for the nanoscale (Malanowski, Heimer, Luther, & Werner, 2006): "nanostructures aren't just smaller than everything made before, they are also the smallest solid thing that is possible to make" (Ratner & Ratner, 2004). Nanotechnologies are primarily composed of nanomaterials. They cover a large range of products which can be differentiated by dimensions, phase-composition, manufacturing process, value added stage, maturity / production volume and processability (Malanowski, Heimer, Luther, & Werner, 2006, S. 38). It is important to keep in mind that nanoscience and nanotechnology can only help to improve the capacities of a product when an effect at the nanoscale is used.

The uncertainty about the degree to which a product becomes "nano" induces a difficulty to coin the scope of nanotechnology (Scheu, Veefkind, Verbandt, Molina Galan, Absalom, & Förster, 2006). The still in progress consensus building about nanotechnology definition is also due to the fact that nanotechnology goes now beyond the S&T world, and is actively present and used in the public and media as a focal term to define a complex reality. This fictive clarity leads to heated

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

debates on the nanoscience and technology coverage which has in fine significant funding consequence (Kaplan & Radin, 2011)[53] .

One of the main elements of that debate concerns the value chain of products with embedded nano component. Assigning the entire end-product value as "nano" is questionable and has dramatic effect on "macro-enabled" market size estimation (Berger, 2007). Also, the large difference of costs within nanomaterials is disregarded when summarizing them all as "nano". For example, the price of nanoparticles features large disparities: from 10 to more than 10000 dollars per kilogram which can be explained by many factors such as the production volume, material type, powder characteristics, manufacturing method and post synthesis processing treatments (Rittner, 2002). However, this reveals the large heterogeneity of what nanoscience and nanotechnology encompass.

Technology dataset

The technology set for nanotechnologies are selected following the sequence:

[53] See also the presentation: http://videolectures.net/nano08_kaplan_bndd/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Identify nanoscience and nanotechnology field using retained measures

Identify nanomaterials which are relevant both for nanoscience and nanotechnology

Define and conduct keyword strategy to link science and technology

Validate keyword (back to step 2 if not passed)

Nanoscience and nanotech dataset

The dataset is based on information retrieved from both scientific publications and patent databases from 1996 to 2008. These are generally accepted indicators: "with these indicators the recent and actual development of emerging technologies can be illustrated and future potentials can be anticipated" (Hullmann & Meyer, 2003, S. 509). The lower and upper years are subject to limitations faced by publication and patent database access respectively.

The nanoscience publication set belongs to Scopus (Elsevier) and comprises peer reviewed scientific articles from 1996 to 2009. The set of nanoscience publications has been identified using the keyword strategy by Noyons & al. (2003). It is to note that other

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

search strategies have been proposed by several studies. As reported by Huang & al., (2008), main references concerning nanoscience and nanotechnology search strategies are Glannzel et al (2003), Noyons et al (2003), Porter et al. (2008) and Schmoch and Thielmann (2012). Concerning the period under scrutiny, the first year of observation in 1996 is due to incompleteness of the Scopus database before this year.

Following Schmoch (2007), this publication time series will be anticipated by one year in order to represent the submission year (e.g. 2002 publication year is 2001 submission year). It is therefore assumed here that it takes on average one year for a submitted article to be published. The available dataset will therefore contain all scientific publications with submission year from 1996 to 2008[54].

In total, the extracted information concerning research activity in nanoscience from 1996 to 2008 is a bit more than four hundred eighty thousands documents (480,417).

Concerning the nanotechnology patents, the

[54] The data was retreived betweeen August and October 2012 at Fraunhofer ISI in Karlsruhe.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

retrieved set spans from 1995 to 2008 where the year represents the priority year (year of first application). The set of documents is identified using the EPO tag "Y01N", a nano-related category. Alternatives exist such as EPO's new category called "B82" implemented in October 2011. However, this new category does not accurately incorporate all patent documents yet[55] . Other keyword strategies to identify patents in nanotechnology can be mentioned such as the one proposed by Noyons & al. (2003) or Schmoch and Thielmann (2012).

The selected patents follow the concept of transnational patents from Frietsch & Schmoch (2010). It consists in EPO and PCT patent applications excluding EURO-PCT patents[56]. The advantage of this approach is to provide a solution to improve international comparisons by retaining "foreign" patent applications only. Indeed, both EPO and WIPO do not provide patent protection at national level. Also both have delays between patent filling and application of 18

[55] This has been checked by looking at the differences in document number for both EPO class Y01N and IPC class B82.

[56] They are PCT patent applications transferred to the EPO. This is done to avoid double counting.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

months[57]. This means that to have a full dataset, the accessed patstat schema (April 2011) contains full information up to September 2009. Since we use yearly information, the dataset will therefore span until 2008 for completeness[58].

Note that adopting transnational patents' definition is usually aimed at achieving reliable international comparisons. For instance, selecting the set to transnational patents might disregard early advancements that do not have an international strategic nature yet. On the one hand, this choice is costly in terms of number of "hits" and data retrieved but on the other hand, this filter enables to reach a similar quality level across the patent population. Also, since a keyword strategy is used, it also avoids the use of different search strings necessary to accurately retrieve information in national patent offices.

In total, the extracted total inventive activity for the 1996 to 2008 period almost reaches fifty seven

[57] However, they differ in that PCT applications give the applicant an additional year to keep or drop its application.

[58] The patent data was retrieved between August and October 2012 from the Patstat database (EPO worldwide patent database) at Fraunhofer ISI in Karlsruhe (schema patstat11a).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

thousands patent applications (57,269)[59].

Identify key nanomaterials

This paper aims at identifying emerging technologies at an early stage. For this, a nanomaterial level of analysis is adopted. Nanomaterials are considered here as technologies in that their advancement enables new product capacities Also, the aim is not to focus on a specific material as for example in the case of graphene (Shapira, 2012) but to compare their emergence with respect to the general increase S&T activity as well as within their specific field.

To identify the set of materials a literature review is conducted to select the most significant nanomaterials from different expert sources: VDI technologiezentrum (VDI, 2010), Ratner & Ratner (2004), EPO nanotechnology categories (2012), EAG (2009), LUX Research, and BCC Research (BCC, 2010). The goal is to collect information at a fine grain level.

Overall, 32 nanomaterials were retained as being

[59] The data does not account for INPADOC and DOCDB families since we use PCT information which should control for duplicates. Also, it is clear that uncertainty remains on the level of non-patented inventions.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

relevant for nanoscience and nanotechnology. These can be grouped in 7 nanomaterial types: bio based, carbon based, ceramic nanoparticles and nanostructures, nanocomposites, metal nanostructures and alloys, polymers, and semiconductor nanostructures. All material names, types, and details can be found in the first three columns of Table 27 in annex.

Define keywords as link between science and technology

The methodological challenge is to link a given technology to both its related research and inventive activities. Existing studies have used many different strategies to link science to technology fields, but which usually do not focus on specific technologies to give priority to field generality. The usual goal is either to identify the degree of correlation between science and technology related fields or between technological fields and economic sectors. A short summary of ongoing strategies that could be applied is mentioned here.

One branch of literature looks at the spillovers from science to technology through cited scientific publications (or non patented literature NPL) in the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

patent literature. This method is used to capture the influence or proximity of a given field of research on inventive technological areas (Hullmann & Meyer, 2003). Schmoch (1997) does mention its adequacy, but only in the case of large samples. Several specific topics have been investigated using this method such as the link between public and corporate research (Jaffe & Trajtenberg, 1996; Bacchiocchi & Montobbio, 2007) or the time delay between research and inventions (Finardi, 2011). One of the limitations of this approach is the causal link "by construction" between science and technology that neglects feedback loops from technology to science. To shed light on the last point, the case of "reverse citations" from publications citing patent literature has been looked at by Glänzel & Meyer (2003) and evidence was found on the importance of instrumentation in several fields.

Another way of connecting technology to science has been to observe scientist (or their affiliation) who are both authors and inventors (Coward & Franklin, 1989; Hullmann & Meyer, 2003; Noyons, et al., 2003) and therefore belonging to two different communities related by their S&T fields (Breschi & Catalini, Tracing

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the links between between science and technology: An exploratory analysis of scientists´and inventors´ networks, 2010).

An additional possibility inspired from the literature connecting innovation and growth (Schmoch, Laville, Patel, & Frietsch, 2003) would be to build a concordance matrix between science and technology activity. However, trying to map publications with patent categories shows difficulties since "generally, patents and publications are classified according to difference philosophies" (Schmoch U. , 1997). The recommendation is usually to call for expert interviews in order to delineate the different topics and identify science to technology links.

The application of those methods in the case of emerging technologies face some difficulties related to the way pre-defined fields from database are constructed. One reason is that those fields might miss out relevant documents because of the novelty of expansion of a given field. Indeed, the challenge of new fields lies into defining its complex and multidisciplinary nature.

To partly solve this issue, additional classes can be

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

added to relate to the boundaries' evolution of a given field. For example, Wydra, Haas, Jungmittag, Reiss, & Thielmann (2012) expand the scope of nanotechnology when looking at the impact of NMP (nanoscience, nanotechnologies, material and new production technologies) on the economy. In another study on nanotechnology activity in Russia, Reiß & Thielmann (2010) reorganize and regroup[60] categories developed by databases such as the Web of Science[61] that do not appear satisfying as such.

Therefore, one way would consist in reorganizing the sub-fields of new fields to match the objective of the study. However, the objective still is to find ways to connect pre-defined fields and not to identify specific research and inventive activity related to a technology of interest. Since this paper aims at identifying and comparing research and inventive activity related to specific technologies within a given field, another strategy has to be found.

One way to proceed is to use adequate keywords associated with a given technology that could be used to

[60] See annex
[61] *http://science.thomsonreuters.com/cgi-bin/jrnlst/jlsubcatg.cgi?PC=K* (last visited Dec. 17, 2010)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

measure both its scientific and technological activity. This strategy appears relevant when investigating new and emerging technologies for comparative purposes. Therefore for each technology in the retained technology set, a keyword strategy is applied. To each technology is attached a set of key terms relevant both for the science and technological content. Indeed, the keyword strategy is defined in such a way that each technology will have the same keyword(s) for both patents as well as publications queries. This strategy appears as the closest alternative to make sure to capture technologically related research and inventive subsets. The reasonable assumption is that although the research questions and objectives are different, the same key terms in science and technology used.

Note that some patents might not mention nanomaterial search terms in the case they represent a useful tool for several materials. However, it is clear that all patents mentioning them are useful inventions.

Keyword terms are then identified based on the specialized nanoscience and technology literature (BCC, 2010; EAG, 2009; VDI, 2010), as well as expert check from the Fraunhofer Institute for System and Innovation

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Research (ISI)[62] . The search is then performed with both specific search terms and nanoscience and technology fields search strategies from point 1.

Validate keywords

The challenge is to make sure that what is detected with the given search terms measures the activity behind the material of interest. That is the objective of this validation step.

In order to perform this task, a representative subset of the concerned data is randomly selected out of the outcome of the keyword strategy. The size of the validation sample will depend on a set of factors among which the population size, sampling error, the confidence level, and the degree of variability . The used formula for the representative subset is taken from Yamane (1967:886): $n = {}^{N}/_{1 + Ne^2}$ where a 95% confidence level is assumed and P=0.5 (maximum variability); e represents the sampling error (level of precision) and is set at the 5% level. For example, if the keyword strategy returns 1000 entries, 39 randomly selected ones will be checked whether they correspond

[62] I am very grateful to Dr. Alex Thielmann and Dr. Thomas Reiß

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

to the given technology. The subset is then verified and keyword revised if non related entries are found in the sample. This process is repeated until reaching the 95% confidence interval.

The end result is a dataset exclusively related to their nanoscience and nanotechnology activity. This restrictive strategy is a reasonable choice since I want to make sure I am only retrieving literature related to a given technology. Also, the aim is to capture the dynamics between technologies and not necessarily their absolute number. Finally, at the end of this sequence, search terms for each retained materials are compiled. The resulting list of keywords and search strategies per material can be found in Table 27 in annex.

Descriptive statistics

The nanoscience and nanotechnology field

A preliminary look can be given at the aggregated number of publications and patents in nanoscience and technology.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

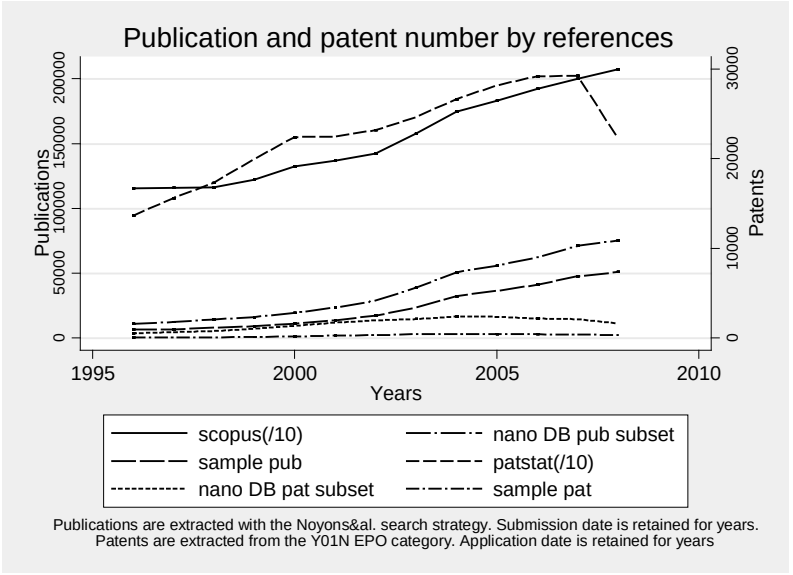


Figure 13: Nanoscience and nanotechnology field sizes

First of all, the numbers are consistent with other search results such as Schmoch and Thielmann (2012). Not surprisingly, there is a larger amount of publications than patents, among other reasons due to the large difference in related costs.

Patents and publications follow different trends. For the overall counts, publications increase over time until slightly reducing its pace in the last years whereas patent numbers accelerate from 2000 and sharply decrease in 2008. Concerning the nano and sample trends, publications show a steady increase although

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

patents show a peak in 2004 followed by a constant decline. Number of reasons can be argued for this: increase in patent costs, substitution of IP strategy from patent to other type of protection, excessive belief in short term nanotechnology returns, "valley of death" stage which could lead to a second boom, etc.

Also, patents are more subject to the economic conjuncture than publications since most of the scientific activity is supported by public funding whereas most inventive activity is produced from private activity. Bearing in mind these elements, a subset of these research and inventive activities will be looked at for a given set of nanomaterials that are described in the next section.

Selected nanomaterials

The selection of nanomaterials is based on the sample strategy described in the previous section. The dataset is composed of 34 nano related materials grouped in seven types of nanomaterials: bio based, carbon based, ceramic nanoparticles and nanostructures, nanocomposites, metal nanostructures and alloys, polymers, and semiconductor nanostructures. This large

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

sampled spectrum of nanomaterials is representative of the nanoscience and technology field in that it is very diverse with potential application in many fields and industrial sectors.

It is to recall that the selected materials are first to second generation nanostructures, and are key as a first step in the evolution of nanoscience and technology towards more complex structures and systems. Figure 14 and Figure 15 summarize the total number of publications and patents per nanomaterials over the 10 year period under scrutiny. A first inspection at the data shows the diversity in research and innovative activities related to the set of nanomaterials. For instance, the range of publications and patents largely differ among materials. Materials appear consistent in that they perform similarly in terms of publication or patent number. Extreme examples concern on the one hand carbon nanotubes with more than 40,000 publications and about 1000 patents and on the other hand carbon aerogels, with less than 300 publications and less than 10 patents in the entire period.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

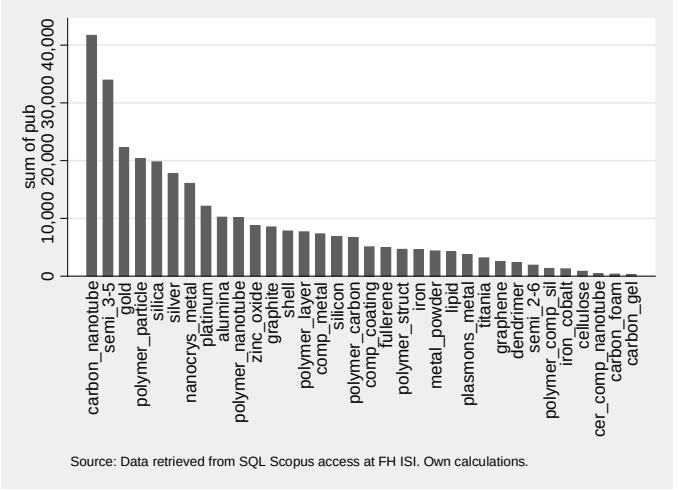


Figure 14: Total publications per material

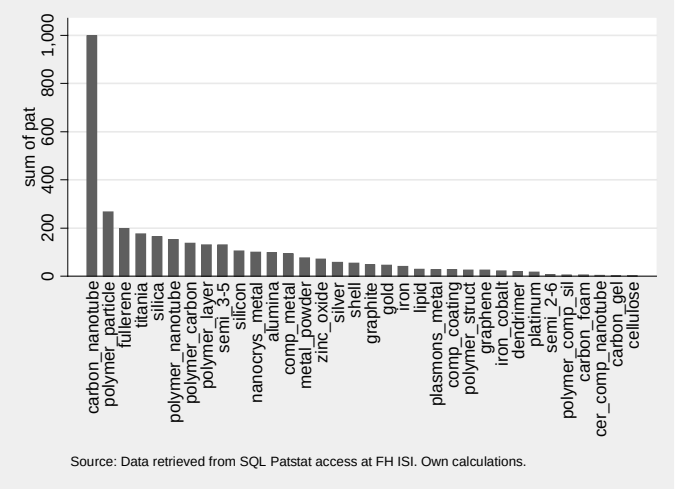


Figure 15: Total patents per material

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

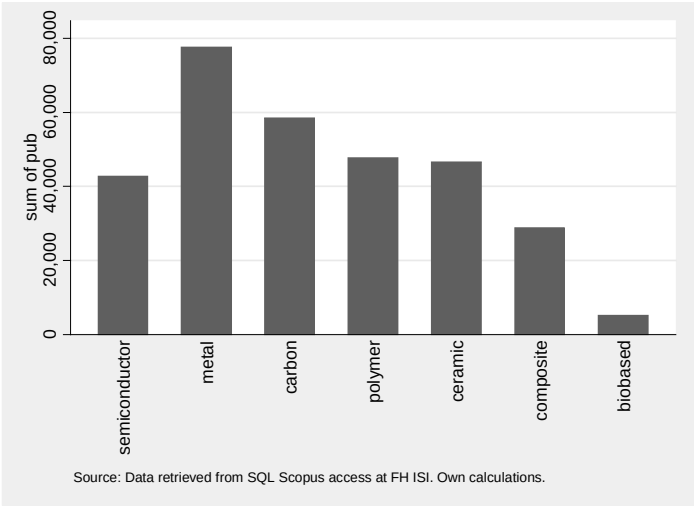


Figure 16: Total publications by material type

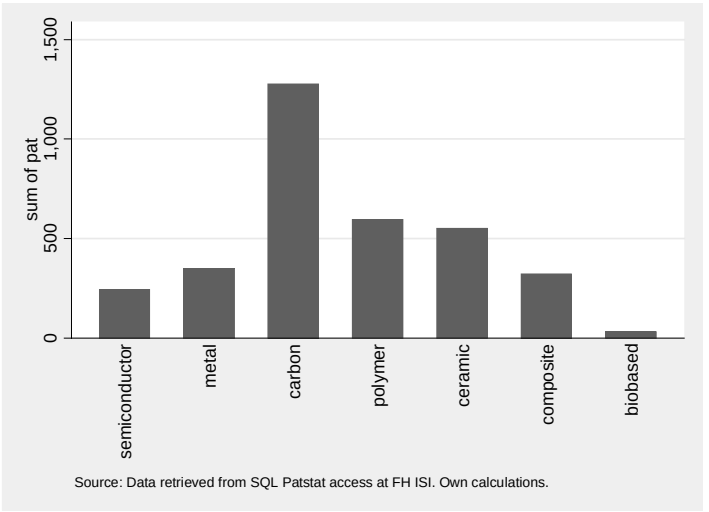


Figure 17: Total patents by material type

Overall, there is relative consistency in the ranking across research and inventive activities in terms of

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

volume: correlation between research and inventive activity is positive and significant across all the years composing the period under scrutiny.

The computed mean is the overall research and inventive literature produced across time and materials. An average of 695 publications and 8 patents were produced across time and materials. However, those averages do not account to the large dispersion of activity across the two dimensions. To clarify, two types of variances can be computed. The between standard deviation tell us about the dispersion between nanomaterial averages around the overall mean whereas the within standard deviation tell us about the average dispersion within nanomaterials' time series. Table 12 provides the results.

Starting with publications, results between and within standard deviations do not strongly differ, which means that the variation of publication activity in the past ten years across materials is similar to that observed within a material over time. In other words, nanoscience has experienced a large variation in its activities both in time and across technologies.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Variable		Mean	Std. Dev.	Min	Max	Observations
pub	overall	694.767	994.8248	2	7318	N = 442
	between		732.2371	22.46154	3209.077	n = 34
	within		684.1747	-2287.31	4803.69	T = 13
pat	overall	7.642534	16.36361	0	147	N = 442
	between		13.21169	.2307692	76.76923	n = 34
	within		9.897909	-64.1267	77.8733	T = 13

Table 12: Within and between year summary

Average publications for each material varied between 22 and 3209 publications. The difference between the minimum and maximum value shows the large difference in materials' "performance". Publications "within" varied between -2287 and 4803. For example, the large negative value means that with respect to its average, one technology deviated by 2287 publications, suggesting very large growth in publication numbers. Concerning patents, an average of almost 8 patents is observed across time and materials. Between standard deviations shows a figure of 13, but an important point concerns the large range of patent produced, especially by the inspection of minimum and maximum figures. Although at a lower level, the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

dispersion of material "performances" in terms of patents mirrors the observation of publication description.

Another interesting aspect of the sample concerns the overlapping research and inventive activity across materials. Indeed, most material types are not isolated, but interact and can be combined with others to create a new, more complex nanostructure. In order to illustrate this, a correlation matrix is shown at the material type level both for publications and patents.

	carbon	ceramic	metal	polymer	biobased	composite
ceramic	4.0%					
metal	8.0%	10.8%				
polymer	9.1%	6.8%	8.2%			
biobased	0.2%	0.3%	0.5%	1.3%		
composite	9.3%	6.3%	10.7%	15.6%	0.2%	
semiconductor	1.8%	2.4%	2.8%	0.8%	0.0%	1.1%

Table 13: Publication correlation matrix for material type. (the statistics are expressed in percentage of the total number of double type publications. Source: own calculations based on selected search strategy.)

About 17% of the sample of publications belongs to two different types of materials, meaning that the border between different types is not clear cut. Indeed, there is an average of almost 2500 double type publications, however with a standard deviation of 2400

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

depicting the large dispersion in overlapping between types. For instance, in the above table polymer and composite types are the most intertwined whereas biobased and semiconductors have insignificant overlapping. Note that the low figure of biobased is largely due to a low size in numbers of the material type.

	carbon	ceramic	metal	polymer	biobased	composite
ceramic	2.2%					
metal	4.0%	4.8%				
polymer	5.9%	6.6%	2.2%			
biobased	0.7%	0.0%	0.4%	0.0%		
composite	42.1%	4.8%	5.9%	16.5%	0.4%	
semiconductor	1.1%	1.8%	0.0%	0.0%	0.0%	0.7%

Table 14: Patent correlation matrix for material types (te statistics are expressed in percentage of the total number of double type patents. Source: own calculations based on selected search strategy.)

On average, 13 patents belong to two different types of nanomaterial. However, the standard deviation is higher than in the publication case with 26 depicting strong differences how different types of material suggest potential inventions. Although the small scale should be kept in mind, what can be seen for the table above is that combination of different materials such as composites shows the highest double patent numbers

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

(42% for carbon and composites and 16.4% for composite and polymer). Note again the low overlapping figures for biobased materials due to the low figures reached for this type of material.

Overall, the number of patents and publications belonging to the same type of material are positively correlated and significant (with r ranging from 0.48 to 0.89), this means that common patterns of exist between the nanoscience and nanotechnology samples.

This static view of nanomaterial performance can now be complemented by a dynamic view. In order to perform this, a first subsection presents an adapted version of the well known S curve concept. The goal is to present the type of information uncovered by this method, and according to which criteria a technology is emerging. In the second sub-section, and in the light of the S-curve baseline case, the method proposed in this paper will be applied, and the relevant differences exposed.

Results

Adapted S curve concept (baseline case)

In order to interpret the S-curve concept with the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

chosen indicators, the usual cumulative count per year data used in S curves is converted to the related Sharpe ratios. To recall, the Sharpe ratio is a comparative indicator that compares the growth performance of a set of materials' underlying activity with respect to a given reference. The two main changes brought by the use of Sharpe ratios are (1) averages over a given period of year to year growth, and (2) relative results. Therefore by transforming the data, results do not answer to: what is the absolute dynamics of a technology? But rather to: do this technology perform relatively better than others in a given period and on average? This section and the following one aim at answering to the second question which is more relevant for the comparative purpose of this paper.

The adaptation of the S-curve pattern can only be made concerning inventions since no theoretical counterpart has been found (yet) for discoveries which tend to show more constant and increasing patterns over time. The following table interprets the S-curve to fit the methodology developed in this paper.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Patent status during period p		Absolute Sharpe ratio	
		Positive	**Negative**
Relative Sharpe ratio	**Positive**	*Rapid growth material (a)*	*Emerging material (b)*
	Negative	*Maturing material (c)*	*New / Declining material (d)*

Table 15: S-curve typology

To stay close to the S curve concept, materials' inventive dynamics are categorised with respect to both their absolute and relative growth measures. By connecting the two measures, similarities –and differences- may be found according to the Technological Life Cycle literature. For instance, a theoretical evolutionary pattern is expected. Starting from a low activity (i.e. new material) the technology emerges and depicts large percentage increase with low absolute increase (i.e. emerging material). Following this stage, high growth in both absolute and relative terms (i.e. rapid growth material) is observed. Then lower percentage increase occur in parallel with an

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

increase of activity in absolute number (i.e. maturing material). Finally, the material ends up declining and outperformed.

In order to locate a given technology on this S curve typology, the value of the two Sharpe ratios with respect to the sample reference for each material is computed. Applying the data to this framework shows the following[63]:

Patents Year 1996 – 2008 Sample reference		**Absolute Sharpe ratio**	
		Positive	**Negative**
Relative Sharpe ratio	**Positive**	*Polymer nanotube, Shell, Graphene, Silver*	*Composite coating, Metal powder*
	Negative	*Carbon nanotube, Silicon, Polymer particle, Silica, composite metal, Titania*	*Platinum, Zinc oxide, Plasmons metal, Gold, Nanocrys metal, Alumina, Dendrimer, Fullerene, Graphite, Iron, Iron cobalt, Lipid, Polymer carbon, Polymer layer, Polymer structure, Semi 2 – 6, Semi 3 – 5*

Table 16: Relative vs. Absolute patent growth

Polymer nanotubes, (core-)shells, graphene and silver all show above average relative and absolute growth.

[63] In line with the following section, period partitions of this table are provided in the annex.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

This means that during the period, there has been an above average increase in number as well as percentage of patent growth (i.e. rapid growth pattern). Classic emerging phases with no significant absolute growth but only relative occur in the case of composite coating and metal powders. This could mean the building up of the necessary know-how base related to these materials. Another interpretation could be the exploration of the material's capacities which might –or might not- reveal potential. Maturity stages can be mapped for carbon nanotubes, silicon, polymer particle, silica, composite metal and titania where large number of patents exist, but very little or no relative growth takes place.

This framework can be put in perspective with the methodology proposed in this paper. Although informative, it is to note that the position of materials in the same quadrant might or not experiencing an increasing knowledge base. As explained in the conceptual framework, research activity related to a material interacts with the know how from inventive activity. The combination of these two activities act as an "engine" which determines a material's future success.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

For example, the technologies in the first quadrant are all equally qualified by this framework as emerging technologies. However, it only provides half of the information concerning the sustainability of the material. For instance, graphene and polymer nanotubes are experiencing a significant relative growth in terms of publications, whereas silver and (core-) shells are not. By providing this additional information, differentiating between technologies which experience research dynamics (e.g. expansion –or contraction- of the knowledge base) and those which only show application dynamics would become possible.

The framework proposed in this paper aims to overcome this limitation. For instance, the theoretical section of this paper showed how research and inventive activity interact and feed each other. In that respect, accounting for research in the assessment of a material dynamic is of great value and sheds more light into the identification and understanding of emerging technologies. This is the focus of the next sub-section.

Applying the new framework

Several changes are made with respect to the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

previous section. First, the inclusion of research activity as an additional dimension[64]. Second, to identify emerging technologies through their underlying research / inventive dynamics in absolute or relative terms instead of absolute / relative dynamics in terms of patent terms.

Applying the methodology to the collected data, the set of nano materials is clustered in a new framework composed of four different groups. The position of each material is then identified according to both scientific and technological Sharpe ratios. The following table shows the related typology:

[64] Results for the research dynamics using the S curve framework shown in annex

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Technology status during period p (quadrant number)		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Emerging material* *(1)* *Strong growth of publications* *Strong growth of patents*	*Emerging applied material* *(2)* *Weak / constant growth of publications* *Strong growth of patents*
	Negative	*Emerging basic material* *(3)* *Strong growth of publications* *Weak / constant growth of patents*	*New / Maturing material* *(4)* *Weak growth / decline of publications* *Weak growth /decline of patents*

Table 17: Framework identifying material S&T dynamics

From the table, a traditional linear view would be to consider the linear sequence 4-3-1-2-4, where a technology starts with a strong interest for science which is progressively replaced by technological interest. However, as expressed in the model, this pattern is not expected as the only one since it is the cooccurence of growth between activities, not the types of growth that qualify a material as emerging. Four different cases are possible. Quadrant 1 concern the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

emerging material. It is characterised by strong underlying growth in both research and inventive activities. Quadrant 2 defines applied materials, and this is due only to high inventive activities. The other way round is found in quadrant 3. And finally the last quadrant is the combination of low to null research and inventive activities.

In this section the location of materials also depend on an additional factor: the reference used. For informative purpose, three references are used to compute the absolute and relative Sharpe ratios. The first reference concerns the average growth of databases from where the data was retrieved, namely Scopus and Patstat. The second reference uses the average growth of the nano related publication and patents in the Scopus and Patstat databases. The last reference is computed from the average growth of the set of sampled materials and provides a "within" sample view of each material dynamics. From the computed Sharpe ratios[65] , each material is categorised in one of the four

[65]All ratios are provided in annex. Note that all growth ratios can be computed due to a lack of patent data, namely carbon aerogels, carbon foam, cellulose, composite ceramic nanotubes and polymer composite with silicate.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

quadrants[66] .

Starting with the absolute growth Sharpe ratios, using the entire databases' growth as reference assigns all materials in quadrant 4. This is sound since no material activity does better than the databases in absolute terms. In addition, as the set of materials are also a subset of nanoscience and technology, the same observation can be made in absolute terms with respect to the nano field reference (provided those references are increasing). The third column uses the average growth of the selected materials as reference and the following tables shows the results.

In this case, results identify 6 emerging technologies namely carbon nanotube, polymer nanotube, polymer particle, core shell, silica and silver. Those materials are subject to both a higher absolute growth in research and inventive than the sample. Note that these materials belong to different material types which mean that nanoscience and technology is diverse and evolves in different directions. Emerging applied materials are found in the case of semiconductors (i.e. semi 3-5,

[66] All quadrant results for the different references and growth types are shown in annex

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

silicon) and carbon based materials (i.e. fullerene, grahene). Emerging basic are found to be more in composites (i.e. alumina, zinc oxide) or metals (i.e. gold, nanocrystalline metals, platinum).

Absolute growth **Technology status during period p**		**Scientific Sharpe ratio**	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*carbon nanotube, polymer nanotubes, polymer particle, shell, silica, silver*	*Composite metal, graphene, iron, semi 3-5, silicon*
	Negative	*Alumina, gold, nanocrystalline metal, platinum, polymer layer, zinc oxide*	*Composite coating, dendrimer, fullerene, graphite, iron cobalt, lipid, metal powder, plasmons metal, polymer carbon, polymer structure, semi 2-6*

Table 18: Quadrant results, absolute growth

In addition to considering the absolute growth, the relative Sharpe ratio is also used to assign materials to the framework's quadrants, but from another perspective. Starting with the database growth reference, results show that the large majority of materials are present in the first emerging material quadrant. This means that most of these materials outperform the database in terms of growth rates,

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

which is evidence that the nanofield is emerging. When technologies are compared to the nano subset of the database, more than five materials move from the first to the second quadrant. This means that those materials are more dynamic in application terms than the nano field. Overall however, nanomaterials are still better on average.

The table below shows results when using the average relative growth of the sample as a reference.

As compared to previous references, dispersion across quadrants increases and most materials end up in quadrant 4 due to the significant performance of two materials namely graphene and polymer nanotube. These two carbon related materials are expected to bring significant changes in the advancement of nanoscience and technology alone and in combination with other materials.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Relative growth Technology status during period p		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Graphene, polymer nanotube*	*Composite coating, metal powder, (core-) shell, silver*
	Negative	*Carbon nanotube, polymer layer, silicon, zinc oxide*	*Alumina, composite metal, dendrimer, fullerene, gold, graphite, iron, iron cobalt, lipid, nanocrystalline metal, plasmons metal, platinum, polymer carbon, polymer particle, polymer structure, semi 2-6, semi 3-5, silica, titania*

Table 19: Quadrant results, relative growth

Two other subsets are worth noticing: emerging basic materials and emerging applied materials. The former is composed of carbon nanotubes, polymer layer, silicon and zinc oxide. Carbon nanotube, altough in the first quadrant in absolute growth terms, still reaches high research activity in percentage. This is not the case for polymer layer which happens to be very active only in terms of research activity. Finally, silicon appears as having matured considering the large absolute growth of inventions while experiencing a strong relative

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

growth in publications. The later subset, emerging applied materials, is composed of composite coatings, metal powders, (core-) shells, and silver. The two first materials appear as having little research growth in both terms which reinforces their application nature. The two last ones reached a large number of publications and patents, patents which are not only increasing in number but in percentage. In the case of core-shells, this might be due to the large potential medical application.

Comparing results

Crossing the three main tables for the overall period, namely the S curve adapted table, the absolute growth table as well as the relative growth table provides an interesting picture. By construction, the same information provided by the first table concerning the inventive dynamics of materials can be identified using the combination of the two others. Indeed, there is an overlap between identifying emerging technologies by looking at their underlying absolute and relative growth of patents and identifying emerging technologies by looking at their underlying research and inventive dynamics in relative and absolute terms. For example,

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

take composite coatings and metal powders. These technologies are both identified as emerging by the S curve framework. Similarly, they are both identified as emerging applied material by the relative growth table. Here, consistency is shown between the two approaches. The same happens when looking at carbon nanotubes or silicon. These technologies are identified as maturing with respect to the S curve framework. The same information is provided by looking at both absolute and relative tables, which provide the same information: high absolute patent growth, but low relative patent growth.

The additional dimension that the new framework provides is the underlying scientific dynamics, which as claimed in the conceptual framework is a key factor for the emergence of technologies. By omitting this important element especially in new technologies, relying on the S curve framework only gives a partial picture of a technological potential and whether a technology is applied or not yet applied. However, science and technology are increasingly interdependent relations which mean that only referring to inventions as signals is not sufficient. Assessing a technology with

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

strong research dynamics is another legitimate signal which can either suggest potential route to technology, reinforce the knowledge base of a technology, or the opposite. Three cases can illustrate this. Carbon nanotubes appear as maturing technology in the S curve typology. However, this technology still experiences large absolute and relative growth in research activity, which suggests it might not be so close to maturity yet...and qualifies it as emerging basic material. Silicon is found to be maturing too in the S curve framework. But again, it shows relative growth of its research activities which maps it to the emerging basic materials. Last but not least, silver or (core-) shells are both appearing in the rapid growth S curve quadrant. However, their underlying research activities tell us that although a large absolute growth of their knowledge base is reached, no relative growth is attained, making them both emerging applied materials in relative terms. To summarize, the framework provided in this paper has two advantages:

identify in which evolution stage a given technology currently is (emerging, rapid growth, maturity and decline)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the inclination of the dynamic (basic, applied, both or none)

Exploring the data: partition results

In order to explore further the overall results and check for possible inconsistencies across time, the period is divided in two partitions: from 1997 to 2002 and from 2003 to 2008.

Several materials only appear in one partition when their Sharpe indicators could not be computed. Materials not appearing in the first partition are due to novelty, as suggested by a lack of related inventive activity. For the first partition this is the case of dendrimer, plasmons metals, platinum, polymer carbon and semiconductor (2-6). The second period also shows constantly low -if not null- patent numbers for iron cobalt alloys and semiconductor (2-6)[67]. The quadrant position for each material is then identified and compared between the two periods. The Sharpe ratios as well as the quadrant results for each materials are available in annex for both growth types and reference (database content growth, their nano related subsets,

[67] Note that Semiconductor 2-6 appear in the overall period because of the existing data between 2002 and 2003.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

and the sample).

The first result compares the two partitions for absolute Sharpe ratios with reference to the Scopus and Patstat database. An overall change of material positions occurs from quadrant 4 to 2, meaning that all selected materials perform better in terms of absolute patent growth in the second than in the first period. Similar results are found for the nano subset reference; the selection of materials outperforms the average nano field in the second period at least in terms of research dynamics (but not necessarily inventive activity). However, as illustrated by the figure 13, in both cases this change can be explained by the decreasing patent number in the last year, which mechanically favours technologies with (average) positive absolute growth rates. More importantly, this means that in times of contraction of patenting activity, those materials do not follow the trend and tend to be subject to relatively higher inventive activities –they suffer less from lower patenting activity with respect to the references-. However, by looking at the increasing trend in publication number, they also logically reach lower absolute growth rates than the publication database.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Finally, the sample average reference group is used and results logically show higher dispersions of positions than in previous reference cases. Also, it has to be bared in mind that the interpretation of the change in quadrant for each material becomes delicate in the sense that the ratios are now computed for a period of 5 years. Quadrants results with sample reference below suggest three patterns for a positive evolution of absolute growth.

Absolute growth 1997-2002		**Scientific Sharpe ratio**	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Carbon nanotubes, polymer nanotube, polymer particle*	
	Negative	*Alumina, gold, nanocrytalline metals, silica, silver*	*Composite coatings, composite metals, dendrimer, fullerene ,graphene, graphite, iron, iron cobalt, lipid, metal powder, polymer layer, polymer structure, Semi 3-5, shell, silicon, titania, zinc oxide*

Table 20: Absolute growth 1997-2002

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Absolute growth 2003-2008		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Gold, platinum, polymer particle, shell, silica, silver, zinc oxide*	*Composite coating, graphene, graphite, iron, lipid, plasmons metal, polymer structure, semi 3-5, silicon, titania*
	Negative	*Carbon nanotubes, nanocrystalline metals, polymer layer, polymer nanotubes,*	*Alumina, composite metal, dendrimer, fullerene, metal powder, polymer carbon,*

Table 21: Absolute growth 2003-2008

The first one depicts increasing inventive without pre existing research activity (i.e. quadrant 4 to 2) in the case of composite coating, graphene, graphite, iron, lipid, polymer structure, semiconductor (3-5), silicon, and titania. This pattern concerns materials with a relative higher number of patents without corresponding higher publication number. This could suggest a potential as applied material more attractive than the exploration of their characteristics. The second one shows increasing research with pre existing inventive activity (3 to 1) for gold, silica and silver. This concerns materials which have been subject to relatively more research activity in

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the first period and in the second period subject to significant inventive activities. This pattern suggests a more linear view in that research precedes applications. The third one features increasing research and inventive activity (4 to 1), this is the case concerning (core) shell and zinc oxide. This pattern consists in a fast growth group of materials for both activities. This means that in the second period, these materials were subject to a strong interest both from a scientific and technological perspective.

The second results compare the two partitions but this time using the relative growth Sharpe ratios. In the database reference results of partition 1, most of the sampled materials appear in quadrant 1, meaning that they are generally more dynamic both in terms of research and inventive activities as compared to the databases growth. This is in line with the expectation that higher percentage growth is attained by young fields. This observation is still true for the second partition, although about ten materials do better only in terms of publications (note that before 2002 the nano patenting showed an increasing trend). The next reference compares materials with the nano subset of

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

the two databases. In the first period, half of the materials are still more dynamic both in research and inventive activities then the sample reference, whereas many more reach quadrant one in the second partition. Although depicting a large number of emerging materials in both periods, one difference can be noticed: in the first period no materials appear in the second quadrant whereas in the second period no materials appear in the third quadrant. This implies that the material selection are characterised by exploratory research activities in the first period, but turning 2002, selected materials are subject to a stronger focus towards applications. This could reasonably suggest that the research part of the nano field before 2002 being relatively more important than after 2002 when the nano activities focus more on the applicability of findings. However, as illustrated in figure page 87 this change can also be explained by the general decreasing nano trend after 2002 (although less pronounced than the full database).

Finally, the material quadrant position with respect to the sample reference results are shown in the following tables.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Relative growth 1997-2002		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Polymer nanotube,*	*composite coating, graphene, lipid, metal powder,*
	Negative	*Carbon nanotubes, polymer structure, silicon, zinc oxide*	*Alumina, composite metal, fullerene, gold, graphite, iron, iron cobalt, nanocrystalline metal, polymer layer, polyer particle, semi 3-5, shell, silica, silver, titania*

Table 22: Relative growth 1997-2002

Relative growth 2003-2008		Scientific Sharpe ratio	
		Positive	**Negative**
Technological Sharpe ratio	**Positive**	*Graphene, plasmons metal, shell, silicon*	*Composite coating, graphite, iron, platinum, polymer structure, semi 3-5, silica, silver*
	Negative	*Lipid, zinc oxide*	*Alumina, carbon nanotube, composite metal, dendrimer, fullerene, gold, metal powder, nanocrystalline metals, polymer carbon, polymer layer, polymer nanotube, polymer particle, titania*

Table 23: Relative growth 2003-2008

In this case, the same caution should be taken as in the previous sample reference case with regard to the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

shorter time span. What can be observed is that within the sample, several patterns take place between the two periods. One is constancy; the position does not change across periods which confirm the material as being particularly applied (i.e. composite coating) or research oriented (i.e. zinc oxide). Another is an increase in publication relative growth with pre existing relative growth of patent activity (i.e. graphene) which can be seen as an emerging basic material moving to an emerging material. Or with no pre-existing research activities but experiencing relative growth in patents as an emerging applied material would suggest (i.e. graphite, iron, semiconductor 3-5, silica, silver). Still, another way can occur; an increase in patent growth occurring with pre-existing relative growth of publication activity (i.e. silicon). Finally, the case of a material sequentially moving from basic to applied material is illustrated by the case of polymer structure, and the other way round for lipids.

Comparing partitions can be useful also to test some hypothesis. For example, carbon nanotubes would have been expected in higher quadrants, but within the sample it does not reach high percentage change due to

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

approaching maturity, as suggested by the absolute growth figures. The comparison with graphene is interesting since carbon nanotubes are simply speaking a graphene sheet that has been "rolled over". In relative growth terms graphene outperforms carbon nanotubes in the second period. This suggests that graphene technology is capturing in the same period relatively more interest or opportunities with respect to carbon nanotubes.

Conclusion

Identifying emerging technologies at an early stage is strategic to better assess the coming S&T challenges, and how to address them best. The claim of this paper is the importance of research alongside inventive activities as key factors for identifying the emergence of technologies.

A coherent framework integrating both research and inventive dimensions was then developed to indentify emerging technologies. According to the typolology, those technologies were either emerging technology, emerging basic technology, emerging applied technology or new/declining technology. For

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

completeness, both the relative and absolute growth Sharpe ratios were used to measure each technology dynamic, and this at three different reference levels namely the Scopus / Patstat database, their nano subsets, and the sample itself. The method was then applied to a sample of potential emerging technologies within the nanoscience and technology field.

As a first step, the selected technologies were mapped to an adapted S curve framework using both the relative and absolute Sharpe ratios to uncover each technology evolution stage. This framework was then used as a "baseline case" that could be compared to the conceptual framework developed in this paper. In turn, the new framework was applied to the data, and brought a new perspective on the emergence of technologies which complements the S curve approach. Two main findings stem from the method developed and the analysis.

First, combining the absolute and relative Sharpe growth results from the new framework provides the adapted S curve framework information.

Second, looking at the research dynamics behind technologies in addition to inventive dynamics enable

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

to discriminate between technologies with higher or lower than average scientific activity. Hence, technologies can now be differentiated whether they are being more dynamic in their basic activities (knowledge base), application activities (know-how base), both, or none.

To conclude, and based on the evolution towards increasingly science based technologies, the framework described in the paper appear as more complete in identifying relevant emerging technologies.

Future research

In this paper, the identification of emerging technologies has been performed using growth indicators related to discoveries and inventions. The approach is deliberately S&T push, but other dimensions, more demand pull, could be applied using the method advanced in this paper. The interest would be to see whether the introduction of other dimensions would "pick" the same or other technologies as being emerging. Several topics could be investigated:

E.T. based on technology and economic sectors. Connecting the data from this paper to industrial fields

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

using concordance matrices like the one developed by Schmoch, Laville, Patel, & Frietsch (2003) is one way to capture technologies with the highest potential: high technological activity in high growth sectors.

E.T based on S&T activity and nano generations. Another possibility is to see how these materials enter different generations of nano products. Indeed, this paper was concerned with nanostructures of first and second generation (i.e. active and passive nanostructures), however it could be interesting to know how those nanostructures enter more complex structures like systems (i.e. third generation), or systems of systems (i.e. fourth generation)[68] .

E.T. based on S&T to regional innovation. Emerging technologies are subject to their environment. Based on this, emerging technologies appear more inclined to be successfull if their environment in which they evolve is equally dynamic.

[68] This is explained in the framework provided by the NMP Expert Advisory Group (EAG, 2009). Four main categories of nanotechnologies are defined. *Passive nanostructures*: dispersed and contact nanostructures (e.g. aerosols) or products incorporating nanostructures (e.g. coatings); *Active nanostructures*: bio-active, health effects (e.g. targeted drugs) or physico-chemical active (e.g. 3D transistors); *Systems of nanosystems*: architectures incorporating multiple nanostructures (e.g. robotics); and *Molecular nanosystems*: new and fundamental nanoscience (e.g. atomic design).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

E.T. based on S&T policy. Emerging technologies could also be identified by using the underlying support they have from policies. For example, one consequence of the increasing S&T specialization is that it makes the nanofield less and less accessible. Agents need to have the resources to build, access, and understand the related knowledge and knowhow (i.e. instruments). Emerging technologies could then be identified by the support they receive since it should increase their chance of success.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

‘Economic activity is carried out by individuals in organizations that require a high degree of social co-operation’

Francis Fukuyama (1952-)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

General conclusion

This thesis has explored the role and importance of instruments in the scientific process, and their implications for the emergence of new technologies.

The first chapter was the starting point analysing the rationale behind scientific teams' incentive to invest time in improving scientific instruments alongside research. In the light of this framework, it was investigated how research productivity depends on the allocation of time between the two activities. What was found is that results are context dependent. The fields of chemistry and biology confirm the hypothesis whereas material science and physics show an opposite pattern.

Based on this micro level evidence, the second chapter looked at institutional instruments namely Research Infrastructures. The aim was to describe their position as well as their contribution to supporting the international collaborations of local research organisations within the Italian material science network. Evidence showed that RIs are central in the research network, that they are part of specific clusters,

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

and that they contribute significantly to enhancing international collaborations of other local research organisations.

The two first chapters therefore provided evidence that instruments are indeed important for contributing to scientific activity both at the micro and macro level.

Finally, the third chapter investigated whether new and emerging technologies could be identified using scientific and technological factors. The main finding was that integrating both research and inventive activities related to a technology enables to identify not only its evolution stage, but also its inclination whether this technology is subject to more basic or applied oriented activities. Based on this result, the third chapter provided a more complete framework to identify emerging technologies at an early stage than the S curve concept.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

References

Acs, Z., Audretsch, D., & Feldman, M. (1992). Real Effects of Academic Resesarch: Comment. The American Economic Review , 82 (1), 363-367.

Andersen, B. (1998). The hunt for S-shaped growth paths in technological innovation. CRIC Discussion paper No 12 .

Andersen, B. (1999). The hunt for S-shaped growth paths in technological innovations: a patent study. Journal of Evolutionary Economics (9), 487-526.

Anderson, J. (1979). A Theoretical Foundation for the Gravity Equation. American Economic Review , 69, 106-116.

Anderson, J. E., & Van Wincoop, E. (2003). Gravity with Gravitas: A Solution to the Border Puzzle. American Economic Review , 93 (1), 170-192.

Arora, A., & Gambardella, A. (1997). Public Policy Towards Science: Picking Stars or Spreading the Wealth? Revue d'economie industrielle , 79 (79), 63-75.

Arora, A., David, A., & Gambardella, A. (1998). Reputation and Competence in Publicy Funded Science: Estimating the Effects on Research Group Productivity.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annales d'economie et de statistiques , 49/50.

Arundel, A., Van de Paal, G., & Soete, L. (1995). Innovation Strategies of Europe's Largest Industrial Firms: Results of the PACE Survey for Information Sources, Public Research, Protection of Innovations, and Government Programmes, Final Report. Prepared for the SPRINT Programme, European Commission .

Audretsch, D., & Feldman, M. (1996). R&D Spillovers and the Geography of Innovation and Production. The American Economic Review , 86 (3), 630-640.

Audretsch, D., & Lehmann, E. (2006). Do Locational Spillovers Pay? Empirical Evidence from German IPO Data. Economics of Innovation and New Technology , 15 (1), 71-81.

Autio, E., Bianchi-Streit, M., & Hameri, A.-P. (2003). Technology Transfer and Technological Learning Through CERN's Procurement Activity. CERN Education and Technology Transfer Division , 5.

Autio, E., Hameri, A.-P., & Vuola, O. (2004). A Framework of Industrial Knowledge Spillovers in Big-Science Centers. Research Policy , 33, 107-126.

Bacchiocchi, E., & Montobbio, F. (2007). Knowledge diffusion from university and public research. A

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

comparison between US, Japan and Europe using patent citations. Journal of Technological Transfer , 34 (2), 169-181.

Balconi, M., Breschi, S., & Lissoni, F. (2004). Networks of inventors and the role of academia: an exploration of Italian patent data. Research Policy , 33, 127-145.

BCC. (2010). Nanotechnology: A Realistic Market Assessment.

Becker, G. S. (1965). A Theory of Allocation of Time. Economic Journal , 75 (299), 493-517.

Berger, M. (2007, April 18). Debunking the trillion dollar nanotechnology market size hype. Retrieved Mars 1, 2012, from Nanowerk: http://www.nanowerk.com/spotlight/spotid=1792.php

Bianchi-Streit, M., Blackburne, N., Buddle, R., Reitz, H., Sagnell, B., Schmied, H., et al. (1984). Economic utility resulting from CERN contracts (second study) (Vols. 84-14). Geneva: European Organisation for Nuclear Research.

Block, F. (2008). Swimming Against the Current: The Rise of a Hidden Development State in United State. Politics & Society , 36 (2), 169-206.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Blondel, V. D., Guillaume, J.-L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. Journal of Statistical Mechanics: Theory and Experiment , 1742-5468.

Boschma, R. (2005). Proximity and Innovation: A Critical Assessment. Regional Studies , 39 (1), 61-74.

Bozeman, B. (2000). Technology Transfer and Public Policy: a Review of Research and Theory. Research Policy , 29, 627-655.

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: implication for scientific and technical human capital. Research Policy , 33 (4), 599-616.

Breschi, & Malerba. (2001). The Geography of Innovation and Economic Clustering: Some Introductory Notes. Industrial and Corporate Change , 10 (4), 817-833.

Breschi, S., & Catalini, C. (2010). Tracing the links between between science and technology: An exploratory analysis of scientists´and inventors´ networks. Research Policy , 39 (1), 14-26.

Breschi, S., Cassi, L., Malerba, F., & Vonortas, N. (2009). Networked research: European policy

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

intervention in ICTs. Technology Analysis & Strategic Management , 21 (7), 833-857.

Bresnahan, Gambardella, & Saxenian. (2001). "Old Economy" Inputs for "New Economy" Outcomes: Cluster Formation in the New Silicon Valleys. Industrial and Corporate Change , 10 (4), 835-860.

Bresnahan, T., & Trajtenberg, M. (1995). General Purpose Technologies. Journal of Econometrics , 65, 83-108.

Briber, Glyde, & Sinha. (2009). Access to Major International X-Ray and Neutron Scattering Facilities. Commitee on International Scientific Affairs of the American Physical Society.

Bureau Van Dijk. (2011). Retrieved from http://www.bvdinfo.com/

Burger, M. J., Van Oort, F. G., & Linders, G.-J. M. (2009). On the Specification of the Gravity Model of Trade: Zeros, Excess Zeros and Zero-Inflated Estimation. Spatial Economic Analysis , 4 (2), 167-190.

Callon, M., & Foray, D. (1997). Introduction: nouvelle economie de la science ou socioeconomie de la recherche scientifique? Revue d'Economie Industrielle , 79 (1), 13-32.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Cassiman, B. (1998). Influence Activity and the Organizational Design of Research and Development. Working paper IESE Business School and UPF, Mimeo .

Coccia, M. (2008). Measuring Scientific Performance of Public Research Units for Strategic Change. Journal of Informetrics , 2 (3), 183-194.

Coward, H., & Franklin, J. (1989). Identifying the Science-Technology Interface: Matching Patent Data to a Bibliometric Model. Science, Technology and Human Values , 14 (50).

Dalpe, R. (2003). Interaction Between Public Research Organizations and Industry in Biotechnology. Managerial and Decision Economics , 24, 171-185.

Dalpe, R., & DeBresson, C. (1989). Le secteur public comme premier utilisateur d'innovations. L'Actualite Economique , 65 (1), 53-70.

Dasgupta, P., & David, P. (1994). Towards a new economics of science. Research Policy , 23, 487-521.

Day, G., Schoemaker, P., & Gunther, R. (2000). Wharton on Managing Emerging Technologies. Hoboken, New Jersey, USA: John Wiley & Sons.

de Nooy, W., Mrvar, A., & Batagelj, V. (2005). Exploratory Social Network Analysis with Pajek.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Cambridge University Press.

de Solla Price, D. (1963). Little Science, Big Science. New York: Columbia University Press.

Diamond, A. (1988). Science as a Rational Enterprise. Theory and Decisions , 24, 147-167.

Ding, W., Levin, S., Stephan, P., & Winkler, A. (2010). The Impact of Information Technology on Academic Scientists' Productivity and Collaboration Patterns. Management Science , Articles in Advance, 1-23.

Dosi, Llerena, & Labini. (2005). "Science-Technology-Industry Links and the ”European Paradox”: Some Notes on the Dynamics of Scientific and Technological Research in Europe. LEM paper series .

EAG, N. E. (2009). Position Paper on Future RTD of NMP for the period 2010-2015.

ERID-Watch. (2008). Deliverable D6/D7: Market Study Final Report. Retrieved from http://www.eridwatch.eu/.

ESFRI. (2011). ESFRI Roadmap.

European Commission. (2007). EC Green paper ERA. Brussels: EC.

European Commission; European Science Foundation. (2007). Trends in European Research

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Infrastructures: Analysis of data from the 2006/2007 survey.

Fagerberg, J. (2005). Innovation: a guide to the literature. In J. Fagerberg, D. Mowery, & R. Nelson, The oxford handbook of innovation (pp. 1-26). Oxford University Press.

Finardi, U. (2011). Time relations between scientific production and patenting of knowledge: the case of nanotechnolgies. Scientometrics , 89, 37-50.

Flowerdew, R., & Aitkin, M. (1982). A Method of Fitting the Gravity Model Based on the Poisson Distribution. Journal of Regional Science , 22 (2), 191-202.

Foray, D. (2004). The Economics of Knowledge. MIT press.

Foray, D., & Lissoni, F. (2009). University research and public-private interaction. In B. Hall, & N. Rosenberg, Handbook of Economics of Technical Change.

Frietsch, R., & Schmoch, U. (2010). Transnational patents and international markets. Scientometrics , 82, 185-200.

Glanzel, W., & Meyer, M. (2003). Patents cited in the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

scientific literature: An exploratory study of "reverse" citation relations. Scientometrics , 58 (2), 415-428.

Glanzel, W., Meyer, M., Du Plessis, M., Thijs, B., Magerman, T., Schlemmer, B., et al. (2003). Nanotechnology: Analysis of an Emerging Domain of Scientific and Technological Endeavour. Leuven: Steunpunkt O&O Statistieken.

Goldfarb, A., & Agrawal, A. (2008). Restructuring Research: Communication Costs and the Democratization of University Innovation. The American Economic Review , 98 (4), 1578-1590.

Gould, R., & Fernandez, R. (1989). Structures of Mediation: A Formal Approach to Brokerage in Transaction Networks. Sociological Methodology , 89-126.

Greene, W. H. (2002). Econometric Analysis. Prentice Hall.

Guellec, D., & Van Pottelsberghe, B. (2004). From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter? Oxford Bulletin of Economics and Statistics , 66 (3), 353-378.

Hall. (2002). The Financing of Research and

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Development. Oxford Review of Economic Policy , 18 (1), 35-51.

Haupt, R., Kloyer, M., & Lange, M. (2007). Patent indicators for the technology life cycle development. Research Policy , 387-298.

Huang, C., & al. (2008). Nanotechnology Publications and Patents: A Review of Social Science Studies and Search Strategies. Working Paper No. 2008-058 , 58.

Hullmann, A., & Meyer, M. (2003). Publications and patents in nanotechnology: An overview of previous studies and the state of the art. Scientometics , 58 (3), 507-257.

ISI Web of Knowledge. (2011). Retrieved from apps.webofknowledge.com/

Jaffe, A. (1989). Real Effects of Academic Research. American Economic Review , 79 (5), 957-70.

Jaffe, A., & Lerner, J. (2001). Reinventing Public R&D: Patent Policy and the Commercialization of National Laboratory Technologies. RAND Journal of Economics , 32 (1), 167-198.

Jaffe, A., & Trajtenberg, M. (1996). Flows of knowledge from universities and federal laboratories: Modeling the knowledge flow of patent citations over

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

time and accross institutional and geographic boundaries. PNAS , 93 (23), 12671-12677.

Jaffe, A., & Trajtenberg, M. (1996). Flows of Knowledge From Universities and Federal Laboratories: Modelling the Flow of Patent Citations over Time and Accross Institutional and Geographic Boundaries. PNAS , 93 (23), 12671-12677.

Jaffe, A., Fogarty, M., & Banks, B. (1998). Evidence from Patents and Patent Citations on the Impact of NASA and Other Federal Labs on Commercial Innovation. Journal of Industrial Economics , 46 (2), 183-205.

Jaffe, B., Trajtenberg, M., & Henderson, R. (1993). Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citation. Quarterly Journal of Economics , 108 (3), 577-598.

Johnson, J., & J, D. (2007). Econometrics Methods (4th Edition ed.). McGraw Hill International.

Jones, Uzzy, & Wuchty. (2008). Multi-University Research Teams: Shifting Impact, Geography, and Stratification of Science. Science , 322, 1259.

Jovanovic, B., & Rousseau, P. (2005). General Purpose Technologies. In P. Aghion, & S. Durlauf, Handbook of

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Economic Growth, Volume 1B (p. Chapter 18). Elsevier B.V.

Kaplan, S., & Radin, J. (2011). Bounding and emerging technology: Para-scientific media and the Drexler-Smalley debate about nanotechnology. Social Studies of Science , 41, 457-485.

Kline, S., & Rosenberg, N. (1986). An Overview of Innovation. In N. R. Council, The Positive Sum Strategy: Harnessing Technology for Economic Growth (pp. 275-305). Washington D.C.: The National Academy Press.

Lacetera, N. (2008). Different Missions and Commitment Power in R&D Organizations: Theory and Evidence on Industry-University Alliances. Organization Science , 20 (3), 565-582.

Lacetera, N., & Zirulia, L. (2008). Knowledge Spillovers, Competition, and R&D Incentive Contracts. Working Papers, Dipartimento Scienze Economiche, Universita di Bologna, Italy , 624.

Lane, J., & Bertuzzi, S. (2011). Measuring the Results of Science Investments. Science , 331, 678-680.

Leyesdorff, & Etzkowitz. (1998). The Triple Helix as a Model for Innovation Studies. Science & Public Policy , 25 (3), 195-203.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Lissoni, F., Llerena, P., & Sanditov, B. (2011). Network of inventors and academics in France. Preliminary Draft .

Long, J. S. (1997). Regression Models for Categorical and Limited Dependant Variables (Advanced Quantitative Techniques in the Social Sciences). Sage Publications.

Malanowski, N., Heimer, T., Luther, W., & Werner, M. (2006). Growth Market Nanotechnology. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA.

Malo, S. (2006). The Contribution of (not so) Public Research to Commercial Innovations in the Field of Combinatorial Chemistry. EUI working papers: RSC .

Malo, S., & Geuna, A. (2000). Science-Technology Linkages in an Emerging Research Platform: The case of Combinatorial Chemistry and Biology. Scientometrics , 47 (2), 303-321.

Mansfield, E. (1990). Academic research and industrial innovation. Research Policy (20), 1-12.

Mansfield, E. (1998). Academic Research and Industrial Innovation: An Update of Empirical Findings. Research Policy , 26, 773-776.

Mazzucato, M. (2011). The Entrepreneurial State.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

DEMOS.

McMillan, S., Narin, F., & Deeds, D. (2000). An Analysis of the Critical Role of Public Science in Innovation: the Case of Biotechnology. Research Policy , 29 (1), 1-8.

Meyer, M. (2000). Does science push technology? Patents citing scientific literature. Research Policy , 29, 409-434.

Montobbio, F., & Sterzi, V. (2011). The globalization of technology in the emerging markets: a gravity model on the determinants of international technological collaborations. Draft, not published yet .

Moore, & Davis. (2001). Learning the Silicon Valley Way. Working Paper, Stanford Institute for Economic Policy Research (SIEPR) .

Narin, F., Hamilton, K., & Olivastro, D. (1997). The Increasing Linkage between U.S. Technology and Public Science. Research Policy , 26 (3), 317-330.

Newman, M. E. (2001). Scientific collaboration networks. I. Network construction and fundamental results. Physical Review E , 64.

Newman, M. E. (2001). Scientific collaboration networks. II. Shortest paths, weighted networks, and

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

centrality. Physical Review E , 64.

Nooy (De), W., Mrvar, A., & Batagelj, V. (2005). Exploratory Social Network Analysis with Pajek. New York: Cambridge University Press.

Noyons, E., & al. (2003). Mapping Excellence in Science and Technology Accross Europe: Nanoscience and Nanotechnology. European Commission.

Noyons, E., Butter, R., Van Raan, A., Schmoch, U., Heinze, T., Hinze, S., et al. (2003). Mapping Excellence in Science and Technology Accross Europe: Nanoscience and Nanotechnology. European Commission.

OECD. (1993). Frascati Manual (Fifth edition ed.).

OECD. (2002). Frascati manual: Proposed Standard Practice for Surveys on Research and Experimental Development. OECD Publications.

OECD. (2005). Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data (3rd Edition ed.). OECD.

Owen, Smith, & Powell. (2005). Accounting for emergence and novelty in Boston and Bay Area Biotechnology. In P. B. Feldman, Cluster Genesis: The Emergence of Technology Clusters and their

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Implication for Government Policies.

Pavitt, K. (2005). Innovation processes. In J. Fagerberg, D. Mowery, & R. Nelson, The oxford handbook of innovation (pp. 86-114).

Plotnikova, T., & Rake, B. (2011). Collaboration in pharmaceutical research: Exploration of country-level determinants. Draft DIME Conference .

Popper, E., & Buskirk, B. (1992). Technology life cycles in industrial markets. Industrial Marketing Management , 23-31.

Porter, A., Youtie, J., Shapira, P., & Schoeneck, D. (2008). Refining search terms for nanotechnology. Journal of Nanoparticle Research , 10, 715-728.

Price, D. d. (1984). The science/technology relationship, the craft of experimental science, and policy for the improvement of high technology innovation. Research Policy , 13, 3-20.

Price, D. J. (1963). Little Science, Big Science. Columbia University Press.

Price, D. J. (1984). The Science / Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation. Research Policy , 13, 3-20.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Ratner, M., & Ratner, D. (2004). Nanotechnology: a gentle introduction to the next big idea.

Reiß, T., & Thielmann, A. (2010). Nanotechnology Research in Russia - An Analysis of Scientific Publications and Patent Applications. Nanotechnology Law & Business , 7, 387.

Reiß, T., Hartig, J., & Schmoch, U. (2009). ERACEP: Emerging Research Areas and their Coverage by ERC-supported Projects.

Rittner, M. (2002). Market analysis of materials. American Ceramic Society Bulletin , 81 (3), 33-36.

Rochow, R., & CIMBA. (2005). Elettra's Social Accountability Report. ST Internal Report.

Roco, M., & Bainbridge, W. (2003). Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. NSF/DOC. Dordrecht: Springer.

Roper, A., Cunnigham, S., Porter, A., Mason, T., Rossini, F., & Banks, J. (2011). Forecasting and management of technology. Wiley & Sons.

Rosenberg, N. (1994). Exploring the black box. Cambridge University Press.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Rosenberg, N. (1994). Exploring the Black Box: Technology, Economics and History. Cambridge University Press.

Rosenberg, N. (1982). Inside the Black Box. Cambridge University Press.

Rosenberg, N. (1992). Scientific Instrumentation and University Research. Research Policy , 21, 381-390.

Salter, A., & Martin, B. (2001). The Economic Benefits of Publicly Funded Basic Research: a Critical Review. Research Policy , 30 (3), 509-532.

Santos Silva, J., & Tenreyro, S. (2011). Further simulation evidence on the performance of the Poisson pseudo-maximum likelihood estimator. Economics Letters , 112 (2), 220-222.

Sauermann, H. (2008). Individual Incentives as Drivers of Innovative Processes and Performance. PhD B.A. Dissertation Duke University .

Scheu, M., Veefkind, V., Verbandt, Y., Molina Galan, E., Absalom, R., & Förster, W. (2006). Mapping nanotechnolgy patents: The EPO approach. World Patent Information , 28, 204-211.

Schmied, H. (1975). A study of the economic utility resulting from CERN contracts (Vols. 75-05). Geneva:

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

European Organisation for Nuclear Research.

Schmoch, U. (2007). Double-Boom Cycles and the Comeback of Science-Push and Market-Pull. Research Policy , 36, 1000-1015.

Schmoch, U. (1997). Indicators and the relations between science and technology. Scientometrics , 38 (1), 103-116.

Schmoch, U., & Thielmann, A. (2012). Cyclical long-term development of complex technologies - premature expectations in nanotechnology? Fraunhofer ISI discussion papers Innovation Systems and Policy Analysis, 31.

Schmoch, U., Laville, F., Patel, P., & Frietsch, R. (2003). Linking technology to areas to industrial sectors. Final report to the European Commission, DG Research, Karlsruhe.

Scopus. (2011). Retrieved from http://www.scopus.com/home.url

Shapira, P. (2012, January). Early patterns of commercial activity in Graphene. Retrieved 2012, from Selected Works.

Sharpe, W. F. (1994). The Sharpe Ratio. Journal of Portfolio Management .

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Smith, K. (2005). Measuring Innovation. In J. Fagerberg, D. Mowery, & R. Nelson, The oxford handbook of innovation (pp. 148-177).

Stephan, P. (1996). The Economics of Science. Journal of Economic Literature , 34 (3), 1199-1235.

Stern, S. (2004). Do Scientists Pay to be Scientists? Management Science , 50 (6), 835-853.

The Getty Research Institute. (2011). Retrieved from http://www.getty.edu/research/

Tijssen, R. (2002). Science dependence of technologies: evidence from inventions and their inventors. Research Policy , 31, 509-526.

Vallas, Kleinman, & Biscotti. (2010). The Making of the Knowledge Economy: State Intervention and the Commercialization of the Life Sciences . In F. Block, (Forthcoming) Half Empty and Half Full: US Government Innovation Policies, 1969-2008.

VDI. (2010). Meta-Roadmap Nanomaterialien: Zukünftige Entwicklunden und Anwendungen.

Verspagen, B. (1999). Large Firms and Knowledge Flows in the Dutch R&D System: A Case Study of Philips Electronics. Technology Analysis & Strategic Management , 11 (2), 211-233.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Von Hippel, E. (2005). Democratizing Innovation. MIT Press.

Von Hippel, E. (1976). The Dominant Role of Users in the Scientific Instrumentation Innovation Process. Research Policy , 5, 212-239.

Von Hippel, E. (1988). The sources of innovation. New York, Oxford: Oxford University Press.

Wydra, S., Haas, K.-H., Jungmittag, A., Reiss, T., & Thielmann, A. (2012). Economic foresight study on industrial trends and the resesarch needed to support the competitiveness of European industry around 2025. Draft of the final report, Karlsruhe.

Young, P. (2009). Innovation Diffusion in Heterogenous Populations: Contagion, Social influence, and Social Learning. American Economic Review , 99 (5), 1899-1924.

Zellner, C. (2003). The Economic Effects of Basic Research: Evidence from Embodied Knowledge Transfer via Scientists' Migration. Research Policy , 32 (10), 1881-1895.

Zucker, L., Darby, M., & Armstrong, J. (1998). Geographically Localized Knowledge: Spillovers or Markets? Economic Inquiry , 36 (1), 65-86.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annexes

Annex chapter 1

RI Definitions

Research Infrastructures. Source: European Commission

"Research Infrastructure" means facilities, resources and related services that are used by the scientific community to conduct top level research in their respective fields and covers major scientific equipment or sets of instruments; knowledge based resources such as collections, archives or structures for scientific information; enabling Information and Communications Technology based infrastructures such as Grid, computing, software and communication, or any other entity of a unique nature essential to achieve excellence in research. Such infrastructures may be "single sited" or "distributed" (an organised network of resources)

http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri

Open access description. Source: ESFRI roadmap (2011)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

In all cases considered for the roadmap, these infrastructures must apply an "Open Access" policy for basic research, i.e. be open to all interested researchers, based on open competition and selection of the proposals evaluated on their sole scientific excellence by international peer-review. In most cases the effort and resources required to build these infrastructures, and to make them available as a service to the general pan-European user community, are well beyond those available to single institutions or even countries. Therefore there is the need for an international approach including the prerequisite to ensure long term sustainability of open access, at no cost to the researcher

CES algebra

$$P = (\alpha \cdot (\gamma \cdot t_r)^{\varepsilon} + (1-\alpha) \cdot (\delta \cdot Q)^{\varepsilon})^{\frac{1}{\varepsilon}}$$

To simplify I sustitute

$$X = \gamma \cdot t_r$$

$$Y = \delta \cdot Q$$

where $Q = \left(\bar{q} + t_q \cdot (q_{max} - \bar{q})\right)$

So that:

$$P = (\alpha \cdot (X)^{\varepsilon} + (1-\alpha) \cdot (Y)^{\varepsilon})^{\frac{1}{\varepsilon}}$$

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

The maximisation problem of the research team has the Lagrangian:

$$L = U\big(X(t_r), Y(t_q)\big) - \lambda(t_r - t_q - 1)$$

Setting the derivatives of t_r and t_q to zero, we find the research and instrumental activity functions which then have to satisfy the tangency conditions:

$$MRSt_r = \frac{1}{\varepsilon}(\alpha \cdot (X)^{\varepsilon} + (1-\alpha)\cdot (Y)^{\varepsilon})^{\frac{1}{\varepsilon}-1}(\varepsilon \cdot \alpha \cdot (X)^{\varepsilon-1})(\frac{dX}{dt_r})$$

$$MRSt_q = \frac{1}{\varepsilon}(\alpha \cdot (X)^{\varepsilon} + (1-\alpha)\cdot (Y)^{\varepsilon})^{\frac{1}{\varepsilon}-1}(\varepsilon \cdot (1-\alpha) \cdot (Y)^{\varepsilon-1})(\frac{dY}{dt_q})$$

$$\frac{MRSt_r}{MRSt_q} = \frac{\frac{1}{\varepsilon}(\alpha\cdot(X)^{\varepsilon}+(1-\alpha)\cdot(Y)^{\varepsilon})^{\frac{1}{\varepsilon}-1}(\varepsilon\cdot\alpha\cdot(X)^{\varepsilon-1})(\frac{dX}{dt_r})}{\frac{1}{\varepsilon}(\alpha\cdot(X)^{\varepsilon}+(1-\alpha)\cdot(Y)^{\varepsilon})^{\frac{1}{\varepsilon}-1}(\varepsilon\cdot(1-\alpha)\cdot(Y)^{\varepsilon-1})(\frac{dY}{dt_q})} = 1$$

$$\frac{MRSt_r}{MRSt_q} = \frac{\alpha}{(1-\alpha)} \cdot \left(\frac{X}{Y}\right)^{\varepsilon-1} \cdot \frac{\frac{dX}{dt_r}}{\frac{dY}{dt_q}} = 1$$

But we have:

$$\frac{dX}{dt_r} = \gamma$$

$$\frac{dY}{dt_q} = \delta \cdot (q_{max} - \bar{q})$$

Replacing:

$$\frac{\alpha}{(1-\alpha)} \cdot \left(\frac{\gamma \cdot t_r}{\delta\cdot\left(\bar{q}+t_q\cdot(q_{max}-\bar{q})\right)}\right)^{\varepsilon-1} \cdot \frac{\gamma}{\delta\cdot(q_{max}-\bar{q})} = 1$$

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Reorganizing:

$$t_r = \frac{\delta \cdot \left(\bar{q} + t_q \cdot (q_{max} - \bar{q})\right)}{\gamma} \cdot \left(\frac{(1-\alpha)}{\alpha} \cdot \frac{\delta \cdot (q_{max} - \bar{q})}{\gamma}\right)^{1/\varepsilon - 1}$$

But I know the time between instrumental and research activity adds up to 1

$$t_r = \frac{\delta \cdot \left(\bar{q} + (1 - t_r) \cdot (q_{max} - \bar{q})\right)}{\gamma} \cdot \left(\frac{(1-\alpha)}{\alpha} \cdot \frac{\delta \cdot (q_{max} - \bar{q})}{\gamma}\right)^{1/\varepsilon - 1}$$

Calling $\frac{\delta}{\gamma}\left(\frac{(1-\alpha)}{\alpha} \cdot \frac{\delta \cdot (q_{max} - \bar{q})}{\gamma}\right)^{1/\varepsilon - 1} = Z$ I have:

$$t_r = \left(\bar{q} + (1 - t_r) \cdot (q_{max} - \bar{q})\right) \cdot Z$$

$$t_r = \bar{q} \cdot Z + (q_{max} - \bar{q}) \cdot Z - t_r \cdot (q_{max} - \bar{q}) \cdot Z$$

$$t_r \left(1 + (q_{max} - \bar{q}) \cdot Z\right) = \bar{q} \cdot Z + (q_{max} - \bar{q}) \cdot Z$$

$$t_r = \frac{\bar{q} \cdot Z + (q_{max} - \bar{q}) \cdot Z}{(1 + (q_{max} - \bar{q}) \cdot Z)}$$

$$t_r = \frac{q_{max} \cdot Z}{(1 + (q_{max} - \bar{q}) \cdot Z)}$$

$$t_r = \frac{q_{max}}{\frac{1}{Z} + (q_{max} - \bar{q})}$$

Replacing the value of Z yields:

$$t_r^* = \frac{q_{max}}{\frac{1}{\left(\frac{\delta}{\gamma}\right)^{\varepsilon/\varepsilon-1}\left(\frac{(1-\alpha)}{\alpha}(q_{max} - \bar{q})\right)^{1/\varepsilon-1}} + (q_{max} - \bar{q})}$$

Cases and simulations

From the theory of constant elasticity of substitution production functions, the value of eta varies between

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

minus infinite and one (perfect substitution for eta equals to one, no substitution for eta equals minus infinite, and unit elasticity of substitution for eta equals 0). In this case, substitution exists and therefore eta is assumed to be strictly inferior to 1.

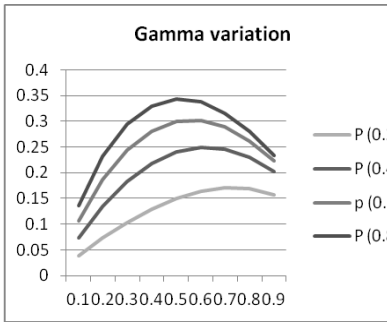
Let us look at special cases of the scientific output:

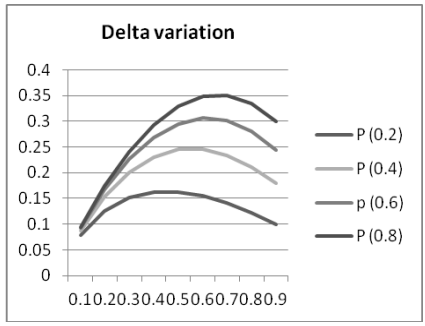
Case t_r =0 In this case the production of scientific knowledge is driven by eta and alpha. Since all the time is devoted on instruments, higher scientific outcome will be achieved when the share of instruments in the outcome is greater (e.g. low alpha) and a low complementarity between factors (e.g. high eta).

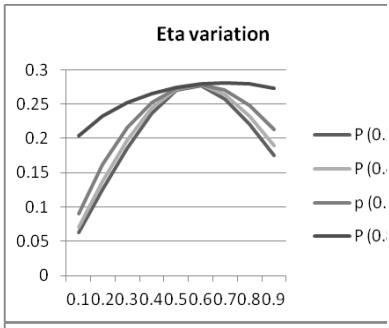
Case t_r =1. This case depicts the other extreme when all the time is allocated to research work. Similarly to the previous case, higher output will be reached with a high share of research in the output (i.e. high alpha) and a high substitutability between factors (i.e. high eta)

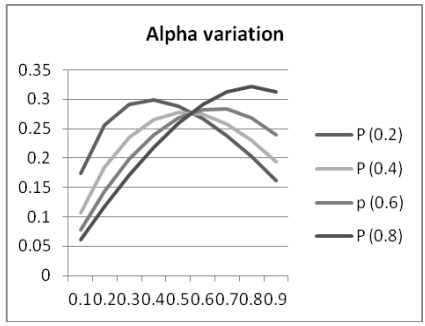
Other cases illustration with t_r ϵ (0,1) and parameter variation.

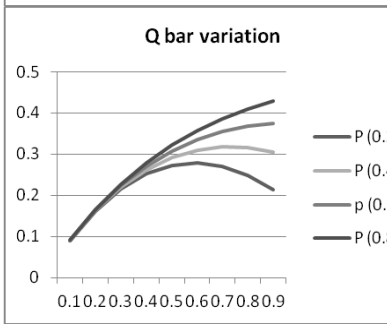
Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.











Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

ISI WoS categories

Team members	instrumental category
AGRICULTURE, DAIRY & ANIMAL SCIENCE	0
AGRICULTURE, MULTIDISCIPLINARY	0
ALLERGY	0
ANATOMY & MORPHOLOGY	0
ANESTHESIOLOGY	0
ASTRONOMY & ASTROPHYSICS	0
BEHAVIORAL SCIENCES	0
BIOCHEMICAL RESEARCH METHODS	1
BIOCHEMISTRY & MOLECULAR BIOLOGY	0
BIOLOGY	0
BIOPHYSICS	0
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	1
CARDIAC & CARDIOVASCULAR SYSTEMS	0
CELL BIOLOGY	0
CHEMISTRY, ANALYTICAL	1
CHEMISTRY, APPLIED	1
CHEMISTRY, INORGANIC & NUCLEAR	0
CHEMISTRY, MEDICINAL	0.5
CHEMISTRY, MULTIDISCIPLINARY	0
CHEMISTRY, ORGANIC	0
CHEMISTRY, PHYSICAL	0
CLINICAL NEUROLOGY	0
COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	1
COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	1
COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	1
COMPUTER SCIENCE, SOFTWARE ENGINEERING	1
COMPUTER SCIENCE, THEORY & METHODS	1
CRITICAL CARE MEDICINE	1
CRYSTALLOGRAPHY	0
DERMATOLOGY	0
DEVELOPMENTAL BIOLOGY	0
ECOLOGY	0.5
ELECTROCHEMISTRY	0
ENDOCRINOLOGY & METABOLISM	0
ECOLOGY	0
ENDOCRINOLOGY & METABOLISM	0
ENERGY & FUELS	1
ENGINEERING, AEROSPACE	1
ENGINEERING, BIOMEDICAL	1

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

ENGINEERING, CHEMICAL	1
ENGINEERING, ELECTRICAL & ELECTRONIC	1
ENGINEERING, ENVIRONMENTAL	1
ENGINEERING, MECHANICAL	1
ENGINEERING, MULTIDISCIPLINARY	1
ENVIRONMENTAL SCIENCES	0.5
FOOD SCIENCE & TECHNOLOGY	0.5
GASTROENTEROLOGY & HEPATOLOGY	0
GENETICS & HEREDITY	0
GEOCHEMISTRY & GEOPHYSICS	0.5
GEOSCIENCES, MULTIDISCIPLINARY	0
GERIATRICS & GERONTOLOGY	0
HEMATOLOGY	0
IMAGING SCIENCE & PHOTOGRAPHIC TECHNOLOGY	1
IMMUNOLOGY	0
INFECTIOUS DISEASES	0
INSTRUMENTS & INSTRUMENTATION	1
MATERIALS SCIENCE, BIOMATERIALS	0
MATERIALS SCIENCE, CERAMICS	0
MATERIALS SCIENCE, CHARACTERIZATION & TESTING	1
MATERIALS SCIENCE, COMPOSITES	0
MATERIALS SCIENCE, MULTIDISCIPLINARY	0.5
MATERIALS SCIENCE, COATINGS & FILMS	0.5
MATHEMATICAL & COMPUTATIONAL BIOLOGY	1
MATHEMATICS, INTERDISCIPLINARY APPLICATIONS	1
MECHANICS	1
MEDICAL LABORATORY TECHNOLOGY	1
MEDICINE, GENERAL & INTERNAL	0
MEDICINE, RESEARCH & EXPERIMENTAL	0.5
METALLURGY & METALLURGICAL ENGINEERING	1
METEOROLOGY & ATMOSPHERIC SCIENCES	0
MICROBIOLOGY	0
MICROSCOPY	1
MULTIDISCIPLINARY SCIENCES	0
MINERALOGY	0
NANOSCIENCE & NANOTECHNOLOGY	0.5
NEUROIMAGING	0
NEUROSCIENCES	0
NUCLEAR SCIENCE & TECHNOLOGY	0.5
NUTRITION & DIETETICS	0
OBSTETRICS & GYNECOLOGY	0
ONCOLOGY	0
OPHTHALMOLOGY	0

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

OPTICS	0.5
OTORHINOLARYNGOLOGY	0
PATHOLOGY	0.5
PEDIATRICS	0
PERIPHERAL VASCULAR DISEASE	0
PHARMACOLOGY & PHARMACY	0
PHYSICS, APPLIED	1
PHYSICS, ATOMIC, MOLECULAR & CHEMICAL	0
PHYSICS, CONDENSED MATTER	0
PHYSICS, FLUIDS & PLASMAS	0
PHYSICS, MATHEMATICAL	1
PHYSICS, MULTIDISCIPLINARY	0
PHYSICS, NUCLEAR	0
PHYSICS, PARTICLES & FIELDS	0
PHYSIOLOGY	0
PLANT SCIENCES	0
POLYMER SCIENCE	0.5
PSYCHIATRY	0
PSYCHOLOGY, BIOLOGICAL	0
PSYCHOLOGY, EXPERIMENTAL	0
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	0
RADIOLOGY, NUCLEAR MEDICINE & MEDICAL IMAGING	0
REPRODUCTIVE BIOLOGY	0
RHEUMATOLOGY	0
SPECTROSCOPY	1
SUBSTANCE ABUSE	0
SURGERY	0.5
TELECOMMUNICATIONS	1
THERMODYNAMICS	0
TOXICOLOGY	0
TRANSPLANTATION	0
UROLOGY & NEPHROLOGY	0.5
VETERINARY SCIENCES	0
VIROLOGY	0
ZOOLOGY	0

Table 24: ISI WoS categories

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annex chapter 2

OLS results for the panel data

		(1)	(2)	(3)
EQUATION	VARIABLES			
collab	lnmassi	0.0772***	0.0517***	0.0501***
		(0.00244)	(0.00204)	(0.00204)
	lnmassni	0.0281***	0.0174***	0.0162***
		(0.00158)	(0.00140)	(0.00143)
	lndist	-0.0159***	-0.0107***	-0.0183***
		(0.00208)	(0.00195)	(0.00352)
	lndyad			0.678***
				(0.0419)
	lntriad			0.706***
				(0.0532)
	lninstprox			0.0245***
				(0.00596)
	europe			-0.00730
				(0.00899)
	americas			0.0277***
				(0.00934)
	asia			-0.00555
				(0.00876)
	lnsocprox		0.691***	
			(0.0328)	
	Constant	-0.146***	-0.0925***	-0.0371
		(0.0173)	(0.0160)	(0.0298)
	Observations	38,544	38,544	38,544
	R-squared	0.045	0.145	0.146

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 25: OLS results

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Poisson and negative binomial regressions for the cross section

		(1)	(2)	(3)	(4)	(5)	(6)
EQUATION	VARIABLES						
collab	lnmassi	1.050***	0.828***	0.804***	1.009***	0.856***	0.841***
		(0.0373)	(0.0372)	(0.0381)	(0.0310)	(0.0296)	(0.0302)
	lnmassni	0.409***	0.280***	0.264***	0.346***	0.280***	0.262***
		(0.0323)	(0.0286)	(0.0302)	(0.0209)	(0.0203)	(0.0211)
	lndist	-0.203***	-0.122***	-0.125**	-0.163***	-0.141***	-0.200***
		(0.0308)	(0.0276)	(0.0516)	(0.0253)	(0.0242)	(0.0488)
	lndyad			1.584***			2.080***
				(0.0922)			(0.109)
	lntriad			1.416***			1.806***
				(0.0963)			(0.141)
	lninstprox			0.268***			0.202**
				(0.101)			(0.0854)
	europe			0.187			0.0381
				(0.234)			(0.190)
	americas			0.383			0.448**
				(0.242)			(0.194)
	asia			-0.0813			-0.182
				(0.250)			(0.195)
	lnsocprox		1.489***			1.969***	
			(0.0733)			(0.0864)	
	Constant	-5.233***	-4.709***	-4.870***	-5.126***	-4.743***	-4.361***
		(0.266)	(0.239)	(0.484)	(0.235)	(0.225)	(0.448)
lnalpha	Constant				1.178***	0.771***	0.750***
					(0.0478)	(0.0552)	(0.0552)
	Observations	12,848	12,848	12,848	12,848	12,848	12,848
	stataaic	16384	14918	14839	13951	13341	13295
	statabic	16414	14955	14913	13989	13385	13377
	ll	-8188	-7454	-7409	-6971	-6664	-6636
	LR test				2435.06***	1578.82***	1545.86***

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 26: Cross sectional Poisson & Negative binomial regressions

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annex Chapter 3

Technology sample and search strategies

Material	VDI material type	material type	material short	Publication strategy (Scopus via SQL)	Patent strategy (Patstat via SQL)
III-V semiconductors	nanostructured semiconductors	semiconductor	Semi_3-5	(aluminium AND (antimonide OR arsenide OR nitride OR phosphide)) OR AlSb OR AlAs OR AlN OR AlP OR (Boron AND (nitride OR phosphide OR arsenide OR BP OR BN)) OR (Gallium and (antinomide OR arsenide OR nitride OR phosphide)) OR GaSb OR GaAs OR GaN OR (Indium AND (antimonide OR arsenide OR nitride OR phosphide) OR InSb OR InAs OR InN OR InP)	(t.appln_title LIKE '% aluminium %' AND (t.appln_title LIKE '% antimonide %' OR t.appln_title LIKE '% arsenide %' OR t.appln_title LIKE '% nitride %' OR t.appln_title LIKE '% phosphide %')) OR t.appln_title LIKE '% AlSb %' OR t.appln_title LIKE '% AlAs %' OR t.appln_title LIKE '% AlN %' OR t.appln_title LIKE '% AlP %' OR t.appln_title LIKE '% boron %' AND (t.appln_title LIKE '% nitride %' OR t.appln_title LIKE '% phosphide %' OR t.appln_title LIKE '% arsenide %') OR t.appln_title LIKE '% BP %' OR t.appln_title LIKE '% BN %' OR t.appln_title LIKE '% gallium %' AND (t.appln_title LIKE '% antimonide %' OR t.appln_title LIKE '% arsenide %' OR t.appln_title LIKE '% nitride %' OR t.appln_title LIKE '% phosphide %') OR t.appln_title LIKE '% GaSb %' OR t.appln_title LIKE '% GaAs %' OR t.appln_title LIKE '% GaN %' OR t.appln_title LIKE '% indium %' AND (t.appln_title LIKE '% antimonide %' OR t.appln_title LIKE '% arsenide %' OR t.appln_title LIKE '% nitride %' OR

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					t.appln_title LIKE '% phosphide %') OR t.appln_title LIKE '% InSb %' OR t.appln_title LIKE '% InAs %' OR t.appln_title LIKE '% InN %' OR t.appln_title LIKE '% InP %' OR r.appln_abstract LIKE '% aluminium %' AND (r.appln_abstract LIKE '% antimonide %' OR r.appln_abstract LIKE '% arsenide %' OR r.appln_abstract LIKE '% nitride %' OR r.appln_abstract LIKE '% phosphide %') OR r.appln_abstract LIKE '% AlSb %' OR r.appln_abstract LIKE '% AlAs %' OR r.appln_abstract LIKE '% AlN %' OR r.appln_abstract LIKE '% AlP %' OR r.appln_abstract LIKE '% boron %' AND (r.appln_abstract LIKE '% nitride %' OR r.appln_abstract LIKE '% phosphide %' OR r.appln_abstract LIKE '% arsenide %') OR r.appln_abstract LIKE '% BN %' OR r.appln_abstract LIKE '% BP %' OR r.appln_abstract LIKE '% gallium %' AND (r.appln_abstract LIKE '% antimonide %' OR r.appln_abstract LIKE '% arsenide %' OR r.appln_abstract LIKE '% nitride %' OR r.appln_abstract LIKE '% phosphide %') OR r.appln_abstract LIKE '% GaSb %' OR r.appln_abstract LIKE '% GaAs %' OR r.appln_abstract LIKE '% GaN %' OR r.appln_abstract LIKE '% indium %' AND (r.appln_abstract LIKE '% antimonide %' OR r.appln_abstract LIKE '% arsenide %' OR r.appln_abstract LIKE '% nitride %' OR r.appln_abstract LIKE

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					'% phosphide %') OR r.appln_abstract LIKE '% InSb %' OR r.appln_abstract LIKE '% InAs %' OR r.appln_abstract LIKE '% InN %' OR r.appln_abstract LIKE '% InP %')
II-VI semiconductor	nanostructured semiconductors	semiconductor	Semi_2-6	(cadmium AND (selenide OR sulfide OR telluride)) OR CdSe OR CdTe OR (Zinc AND (selenide OR sulfide OR telluride)) OR ZnSe OR ZnS OR ZnTe	(t.appln_title LIKE '% cadmium %' AND (t.appln_title LIKE '% selenide %' OR t.appln_title LIKE '% sulfide %' OR t.appln_title LIKE '% telluride %' OR t.appln_title LIKE '% phosphide %') OR t.appln_title LIKE '% CdSe %' OR t.appln_title LIKE '% CdTe %' OR t.appln_title LIKE '% zinc %' AND (t.appln_title LIKE '% selenide %' OR t.appln_title LIKE '% sulfide %' OR t.appln_title LIKE '% telluride %') OR t.appln_title LIKE '% ZnS%' OR t.appln_title LIKE '% ZnTe %' OR r.appln_abstract LIKE '% cadmium %' AND (r.appln_abstract LIKE '% selenide %' OR r.appln_abstract LIKE '% sulfide %' OR r.appln_abstract LIKE '% telluride %' OR r.appln_abstract LIKE '% phosphide %') OR r.appln_abstract LIKE '% CdSe %' OR r.appln_abstract LIKE '% CdTe %' OR r.appln_abstract LIKE '% zinc %' AND (r.appln_abstract LIKE '% selenide %' OR r.appln_abstract LIKE '% sulfide %' OR r.appln_abstract LIKE '% telluride %') OR r.appln_abstract LIKE '% ZnS%' OR r.appln_abstract LIKE '% ZnTe %')

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Non-oxide ceramics nanoparticles	Ceramic nanoparticles and nanostructures	-	Non-oxide ceramics nanoparticles	-	-
aluminum oxide nanoparticles	Ceramic nanoparticles and nanostructures	ceramic	alumina	alumina OR (aluminium AND %oxid%) OR aloxide	(t.appln_title LIKE '% alumina %' OR (t.appln_title LIKE '% alumin%' AND t.appln_title LIKE '%oxid%') OR t.appln_title LIKE '% aloxide %' OR r.appln_abstract LIKE '% alumina %' OR (r.appln_abstract LIKE '% alumin%' AND r.appln_abstract LIKE '%oxid%') OR r.appln_abstract LIKE '% aloxide %')
carbon nano foam	carbon based nanomaterials	carbon	carbon_foam	%carbon% AND %foam%	(t.appln_title LIKE '%carbon%' AND t.appln_title LIKE '%foam%') OR (r.appln_abstract LIKE '%carbon%' AND r.appln_abstract LIKE '%foam%')
carbon aerogel	carbon based nanomaterials	carbon	carbon_gel	%carbon% AND %aerogel%	(t.appln_title LIKE '%carbon%' AND t.appln_title LIKE '%aerogel%') OR (r.appln_abstract LIKE '%carbon%' AND r.appln_abstract LIKE '%aerogel%')
carbon nanotubes	carbon based nanomaterials	carbon	carbon_nanotube	%carbon% AND (nanotube% OR CNT)	(t.appln_title LIKE '%carbon%' AND (t.appln_title LIKE '% nanotube%' OR t.appln_title LIKE '%CNT%')) OR (r.appln_abstract LIKE '%carbon%' AND (r.appln_abstract LIKE '% nanotube%' OR r.appln_abstract LIKE '%CNT%'))
cellulose nanofibers	biobased nanomaterials	biobased	cellulose	%cellulose AND % fib%	(t.appln_title LIKE '%cellulose %' AND t.appln_title LIKE '% fib%') OR (r.appln_abstract LIKE

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					'%cellulose %' AND r.appln_abstract LIKE '% fib%')
Ceramic matrix composite with carbon nanotubes	nanocomposites	composite	cer_comp_nanotube	%ceramic% AND (carbon AND (nanotube% OR CNT)	(t.appln_title LIKE '%ceramic%' AND ((t.appln_title LIKE '%carbon%' AND t.appln_title LIKE '%nanotube%') OR t.appln_title LIKE '%CNT%')) OR (r.appln_abstract LIKE '%ceramic%' AND ((r.appln_abstract LIKE '%carbon%' AND r.appln_abstract LIKE '% nanotube%') OR r.appln_abstract LIKE '%CNT%'))
nanocomposite coatings	nanocomposites	composite	comp_coating	%composite% AND %coating%	(t.appln_title LIKE '%composite%' AND t.appln_title LIKE '%coating%') OR (r.appln_abstract LIKE '%composite%' AND r.appln_abstract LIKE '%coating%')
metal matrix composites (MMC)	nanocomposites	composite	comp_metal	%composite% AND metal%	(t.appln_title LIKE '%composite%' AND t.appln_title LIKE '%metal%') OR (r.appln_abstract LIKE '%composite%' AND r.appln_abstract LIKE '% metal%')
Dendritic Polymers	polymers	polymer	dendrimer	dendrimer% OR (dendritic AND polymer%)	(t.appln_title LIKE '%dendrimer%' OR t.appln_title LIKE '%dentritic % polymer%') OR (r.appln_abstract LIKE '% dendrimer%' OR r.appln_abstract LIKE '% dentritic % polymer%')
fullerenes	carbon based nanomaterials	carbon	fullerene	fullerene% OR C60 OR buckyball%	(t.appln_title LIKE '%fullerene%' OR t.appln_title LIKE '%C60%' OR t.appln_title LIKE '%buckyball%') OR (r.appln_abstract LIKE '% fullerene%' OR r.appln_abstract LIKE '%C60%' OR r.appln_abstract LIKE

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					'% buckyball%')
Gold nanoparticles	Metal and nanostructured alloys	metal	gold	gold	(t.appln_title LIKE '% gold %' OR r.appln_abstract LIKE '% gold %')
graphene	carbon based nanomaterials	carbon	graphene	graphene	(t.appln_title LIKE '% graphene %') OR (r.appln_abstract LIKE '% graphene %')
graphite nanoparticles	carbon based nanomaterials	carbon	graphite	graphite%	(t.appln_title LIKE '% graphite%') OR (r.appln_abstract LIKE '%graphite%')
iron oxide nanoparticles	Ceramic nanoparticles and nanostructures	ceramic	iron	iron oxide OR Fe_O%	(t.appln_title LIKE '% iron % oxide %' OR t.appln_title LIKE '% Fe_O%') OR (r.appln_abstract LIKE '% iron % oxide %' OR r.appln_abstract LIKE '% Fe_O%')
Nanoparticles of iron or cobalt (alloys)	Metal and nanostructured alloys	metal	iron_cobalt	alloy% AND (iron OR cobalt)	((t.appln_title LIKE '% alloy%' AND (t.appln_title LIKE '%iron%' OR t.appln_title LIKE '%cobalt%')) OR (r.appln_abstract LIKE '% alloy%' AND (r.appln_abstract LIKE '%iron%' OR r.appln_abstract LIKE '%cobalt%')))
lipid nanocarriers (LNC)	biobased nanomaterials	biobased	lipid	(lipid% AND %carrier%) OR (lipid% AND %particle%) OR (liposome%)	(t.appln_title LIKE '%liposome%' OR r.appln_abstract LIKE '%liposome%') OR (t.appln_title LIKE '%lipid%' AND t.appln_title LIKE '%particle%') OR (r.appln_abstract LIKE '%lipid%' AND r.appln_abstract LIKE '%particle%') OR (t.appln_title LIKE '%lipid%' AND t.appln_title LIKE '%carrier%') OR (r.appln_abstract LIKE '%lipid%' AND r.appln_abstract LIKE

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					'%carrier%')
Nanoparticulate metal powder	Metal and nanostructured alloys	metal	metal_powder	metal% AND powder%	(t.appln_title LIKE '% metal%' AND t.appln_title LIKE '%powder%') OR (r.appln_abstract LIKE '% metal%' AND r.appln_abstract LIKE '%powder%')
Nanocrystalline metals	Metal and nanostructured alloys	metal	nanocrys_metal	%crystal% AND metal%	(t.appln_title LIKE '%crystal%' AND t.appln_title LIKE '% metal%') OR (r.appln_abstract LIKE '%crystal%' AND r.appln_abstract LIKE 'metal%')
plasmons in metallic nanostructures	Metal and nanostructured alloys	metal	plasmons_metal	plasmon% AND metal%	(t.appln_title LIKE '% plasmon%' AND t.appln_title LIKE '% metal%') OR (r.appln_abstract LIKE '% plasmon%' AND r.appln_abstract LIKE '% metal%')
platinum nanoparticles	Metal and nanostructured alloys	metal	platinum	platinum OR "Pt"	t.appln_title LIKE '%platinum%' OR t.appln_title LIKE '% Pt %' OR r.appln_abstract LIKE '%platinum%' OR r.appln_abstract LIKE '% Pt %'
polymers with carbon nanoparticles	nanocomposites	composite	polymer_carbon	polymer AND carbon%	(t.appln_title LIKE '% polymer%' AND t.appln_title LIKE '%carbon%') OR (r.appln_abstract LIKE '% polymer%' AND r.appln_abstract LIKE '%carbon%')
matrix polymer-silicate nanocomposites	nanocomposites	composite	polymer_comp_sil	polymer% AND silicate% AND %composite%	(t.appln_title LIKE '% polymer%' AND t.appln_title LIKE '% silicate %' AND t.appln_title LIKE '%composite%') OR (r.appln_abstract LIKE '% polymer%' AND r.appln_abstract LIKE '%composite%' AND r.appln_abstract LIKE '% silicate %')

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Polymeric nano coating systems	polymers	polymer	polymer_layer	polymer AND layer%	(t.appln_title LIKE '% polymer%' AND t.appln_title LIKE '%layer%') OR (r.appln_abstract LIKE '% polymer%' AND r.appln_abstract LIKE '%layer%')
polymer nanotubes, nanowires and nanofibres	polymers	polymer	polymer_nanotube	polymer% AND (nanotube% OR nanowire% OR %fiber%)	((t.appln_title LIKE '% polymer%' AND (t.appln_title LIKE '% nanotube%' OR t.appln_title LIKE '% nanowire%' OR t.appln_title LIKE '%fiber%')) OR (r.appln_abstract LIKE '% polymer%' AND (r.appln_abstract LIKE '% nanotube%' OR r.appln_abstract LIKE '% nanowire%' OR r.appln_abstract LIKE '%fiber%')))
Polymer Nanoparticles	polymers	polymer	polymer_particle	polymer% AND %particle%	(t.appln_title LIKE '% polymer%' AND t.appln_title LIKE '%particle%') OR (r.appln_abstract LIKE '% polymer%' AND r.appln_abstract LIKE '%particle%')
polymer nanostructures	polymers	polymer	polymer_struct	polymer% AND nanostructure%	(t.appln_title LIKE '% polymer%' AND t.appln_title LIKE '% nanostructure%') OR (r.appln_abstract LIKE '% polymer%' AND r.appln_abstract LIKE '% nanostructure%')
core-shell nanoparticles	nanocomposites	composite	shell	core AND shell%	(t.appln_title LIKE '% core %' AND t.appln_title LIKE '% shell%') OR (r.appln_abstract LIKE '% core %' AND r.appln_abstract LIKE '% shell%')
silica and metal oxide nanoparticles	Ceramic nanoparticles and nanostructures	ceramic	silica	silica OR silicon dioxide OR Si_O%	(t.appln_title LIKE '% silica %' OR t.appln_title LIKE '% silicon % dioxide%' OR t.appln_title LIKE '% Si_O%') OR

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

					(r.appln_abstract LIKE '% silica %' OR r.appln_abstract LIKE '% silicon % dioxide%' OR r.appln_abstract LIKE '% Si_O%')
Silicon	nanostructured semiconductors	semiconductor	silicon	(silicon OR Si) AND (quantum dot% OR nanowire% OR photonic crystal%)	(t.appln_title LIKE '% silicon %' OR t.appln_title LIKE '% Si %') AND (t.appln_title LIKE '% quantum dot%' OR t.appln_title LIKE '% nanowire%' OR t.appln_title LIKE '% photonic % crystal%') OR (r.appln_abstract LIKE '% silicon %' OR r.appln_abstract LIKE '% Si %') AND (r.appln_abstract LIKE '% quantum dot%' OR r.appln_abstract LIKE '% nanowire%' OR r.appln_abstract LIKE '% photonic % crystal%')
silver nanoparticles	Metal and nanostructured alloys	metal	silver	silver OR Ag	(t.appln_title LIKE '% silver %' OR t.appln_title LIKE '% Ag %') OR (r.appln_abstract LIKE '% silver %' OR r.appln_abstract LIKE '% Ag %')
titanium oxide nanoparticles	Ceramic nanoparticles and nanostructures	ceramic	titania	(titan% AND oxide%) OR Ti_O%	(((t.appln_title LIKE '% titan%' AND t.appln_title LIKE '%oxid%') OR t.appln_title LIKE '% Ti_O%') OR (r.appln_abstract LIKE '% titan%' AND r.appln_abstract LIKE '%oxid%') OR r.appln_abstract LIKE '% Ti_O%')
zinc oxide nanoparticles	Ceramic nanoparticles and nanostructures	ceramic	zinc_oxide	zinc oxid% OR ZnO	(t.appln_title LIKE '% zinc % oxide%' OR t.appln_title LIKE '% ZnO %' OR r.appln_abstract LIKE '% zinc % oxide%' OR r.appln_abstract LIKE '% ZnO %')

Table 27: Materials' description

.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Remark: Concerning a possible correlation between the number of hits between publication / patent number and search terms, the hypothesis of null correlation could not be rejected at the 1% level of significance

Between and within standard deviations formulas

Between and within standard deviations are computed in stata as:

$$\sigma_{BG} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\overline{x_i} - \bar{\bar{x}})^2}$$

$$\sigma_{WG} = \sqrt{\frac{1}{m-1}\sum_{m=1}^{m}(\widetilde{x_m} - \bar{\bar{x}})^2}$$

Where:

$$\widetilde{x_m} = x_{it} - \overline{x_i} + \bar{\bar{x}}$$

Note that n is the technology number and T is the number of observations and highlighted the reported minimum and maximum value in the following table.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Between and within standard deviations results

Variable		Mean	Std. Dev.	Min	Max	Observations
pub	overall	694.767	994.8248	2	7318	N = 442
	between		732.2371	22.46154	3209.077	n = 34
	within		684.1747	-2287.31	4803.69	T = 13
pat	overall	7.642534	16.36361	0	147	N = 442
	between		13.21169	.2307692	76.76923	n = 34
	within		9.897909	-64.1267	77.8733	T = 13
scopus	overall	1537223	327877.5	1157821	2074806	N = 442
	between		0	1537223	1537223	n = 34
	within		327877.5	1157821	2074806	T = 13
patstat	overall	226927.5	48364.89	136634	292593	N = 442
	between		0	226927.5	226927.5	n = 34
	within		48364.89	136634	292593	T = 13
pat_nano	overall	1592.462	639.6198	515	2383	N = 442
	between		0	1592.462	1592.462	n = 34
	within		639.6198	515	2383	T = 13
pub_nano	overall	36955.15	22562.28	11039	75392	N = 442
	between		0	36955.15	36955.15	n = 34
	within		22562.28	11039	75392	T = 13

Table 28: Summary statistics

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

S curve partitions results

Patents Year 1997-2002 Sample reference		Absolute Sharpe ratios	
		Positive	Negative
Relative Sharpe ratios	Positive	Polymer nanotube	Composite coating, Graphene Lipid, Metal powder
	Negative	Carbon nanotube, Polymer particle, Fullerene	Polymer structure, Silicon, Zinc oxide, Alumina, Gold, Nanocrys. Metal, Silica, Silver, Composite metal, Graphite, Iron, Iron cobalt, Polymer layer, Semi 3-5, Shell, Titania

Table 29: Relative vs Absolute Sharpe ratios (1997-2002

Patents Year 2003-2008 Sample reference		Absolute Sharpe ratios	
		Positive	Negative
Relative Sharpe ratios	Positive	Shell, Graphene, Silicon, Plasmons metal, Silica, Silver, Platinum, Composite coating, Graphite, Iron, Polymer structure, Semi 3-5	
	Negative	Zinc oxide, Lipid, Gold, Polymer particle, Titania	Carbon nanotube, Polymer layer, Polymer nanotube, Nanocrys. Metal, Alumina, Composite metal, Dendrimer, Fullerene, Metal powder, Polymer carbon

Table 30: S-curve Relative vs Absolute Sharpe ratios (2003-2008)

Descriptive analysis: Considering the first partition, polymer nanotubes stand out as rapid growth material.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Also carbon based, note the presence of carbon nanotubes and fullerene as maturing materials and graphene as emerging. From this picture it appears very clear that carbon materials contributed to the expected "nano" revolution before 2002. Other material such as lipids and metal powders stand out as emerging material or polymer particle as maturing material. Quite radical changes occur between the first and second partition which suggests the high dynamics in inventive activities related to new technologies. First, no material appear in the emerging quadrant but many in the rapid growth one, which means that all materials experiencing a higher than average an relative growth also experience higher than average absolute growth. From the previous partition, both composite coating and graphene move to the next stage of rapid growth whereas metal powder starts declining. In addition, material in the in the rapid growth quadrant only shown little activity in the previous period, which shows how fast nanotechnology is evolving (i.e. (core-) shell, silicon, silica, silver, graphite, iron, semi. 3-5). Note that apart from graphene / graphite which stand in the first quadrant; most other carbon based materials

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

experience a slow down or decrease in both relative and absolute growth with respect to the sample. The next quadrant is maturing materials and the ones appearing in the first partition either stands in the same position (i.e. polymer particle) or move to the declining quadrant (i.e. carbon nanotubes, fullerenes). Concerning the newcomers, they mostly come from the last quadrant which would mean that some materials show more constant / linear than exponential growth, therefore showing significant absolute growth but no relative growth patterns.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

S curve framework applied to research dynamics

Publications **Year 1996 – 2008** **Sample reference**		**Absolute Sharpe ratio**	
		Positive	**Negative**
Relative Sharpe ratio	**Positive**	Polymer nanotube, polymer layer, zinc oxide	
	Negative	Carbon nanotube, polymer particle, shell, silica, silver, Alumina, gold, nanocrystalline metal, platinum,	Fullerene Composite coating, dendrimer, graphite, iron cobalt, lipid, metal powder, plasmons metal, polymer carbon, polymer structure, semi 2-6

Table 31: Research S curve framework

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Sharpe results

nano_mat	Sharpe_pub_abs_Scopus	Sharpe_pub_abs_pub_nano	Sharpe_pub_abs_sample	Sharpe_pat_abs_Patstat	Sharpe_pat_abs_pat_nano	Sharpe_pat_abs_sample
alumina	-844.3785	-58.06048	-.1070416	-1303.883	-16.58246	-.147701
carbon_nanotube	-221.1085	-13.91493	1.355706	-292.5168	-3.442251	.2483171
comp_coating	-1441.631	-99.91227	-1.024535	-3618.682	-45.76728	-.1524558
comp_metal	-996.8473	-69.00146	-.6170922	-1624.651	-20.45753	.0229615
dendrimer	-3049.581	-212.9707	-3.905995	-3921.17	-49.91331	-.4895934
fullerene	-1494.557	-104.1328	-1.655317	-1085.752	-13.70899	-.0223866
gold	-298.5279	-19.83527	.7050178	-3753.91	-47.46421	-.1446003
graphene	-659.9931	-45.70933	-.4352051	-2018.512	-25.31541	.1314186
graphite	-1545.61	-107.2159	-1.202951	-2415.181	-30.5374	-.0930326
iron	-1332.501	-92.28402	-.8772087	-3914.298	-49.414	-.0716386
iron_cobalt	-4105.033	-287.6829	-6.335457	-4502.506	-57.44196	-.6925343
lipid	-1060.325	-73.68726	-.969786	-4601.671	-58.47029	-.467973
metal_powder	-1198.83	-83.57434	-1.37743	-1810.647	-22.96524	-.1421947
nanocrys_metal	-468.0799	-32.01571	.1232201	-1526.756	-19.34706	-.1022167
plasmons_metal	-1492.225	-103.5885	-1.24277	-3863.932	-48.9196	-.2139372
platinum	-556.7706	-38.01566	.2177709	-3756.988	-47.47968	-.1209819
polymer_carbon	-884.916	-61.07823	-.3595038	-715.6597	-9.11795	-.0976446
polymer_layer	-1161.712	-80.338999	-.6392989	-1556.46	-19.67007	-.0501209
polymer_nanotube	-568.0243	-38.76959	.237697	-1071.035	-13.46191	.0399521
polymer_particle	-385.4581	-25.74553	.766114	-720.2769	-8.962569	.1186668
polymer_struct	-1285.079	-89.19427	-1.054837	-3733.086	-47.43378	-.3796411
semi_2-6	-4032.95	-281.944	-5.486262	-14389.67	-183.3333	-1.963325
semi_3-5	-479.0886	-33.04647	-.1721476	-1166.078	-14.70987	-.0105353
shell	-698.5541	-47.87352	.08313	-1132.323	-14.24952	.0247482
silica	-361.4599	-24.36659	.4779583	-1234.211	-15.48465	.0746358
silicon	-808.0851	-55.64626	-.1897961	-1032.451	-12.96278	.0528659
silver	-436.6899	-29.3444	.6778954	-2360.345	-29.73214	.0224221
titania	-2168.096	-150.9954	-2.330411	-1565.484	-19.62296	.1128057
zinc_oxide	-472.6942	-32.13589	.3342719	-1929.521	-24.40677	-.0844839

Table 32: Sharpe results for absolute growth

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

nano_mat	Sharpe_ pub_rel_ Scopus	Sharpe_ pub_rel_ pub_nano	Sharpe_pub rel_sample	Sharpe_pat rel_Patstat	Sharpe_pat rel_pat_ nano	Sharpe_pat_ rel_sample
alumina	.869222	.1876951	-.6252839	.190736	.1424428	-.5680464
carbon_ nanotube	1.472311	.8527068	.1135942	.5013911	.3427036	-.2536129
comp_coating	1.102081	.3337982	-.5826704	.4824438	.0978144	.0499995
comp_metal	.7727245	-.0218546	-.9696913	.393484	.053916	-.0774813
dendrimer	.6799074	.1002529	-.5912046	.0973509	.0957766	-.4904085
fullerene	.5520357	-.2990658	-1.314327	.2226223	.022165	-.3903062
gold	1.49374	.5346308	-.6094698	.4201786	.2517081	-.5633625
graphene	1.578667	1.103377	.5364149	.5593492	.177435	.2993652
graphite	.7809757	-.6485687	-2.353842	.4298097	.0061457	-.108107
iron	1.433587	.5142559	-.5823948	.430078	.1743648	-.2499899
iron_cobalt	.4235496	-.0342045	-.5802498	-.0846077	.0821686	-.8818801
lipid	.5941651	.0051715	-.6974264	.2221887	.0604048	-.2678961
metal_powder	.38716	-.1482266	-.786878	.3113903	.0091446	.1426213
nanocrys_ metal	.5406883	-.1908481	-1.063482	.2789266	.0285113	-.2122567
plasmons_ metal	1.324102	.7206894	.0008913	.4728826	.3529187	-.3880304
platinum	1.127386	.6192683	.0131452	.4729348	.2372212	-.0975363
polymer_carbon	.88726	.321546	-.3532823	.1432259	.2094214	-.6666902
polymer_layer	1.379893	.8404626	-1.417178	.2787347	.2972328	-.3182616
polymer_ nanotube	1.249496	.7612356	.1788006	.3984828	.0782165	.2414619
polymer_ particle	1.488915	.5233349	-.6284851	.4589472	.2231189	-.4257849
polymer_ struct	.9628537	.4681941	-.121875	.2469018	.2174429	-.3743614
semi_2-6	1.224429	.4842001	-.3988035	-.6879548	.5824113	-2.77319
semi_3-5	-.2092271	-2.16377	-4.495303	.3033053	-.0741284	-.2024767
shell	1.580266	.860989	.002979	.4817237	.1123388	.2081133
silica	1.146378	.2710537	-.7731017	.3501917	.1508421	-.419375
silicon	1.395755	.7786649	.0425516	.4588491	.3029534	-.2518883
silver	1.722879	.4519038	-1.064215	.4672776	.081414	.0741769
titania	1.031151	.2912921	-.5912703	.2864538	.3123783	-1.157512
zinc_oxide	1.472345	.983236	.3997882	.3577181	.2749611	-.0950961

Table 33: Sharpe results for relative growth

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Year 1997-2002	Sharpe_pub_abs_Scopus	Sharpe_pub_abs_pub_nano	Sharpe_pub_abs_sample	Sharpe_pat_abs_Patstat	Sharpe_pat_ab_pat_nano	Sharpe_pat_abs_sample
alumina	-982.9592	-59.93654	.2147012	-2231.003	-38.48235	-.121742
carbon_nanotube	-294.823	-16.33584	1.812521	-1011.294	-16.16786	1.242992
comp_coating	-2519.581	-155.9769	-1.946297	-9905.608	-170.6464	-.322326
comp_metal	-1396.573	-85.95062	-.5403831	-9209.164	-159.3264	-.9893662
fullerene	-1718.727	-106.5029	-1.438051	-2343.023	-40.23195	.057964
gold	-578.4532	-34.53659	.9091989	-33836.63	-585.4026	-3.635163
graphene	-11360.78	-709.1389	-14.99645	-2675.056	-46.31549	-.3227402
graphite	-2062.7	-127.181	-1.047684	-9977.613	-172.3621	-.808199
iron	-1632.592	-101.1771	-1.378317	-6980.148	-120.9438	-.9343832
iron_cobalt	-2563.342	-159.8674	-3.238537	-8088.608	-140.0449	-.9758747
lipid	-3828.39	-238.0995	-4.128596	-9905.608	-170.6464	-.322326
metal_powder	-1657.019	-102.7849	-1.499091	-2704.553	-46.5803	-.0760897
nanocrys_metal	-590.2543	-35.72456	.4128527	-6572.486	-113.1974	-.1849099
polymer_layer	-843.1677	-51.53851	-.2790895	-2950.421	-50.77654	-.0440091
polymer_nanotube	-843.1677	-51.53851	.0501228	-2192.955	-37.22057	.4964152
polymer_particle	-600.7865	-36.04979	.7527918	-3240.062	-55.17186	.5513557
polymer_struct	-1624.267	-100.4538	-1.150361	-21401.15	-371.2311	-3.289029
semi_3-5	-622.3806	-38.48044	-.4290315	-2129.565	-37.00923	-.3976303
shell	-2351.805	-144.8896	-1.070052	-15132.4	-262	-1.825694
silica	-512.3489	-30.49485	.9064519	-2730.781	-46.96108	-.0046374
silicon	-1867.413	-115.3123	-1.132019	-15131.4	-261	-.8256944
silver	-855.832	-51.96581	.4202768	-6177.776	-106.9611	-.7453366
titania	-2791.211	-173.5249	-2.936308	-8329.342	-143.4556	-.2343371
zinc_oxide	-869.1891	-53.60438	-.4546203	-4462.301	-77.25958	-.5383679

Table 34: Sharpe results for absolute growth 1997-2002

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Year 1997-2002	Sharpe_pub_rel_Scopus	Sharpe_pub_rel_pub_nano	Sharpe_pub_rel_sample	Sharpe_pat_rel_Patstat	Sharpe_pat_rel_pat_nano	Sharpe_pat_rel_sample
alumina	1.248375	.5512552	-.3640727	.5338757	.063465	-.6462753
carbon_nanotube	3.494322	2.257166	.6327627	1.163925	.2678415	-.1236256
comp_coating	3.240952	.7338537	-2.558002	.8180982	-.0129735	.1864774
comp_metal	1.915757	.4282127	-1.524955	.0652765	-.0405813	-1.843267
fullerene	.8501779	-.1199209	-1.393675	.3934875	-.0644129	-.3857393
gold	2.986778	1.015906	-1.571879	.2601268	.0273939	-1.897269
graphene	1.012591	.1822132	-.9080856	.4467537	-.0089469	.1624918
graphite	1.175802	-.8074996	-3.411603	.5037956	-.1614112	-.7878035
iron	1.296229	.5333745	-.4682643	.2155868	.0358086	-.6771287
iron_cobalt	.4977567	.0731574	-.4843476	.190118	-.0518101	-1.155338
lipid	.9609835	-1.273617	-4.20768	.8180982	-.0942775	.1864774
metal_powder	.7913018	.0627874	-.8937625	.5393074	-.010811	.3287986
nanocrys_metal	1.082227	.0685245	-1.262481	.5681186	-.0386374	-.1456675
polymer_layer	1.856862	1.248873	-2.126509	.4195924	.179066	-.3194705
polymer_nanotube	1.814159	1.260993	.534678	.7322329	.0562379	.5284237
polymer_particle	2.050076	.6759638	-1.128265	.6367573	.0119297	-.6618835
polymer_struct	1.30135	.9162434	.4105928	-1.062079	1.190336	-5.155449
semi_3-5	-.5512272	-4.168392	-8.917782	.208123	-.1453226	-.4072024
shell	6.233927	3.298147	-.5565749	.1086711	.13064	-1.15457
silica	2.451195	.9628591	-.9913477	.2771673	.0409229	-.9891641
silicon	2.70944	1.710242	.3982805	.7085514	.3622649	-1.186311
silver	2.813174	.3145581	-2.966161	.2954011	-.0259142	-.2749962
titania	1.027992	.3516815	-.5363239	.6406407	.0511678	-3.184943
zinc_oxide	1.090498	.699979	.1872214	.2864534	.1651398	-.5260754

Table 35: Sharpe results for relative growth 1997-2002

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Year 2003-2008	Sharpe_pub_ abs_Scopus	Sharpe_pub_abs pub_nano	Sharpe_pub_ abs_sample	Sharpe_pat_ abs_Patstat	Sharpe_pat_ abs_pat_nano	Sharpe_pat_ abs_sample
Alumina	-879.7673	-63.55556	-.4235115	799.0601	16.60252	-.0168712
carbon_ nanotube	-366.0775	-24.40745	2.019922	179.2637	3.373407	-.3625032
comp_coating	-1945.938	-141.5362	-1.970058	1779.381	37.2673	.2648084
comp_metal	-979.2062	-71.13741	-.9004393	1295.449	26.80847	-.1374506
dendrimer	-2922.534	-214.4282	-4.96255	3740.784	77.76329	-.0392454
Fullerene	-1411.18	-103.3226	-2.162995	913.9411	18.57098	-.4466716
Gold	-336.1126	-23.27528	.921944	1634.24	34.3634	.3820298
graphene	-707.3378	-51.01413	-.2490444	1665.519	35.92102	1.308366
Graphite	-1748.307	-127.7019	-2.351905	1184.275	24.70489	.0756285
Iron	-2553.019	-185.0604	-1.904434	3647.808	77.53712	1.704591
Lipid	-1079.224	-78.42377	-1.014194	3103.836	64.61929	.066345
metal_ powder	-1124.295	-82.21465	-1.612205	1875.075	38.72541	-.2786407
nanocrys_metal	-481.5689	-34.56151	.0134526	1920.726	39.02853	-.938719
plasmons_ metal	-2645.708	-192.2005	-2.427548	2270.496	47.74204	.5307648
platinum	-752.6544	-53.91661	.1291022	2038.682	42.83939	.4477138
polymer_carbon	-987.0741	-71.49074	-.6725336	680.9509	13.58137	-.5935527
polymer_layer	-668.4758	-47.77599	-1.062816	928.4119	19.21288	-.098507
polymer_ nanotube	-668.4758	-47.77599	.2336738	1341.323	27.08763	-.8267096
polymer_ particle	-527.7227	-36.82964	1.139767	305.6885	6.415043	.0584767
polymer_struct	-1278.242	-93.0701	-1.399835	1921.951	40.25328	.2860258
semi_3-5	-848.5618	-60.9144	.0082615	681.1639	14.49285	.3327595
shell	-986.3619	-70.5509	.2849224	535.8992	11.313	.1707895
silica	-332.8914	-23.64038	.2794557	914.9124	19.54227	.5246143
silicon	-1009.536	-72.61777	-.1493731	494.306	10.33217	.0525657
silver	-755.1935	-52.76172	1.569715	1236.591	26.15624	.446604
titania	-3159.871	-230.594	-4.021389	777.3125	16.47394	.3137341
zinc_oxide	-1086.457	-76.55415	1.559408	1103.478	23.06532	.1173465

Table 36: Sharpe results for absolute growth 2003-2008

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Year 2003-2008	Sharpe_pub_rel_Scopus	Sharpe_pub_relpub_nano	Sharpe_pub_rel_sample	Sharpe_pat_rel_Patstat	Sharpe_pat_relpat_nano	Sharpe_patrel_sample
alumina	.5954484	.0257747	-.7487736	.034046	.339619	-.3636308
carbon_nanotube	1.062073	.112091	-1.179537	-.2756184	.9506318	-1.353022
comp_coating	1.700528	-.6322175	-3.8039	.2859437	.2066696	.0031649
comp_metal	.5031317	.0342857	-.6031736	-.0819287	.6087689	-.7858172
dendrimer	.458299	.0297411	-.5529412	-.1503504	.2606014	-.4521774
fullerene	.3027658	-.2811593	-1.075084	-.4797974	.6519533	-1.484518
gold	.851335	.3388818	-.3578677	.3447119	.4152339	-.0348781
graphene	4.372486	3.767823	2.945702	.8001586	.4431504	.6643434
graphite	.2978383	-.9132281	-2.559836	.2849264	.0941043	.1115419
iron	3.106635	1.414955	-.8851135	1.09212	.6051717	.5713612
lipid	.7726535	.4517344	.0154015	-.3010465	.7791564	-.8638058
metal_powder	.3827238	.0323174	-.4441074	-.6780052	.778356	-1.570305
nanocrys_metal	.4679242	-.0622919	-.7831923	-1.316814	1.090625	-2.696234
plasmons_metal	1.172359	.7017184	.0618181	.632343	.4920296	.2851068
platinum	1.178176	.5418317	-.3233645	.3069696	.2553869	.0883089
polymer_carbon	.7837685	.2339611	-.5135763	-.793723	.9504495	-1.742186
polymer_layer	.8570564	.3737019	-1.142238	-.1227505	.8118086	-.8364559
polymer_nanotube	.8570564	.3737019	-.2834839	-.9901397	1.682825	-2.469603
polymer_particle	.8949452	.3150531	-.4733885	.2232278	.5361598	-.2883983
polymer_struct	.7004059	.2438639	-.3768666	.3681481	.2257365	.1520066
semi_3-5	.2934254	-1.519762	-3.985035	.4477541	.1750576	.1045033
shell	1.011744	.6048642	.0516565	.4158475	.1569412	.3049568
silica	.4901824	-.0056024	-.6796888	.5013726	.3623287	.0658754
silicon	.8247955	.4944258	.0452434	.3050483	.3406799	.0649923
silver	1.217737	.5544402	-.3474014	.5656708	.5334493	.1065483
titania	1.112601	.5425828	-.2324341	.3595194	.878581	-.368353
zinc_oxide	1.733955	1.229998	.5448009	.144489	.652355	-.2206062

Table 37: Sharpe results for relative growth 2003-2008

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Year 1996 - 2008	Absolute Sharpe ratio (A)			Relative Sharpe ratio (B)		
nano_mat	Quadrant_abs_DB (1)	Quadrant_abs_nanoDB (2)	Quadrant_abs_sample (3)	Quadrant_rel_DB (4)	Quadrant_rel_nanoDB (5)	Quadrant_rel_sample (6)
Alumina	4	4	4	1	1	4
Carbon_nanotube	4	4	1	1	1	3
Comp coating	4	4	4	1	1	2
Comp metal	4	4	2	1	2	4
Dendrimer	4	4	4	1	1	4
Fullerene	4	4	4	1	2	4
Gold	4	4	3	1	1	4
Graphene	4	4	2	1	1	1
Graphite	4	4	4	1	2	4
Iron	4	4	4	1	1	4
Iron cobalt	4	4	4	3	2	4
Lipid	4	4	4	1	1	4
Metal powder	4	4	4	1	2	2
Nanocrys metal	4	4	3	1	2	4
Plasmons metal	4	4	4	1	1	3
Platinum	4	4	3	1	1	3
Polymer carbon	4	4	4	1	1	4
Polymer layer	4	4	4	1	1	4
Polymer nanotube	4	4	1	1	1	1
Polymer particle	4	4	1	1	1	4
Polymer struct	4	4	4	1	1	4
Semi_2-6	4	4	4	3	1	4
Semi_3-5	4	4	4	2	4	4
Shell	4	4	1	1	1	1
Silica	4	4	1	1	1	4
Silicon	4	4	2	1	1	3
Silver	4	4	1	1	1	2
Titania	4	4	2	1	1	4
Zinc_oxide	4	4	3	1	1	3

Table 38: Sharpe ratio results summary

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Legend: The supercolumn A, for example, depicts the results from the absolute growth Sharpe ratios. The number illustrates in which quadrant the material appear as suggested by the framework; and columns differ by which reference is considered.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

	Quadrant from absolute Sharpe ratio with DB ref (A)		Quadrant from absolute Sharpe ratio with nano DB ref (B)		Quadrant from absolute Sharpe ratio with sample ref (C)	
Period	1997 – 2002 (1)	2003 – 2008 (2)	1997 – 2002 (3)	2003 – 2008 (4)	1997 – 2002 (5)	2003 – 2008 (6)
Alumina	4	2	4	2	3	4
Carbon nanotube	4	2	4	2	1	3
Comp coating	4	2	4	2	4	2
Comp metal	4	2	4	2	4	4
Dendrimer	4	2	4	2	4	4
Fullerene	4	2	4	2	2	4
Gold	4	2	4	2	3	1
Graphene	4	2	4	2	4	2
Graphite	4	2	4	2	4	2
Iron	4	2	4	2	4	2
Iron Cobalt	4		4		4	
Lipid	4	2	4	2	4	2
Metal powder	4	2	4	2	4	4
Nanocrys metal	4	2	4	2	3	3
Plasmons metal		2		2		2
Platinum		2		2		1
Polymer carbon		2		2		4
Polymer layer	4	2	4	2	4	3
Polymer nanotube	4	2	4	2	1	3
Polymer particle	4	2	4	2	1	1
Polymer struct	4	2	4	2	4	2
Semi_3-5	4	2	4	2	4	2
Shell	4	2	4	2	4	1
Silica	4	2	4	2	3	1
Silicon	4	2	4	2	4	2
Silver	4	2	4	2	3	1
Titania	4	2	4	2	4	2
Zinc_oxide	4	2	4	2	4	1

Table 39: Quadrant material position by period in terms of absolute growth

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

	Quadrant from relative Sharpe ratio with DB ref (D)		Quadrant from relative Sharpe ratio with nano DB ref (E)		Quadrant from relative Sharpe ratio with sample ref (F)	
Period	1997 – 2002 (5)	2003 – 2008 (6)	1997 – 2002 (7)	2003 – 2008 (8)	1997 – 2002 (3)	2003 – 2008 (4)
Alumina	1	1	1	1	4	4
Carbon nanotube	1	3	1	1	3	4
Comp coating	1	1	3	2	2	2
Comp metal	1	3	3	1	4	4
Dendrimer		3		1		4
Fullerene	1		4	2	4	4
Gold	1	1	1	1	4	4
Graphene	1	1	3	1	2	1
Graphite	1	1	4	2	4	2
Iron	1	1	1	1	4	2
Iron cobalt	1		3		4	
Lipid	1	3	4	1	2	3
Metal powder	1	3	3	1	2	4
Nanocrys metal	1	3	3	2	4	4
Plasmons metal		1		1		1
Platinum		1		1		2
Polymer carbon		3		1		4
Polymer layer	1	3	3	2	4	4
Polymer nanotube	1	3	1	1	1	4
Polymer particle	1	1	1	1	4	4
Polymer struct	3	1	1	1	3	2
Semi_3-5	2	1	4	2	4	2
Shell	1	1	1	1	4	1
Silica	1	1	1	2	4	2
Silicon	1	1	1	1	3	1
Silver	1	1	3	1	4	2
Titania	1	1	1	1	4	4
Zinc_oxide	1	1	1	1	3	3

Table 40: Quadrant material position by period in terms of relative growth

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annex Short Case Study: European Research Infrastructures and their innovation effect as an "institutional" instrument

Abstract

Nowadays returns to the private sector are expected from investments in scientific projects which in the case of single-sited RIs in material science can reach very large dimensions. Two channels of RI-firm interactions are scrutinized: technological transfer (downstream) and procurement activities (upstream). From the available analysis, results suggest that both channels exist but at different scales. First, a citation analysis is used to identify technological transfer, and although linkages remain anecdotic, they show some evidence of the technological use of RI supported research. Second, an analysis of procurement activities from collected EU project survey data (ERID-Watch) show strong RI-firm interaction for the scientific instrument sector, but contingent on firms conducting business both on RI as well as non RI markets for avoiding idiosyncratic risks.

Introduction

In most European countries, the state has been at the forefront of research in young and emerging scientific

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

fields. The economic rationale behind this fact suggests that the public action is, in some cases, the only level at which young science and technology fields can be supported or promoted. But in today's political and economic constraints, economic returns will be expected by stakeholders for any large investments in science.

One type of these large scientific projects consists of the implementation of a research infrastructure (RI). Usually specialised in a given scientific field, those facilities support the scientific community by providing cutting edge tools as well as related services for expanding the frontier of science. However, as mentioned before, the significant size of such investments also means that the stakeholders' opinions need to be taken into account.

Indeed, the public nature of such facility calls for stakeholders to be directly or indirectly involved either as a mean or an objective. Public authorities see in RIs both a mean and an objective. A mean since such a large facility is expected to stimulate the local economic activity and an objective since it represents an ambitious achievement. The scientific community is often at the origin of these types of projects and considers it as a

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

mean to make discoveries. The supply firm sees the project mostly as an objective since their aim is to provide scientific instruments and equipment needed to achieve the facility; but they can also see it as a mean to improve the goods and services offered, thanks to a technologically advanced environment. Last but not least, the user firm sees it as a mean to conduct experiments and a source of new knowledge which can help them in the early stage conception phase of new technologies.

Such large scientific projects will therefore be successful only if most actors in relation with the facility are satisfied: respected budget, time and environmental constraints for public authorities, achieved capacities for the scientific community, contract size and technology transfer for supply firms, and quality of results for using firms.

This third and last chapter aims at shedding light on the effects RIs have on firms by assessing the expected technology transfer and procurement impact related to RIs. The former is defined in this chapter as the "direct effect" expected from the core activity of the RI: the use of knowledge developed at an RI for supporting the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

technology process towards the user firms which are often in need of cutting edge instruments to conduct all sorts of experiments that enter the process of product innovation. This effect benefits the society on the long run by a complex and non-linear path from new knowledge to commercial product. The later is defined as "indirect effect" and is measured from the new knowledge and know-how created from contracts made between RIs and other research organisations for the supply of high-tech customized scientific instruments. This is the procurement market towards supply firms where technologies / prototypes developed in the RI construction / development process might turn out to spillover on the commercial goods or services markets.

In summary, I want to explore two impact channels from RIs to firms and show the related evidence. In order to conduct this study, a sample of European RIs in material science (i.e. light sources: synchrotrons and accelerators) was selected. There are two reasons to focus on these types of facilities. First, their critical importance in providing cutting edge tools for research which in turns delivers at least both certain scientific and uncertain technological direct effects in several

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

sectors of the economy; and second, the large size of procurement contracts from RIs in the field that benefits innovative firms.

Literature background

The number of existing studies on the economic effects of RIs are limited, and in particular in academic literature. Therefore, the goal of this review is to highlight economic studies of interest for RIs but which often focus on other research organisations such as universities or PROs. Concerning the effects to measure, the economic literature gives directions on how to evaluate both direct and indirect economic effects of an entity; I focus on a branch of literature called the economics of science and innovation which studies these effects for S&T organisations.

The direct effects are broadly defined here as the extent to which a research organisation contributes to expanding the frontier of science and technology. Important methods to measure them will be described in what follows.

A "classic" method consists of focusing on indicators. A natural one is scientific publications count which aims

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

at measuring the performance of a research facility in a systematic way. Ultimately, it is a tool used to compare different research facilities and support policy makers with funding decisions they have to make. Coccia (2008) developed a "scientometric" model which aims at assessing the scientific performances of public institutes (including research facilities) through a "research score" indicator which in turn could separate high and low productive institutes. Another type of model is proposed by Arora & Gambardella (1997), which aims at identifying the possible determinants of publication performance from publicly funded research institutes. Intellectual propriety indicators have also been used extensively and in particular, a patent count, both for its commercial nature and the amount of information available. For example, an interesting study looked at the relation between the patent production in US federal laboratories and the average price per patent compared to the one of universities (Jaffe, Fogarty, & Banks, 1998). In other words, to what price federal labs would license their R&D. Close to this topic, Jaffe & Lerner (2001) found that US federal laboratories patent per dollar picked up the delay from 1980 to 1993 with university

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

patent prices until reaching similar levels. However, they also found evidence that federal laboratories tend to patent less than universities therefore leading to evidence that patent count is traditionally not part of the first objectives of these facilities.

Other methods have been used to capture correlations between research organisations and firms such as the effect of university R&D on firm corporate patents. Jaffe (1989) used monetary measures of industrial and university R&D spending as determinants of innovative output and found that university R&D expenditure has a positive effect on private patenting. Acs, Audretsch & Feldman (1992) found the same results by using the announcement of product innovations as dependant variable. Another example is given by Guellec & Pottelsbergue (2004) and Audretsch & Lehmann (2006): using productivity growth as dependant variables, the first study finds that there is a positive effect from public R&D expenditure to industrial patents. But this result has to be taken with care since a second study, based on a German dataset, does not find any correlation at all. The problem with these types of studies seem to be that the models do not

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

give a definite proof of knowledge flowing from public to private, only correlations.

Common ways of solving this causality link issue is to use the citations from traceable knowledge documents such as patents or publications. In Jaffe, Trajtenberg & Henderson (1993), a solution to link public and private knowledge flows through the patent citations of firms towards public research institutions was proposed: by investigating the nature of affiliations from patent citations, one can investigate the effects of public knowledge on private industries. Indeed, the study shows that patents granted to U.S. universities received more citations than patents granted to corporations, therefore confirming the importance of public knowledge for industries. Extending this study, Narin, Hamilton & Olivastro (1997) found that 73% of the papers cited by U.S. industry patents were produced by PROs, especially in certain scientific fields such as biotechnology (McMillan, Narin, & Deeds, 2000) or chemistry, genomics and biochemistry (Malo, 2006). Finally, Malo and Geuna (2000), using the same methodology but with data from the European Patent Office found that 81% of private patent cite public

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

institutions.

Topics closer to RIs have also been explored. One is the flow of knowledge from federal labs and universities to other actors of the economy (Jaffe & Trajtenberg, 1996), where evidence has been found that federal lab patents are less cited than university or corporate ones although they do have more persistence over time. For the flow from federal labs to firms a study by Jaffe, Fogarty, Banks (1998) also finds that spillover in the form of patent citation exists from firms close to a NASA R&D department.

Otherwise, a more qualitative method such as surveys can be applied. Evidence from the PACE survey analysed by Arundel, Van de Paal & Soete (1995) showed that in addition to specialised knowledge (56%) and general knowledge from basic research (32%), important outputs from a research organisation used by the industries can also be instrumentation (35%) and prototypes (19%). Another important empirical study of the same type is achieved by Mansfield (1998), who suggests that 10% of commercialised products could not have been possible without academic research – assuming a 15 year period for the process from the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

knowledge to the product-. Focusing on PROs and universities, a review from Salter and Martin (2001) conducted a survey and enumerated the possible outputs stemming from PROs: an increase in the available pool of knowledge to firms; new instrumentation and techniques developed for PROs; and a supply of highly skilled researchers to the labour market.

Concerning RIs, a simple look at publications done in collaboration with them shows that these facilities are also well represented in the top scientific journals, especially in cutting edge scientific fields. For example, according to the American Physics Society[69] , 70% of publications in neutron scattering between 2000 and 2006 stemmed from research at a large research facility (ILL[70], ISIS[71], LLB[72] or NCNR[73]). Therefore, the evolution of the role of a research facility and its relation

[69] Access to major international X-RAY and Neutron Scattering Facilities, APS, 2009

[70] Institut Laue-Langevin. Neutron Facility, FR

[71] ISIS, Neutron and Muons, UK

[72] Laboratoire Leon Brillouin, FR

[73] NIST Centre for Neutron Research, US

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

with the innovation system and especially with universities has to be taken into account when looking at the EU case.

Turning into the nature of knowledge spillovers, one may ask about the additional diffusion vehicles of information taking place which are not scientific publications or IPR. One example is skill labour mobility. Zucker, Darby & Armstrong (1998) found that scientists working at a university but affiliated to firms was at the origin of the high performance of US pharmaceutical firms. Also, Zellner (2003) found that the mobility of scientists from Research Agencies (Max Planck in Germany) to industry R&D activities is beneficial thanks to the transfer of scarce skills. Indeed, since researchers need to be physically present in the facility to conduct their research with local expert researchers, the value of acquiring the essential know-how to conduct experiments is essential and of great value.

The indirect effects are defined in this chapter as additional economic activity in the high-tech sector induced from the construction and operation of a research organisation. At the moment, this topic attracts

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

little attention from academia but is of great interest for RIs. For research organisations, this concerns the supply of products such as new instrumentation and scientific equipments which are usually unique and on the edge of the scientific equipment and instrumentation capabilities.

In the case of RIs, these supply high-tech firms provide the necessary parts for building or improving RIs and therefore generate important industrial activity in the domain of instrumentation and equipments. Interestingly, this type of indirect effect from firm to research organisation has been more studied in the grey literature. Indeed, three CERN studies (Schmied, 1975; Bianchi-Streit, et al., 1984; Autio, Bianchi-Streit, & Hameri, 2003) have been exploring this relation. The first two studies aimed at quantifying the total added value of this relationship using an economic quantification model. The assessment, based on information collected through interviews with CERN staff and with managers of supplier companies estimate for the period of 1973-87 an economic utility of 4194 M€

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

for sales amounting to 1010 M€[74] . The last study, more microeconomic, conducted a statistical analysis of specific innovation benefits and found significant spillovers from technological learning.

Direct effect from RIs: science & technology transfer

The effect of knowledge and know-how from RIs to high-tech firms exists, but the transition mechanism appears far from straightforward. In theory, there should be three types of technology transfer: RI S&T transfer towards collaborative, user and new firms. In all of these cases, an exchange of knowledge and know-how takes place for developing or improving a given technology. This part aims at finding evidence of this, and therefore trying to measure to what extent S&T transfers can be observed. However, for collaborative interactions, little information is revealed due to the proprietary nature of the research and for new firms, figures show that they remain anecdotic. Therefore the only technology transfer channel that will be explored

[74] Figures account for inflation, and conversion from swiss francs to euros based on Jan 3 2011 rate (1€=0.822 CHF).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

in this part concerns user firms.

In order to trace the channel of knowledge from a research facility to a user firm, an explanatory exercise is performed to identify the link between research developed either by the RI or the RI together with another actor, and technologies developed by firms using that research. This method consists in using the scientific articles cited by patents as proxy for technology transfer. To illustrate this channel of technology transfer, three RIs (synchrotrons) in material science are selected: Elettra Sincrotrone (Trieste), Desy (Hamburg) and Soleil (Paris). For the scientific articles, three years have been retained from the Scopus database[75] : 2007, 2008 and 2009. The collected dataset contains 1933 scientific articles among which only 13 are cited in patents from the European Patent Office. This result is symptomatic of the link that exists between science and technology: signals of technological transfer are not only to be weak but also underestimated[76] .

[75] http://www.scopus.com/home.url

[76] A common reason for the sparse recorded data is the lack of scientists citing the research infrastructures in addition to their own institutions.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Faced by a statistical significance problem, one can still look at each patent-publication pair closely, in order to understand the possible paths and stories behind the technological transfer from RIs to other actors, and the importance of firms among them. The dataset contains 15 different citations from 15 patents to 13 articles developed by or in collaboration with one of the three RIs contained in the data. What would be interesting to find out is the relation that exists between the selected patents and related articles. This can be done by looking at specific elements for each article-patent pair.

Author Correspondence

Is there a mapping between scientists that participated to patents (inventions) and scientific articles (discoveries)? From the nature of an RI, one would think not since its work consists of supporting the scientific community and not to actively participate to the technology transfer process. Indeed, from the sample, RI article authors are found to be hardly represented as patent inventors (2 out of 15) stemming from their research, compared to the other non-RI article authors (7 out of 15). This evidence suggests that

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

RI scientists are mostly involved in basic research, an observation in line with the RI objective.

Applicant nature

The nature of the users of knowledge developed in collaboration with RIs is very diverse and one can see that from the patents' applicants. By order of importance, the most represented applicants are individual scientists (9 out of 15) followed by universities (6 out of 15), PROs (5 out of 15) and Firms (4 out of 15). The users' firms, which were expected to be the most important category, actually comes last. This suggests a more complex description of technology transfer than traditional linear theories since technology development appears to be developed in number by public institutions. One interesting point is that although universities integrate the development of new commercial technologies as one main objective of their research organisation –e.g. entrepreneurial promotion (Bozeman, 2000)-, RIs do not follow the same logic. Therefore, PROs and universities unlike RIs might develop, in quantity, a large amount of new knowledge and know how resulting in high patent count.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Concerning firms, it appears that their participation to the science and technology process is limited.

Field Correspondence

The relation between article and patent fields in the sample is straightforward: the scientific fields as defined by the journals in the Scopus database are well mapped with the EPO or USPTO broad technology categories. This defines a deep specialisation and consistence between scientific and technological outcome. By order of importance they involve chemistry to chemistry; material science, biochemistry and physics to physics and biochemistry; optics to optics; and medicine to medicine.

Country correspondence

Looking at the correspondence between the authors' country location(s) and the patent's applicant location(s), it can be seen how science and technology communities overlap. The sample mostly shows partial mapping (7 out of 15) or none (6 out of 15), the overlap being rare (2 out of 15). This result confirms the evidence gathered from the literature of the internationalisation of the use of research but also an

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

important point related to our case: it is rare to observe suppliers of S&T being close to the users of S&T.

To summarize, RIs contribute towards knowledge which directly supports new technologies and are part of teams which create useful knowledge for a given field but have a limited involvement in the technology process. Indeed, the users are mostly PROs and universities and in a few cases firms. Also, the concerned knowledge is mostly used outside of the region where it has been developed, hence not giving evidence of a local economic development use. These elements tell us that looking at economic effects through technology transfer does not give significant evidence of the firm activity related to RI research.

However, one could also look at technologies developed by RIs via their patents as applicants. This might give some evidence of the use of their in-house technology development. Indeed, within the sample period and looking at the same RIs, 10 patents are found to be registered in the EPO office, which is roughly about the same number as the number of cited RI articles above. From those 10 patents only 1 was cited by other patents; 7 were developed in-house; 1 RI – firm

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

collaboration; 2 RI – University collaboration and 1 RI – PRO collaboration. Overall, this anecdotal evidence means that patents developed within RIs tend to have a specific use directed at improving the knowledge or know-how related to their own scientific instruments, but not necessarily of use for firms. Again, this is in line with the overall objective of the RI to focus on the support of the scientific community with cutting edge instruments and not to develop business products and services.

Let us now explore another possible channel of local economic development related to the RIs: the indirect economic effect through supply firms.

Indirect effect from RIs: the procurement market

New or improved technologies can take place at different stages of the RI development. During the construction and operation phase, numerous parts of the facility are supplied. Some of them are customised parts from supply firms to fit the facility's needs; others are almost prototypes and are so "risky" to develop that they are generally supplied by other PROs or universities which put their "industrial cap" on for the

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

occasion[77] .

However, the interest lies here in the supply firms involved. One has to bear in mind that the challenge from such large investments in scientific equipments is to reach the needed contractual mass for firms to get involved. If a sufficient level was not reached or the customization too costly, it would turn out to be too risky for firms and especially SMEs to invest in what can be called a "one shot" procurement market.

In order to observe firms' involvement in the RI procurement market, a dataset is built from survey data collected by the ERID-Watch European project[78] . In short, this project aimed, among other themes, at measuring the size of the procurement market related to RIs. The data used comes from interviews made by 128 major instrument supply firms from several European countries in 2006. Although not exhaustive, the dataset can give us a good indication of firm involvement in the RI market. The analysis was refined to focus on material

[77] For example, the building of the RI Fermi@Elettra in Trieste had most of the scientific equipments supplied as in-kind contribution from public research organisations and universities.

[78]Courtesy of the project's coordinator from CEA-Saclay Ch. Porcheray

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

science facilities: synchrotrons including accelerators.

From the data obtained, a large number of firms supplying cutting edge goods and services can be observed, in particular during the construction phase. It is good to mention that many key products and services required during the construction phase concern procurement contract for "one shot" highly advanced scientific equipment. In the context of a new and unique RI, this often means that a firm has to modify and customize the product or services offered.

But a new RI is a peculiar client. Due to the novelty of its design, engineering and industrial work, it can itself be seen as a prototype. As such, it may endure some unexpected problems such as the one experienced by the famous Large Hadron Collider (LHC) at CERN[79] . It is this "hidden risk" which can be a hurdle for a firm's involvement. Indeed, firms usually need to base their investment decisions on how foreseeable and sustainable a market is.

However, this so-called technical procurement

[79] http://www.wired.com/wiredscience/2009/07/lhc-suffers-more-leaks-and-delays/

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

market[80] , although risky, is expected to bring additional benefits than just monetary ones to firms since they have to consider a new application for their products or services. Indeed, new knowledge or know-how may be generated from the collaborative experience which may in turn improve the firm's performance in the RI procurement or commercial markets. For instance, ERID-Watch reported that 63% of firms declared that other market segments had benefited from technologies first developed for RIs (ERID-Watch, 2008).

Overall, this technical procurement market for high tech firms represents a yearly expenditure estimated between 925 and 1175 M€ per year. This represents the yearly market size and an aggregated figure for all material science RIs in Europe. However, the cyclical nature of this market is a hurdle for firms to anticipate future demand, where, instead of relying on marketing, they have to rely on information concerning procurement calls. This uncertainty from future

[80] Semiconductor equipments, Optics, Vacuum, Electronics , Optics (X ray photography), Vacuum Mechanical engineering , Fuel Processing / Manufacturing, Mechanical Engineering, Electronic Engineering, Neutron guides

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

activities suggests that it is necessary for supply firms to diversify the targeted markets. For instance, they would reduce uncertainty by being present on "safer" commercial markets. Actually, evidence of this diversification can be illustrated by the part of business from supply firms relying on the RI market versus non RI market.

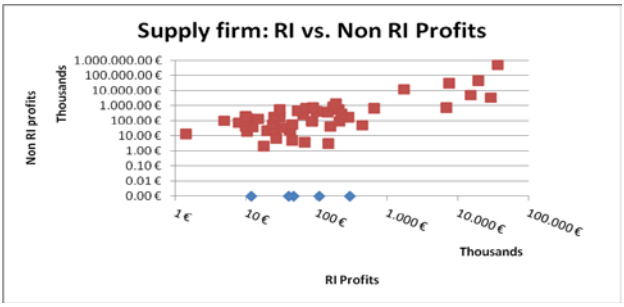


Figure 18: RI vs non-RI markets[81]

The above log-log plot (base 10) clearly shows a positive relation between profits from RI and non RI markets as well as a great diversity of size in the firm sample. The interesting observation is that almost all firms diversify their markets, only some firms (in blue) are the exception and constitute a small amount of firms which entirely specialise on the RI market. Overall, this

[81]Source: ERID-Watch (2008)

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

evidence confirms the risky nature of the technical procurement market but also that firms enter this market by balancing the potential risk by diversification, and do generate substantive profits with RIs.

Looking more closely at the data, a difference may be noticed when considering the sector of activity of these companies. The following graph shows the position of supply firms by sector (Nace rev. 2)

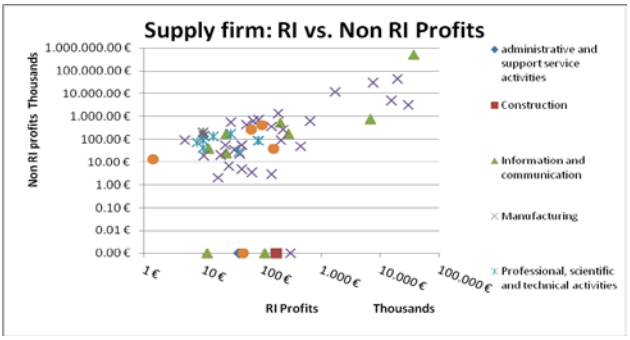


Figure 19: Supply firms RI versus non-RI profits by NACE rev 2 sector[82]

The main element to retain from this graphic is that although firms in ICT and manufacturing activities are found at all levels of RI and non RI profits, ICT and support services tend to be present at smaller level of

82 *Source: ERID-Watch (2008) and AMADEUS (Bureau Van Dijk, 2011)*

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

contracts, mostly due to the fact that they provide supply service activities.

From the above evidence, one can see that firms get involved in the technical procurement market and therefore that RIs have a positive effect on supply firms. Two reasons can be put forward: on the one hand, there is the "one shot" nature of the majority of the RI procurement market which can be balanced with other markets and on the other hand, high tech supply firms tend to benefit both financially and by an increased knowledge / know how of their product or service application.

A short comment on local development

A legitimate question from policy makers is whether the implementation of RIs attracts experienced supply firms in the local area in order to perform, if not the production, the adaptation of their products to the new RI design. Evidence can be given by computing the average distance from the sample of supplier's headquarters to RIs in the field of material science. Results obtained are summarized in the graph below.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

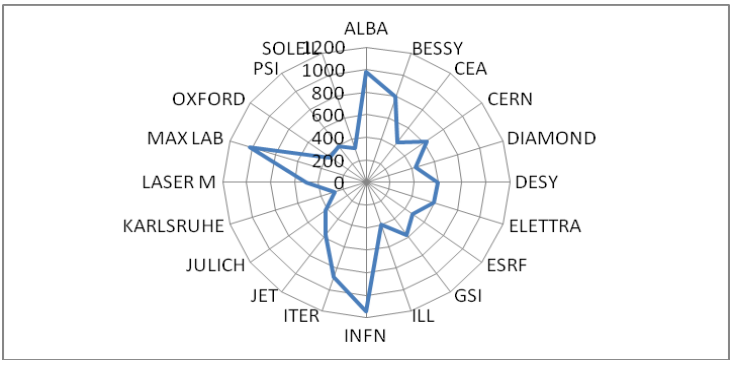


Figure 20: Average distance of RI suppliers

As one can notice, the average distance is roughly between 250 and 1200 kilometres away from the facilities in the sample. This suggests that specialised high-tech supply firms are not particularly close to RIs, but develop their product and services and ship them to the demanding facility. Therefore, local economic development generated by a new facility can rarely – there are exceptions for historical innovative regions- rely on the activity from specialised supply firms.

Conclusion

One part of the economic literature strongly mentions the role of the state in enabling new or young industries to appear. The "key role of government (...) not being (...) about fixing market failures but rather about actively creating the market for the new technologies by

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

envisioning the opportunity space and allowing the right network of private and public actors to meet in order for radical innovation to occur" (Mazzucato, 2011). This can be observed in some key regional success stories such as the biotechnology industry in California (Vallas, Kleinman, & Biscotti, 2010) (Dalpe, 2003).

However, most "mainstream" public policies put in place to create a dynamic environment usually involves fiscal incentive and financial support towards firms such as subsidies, tax cuts (Hall, 2002) or other kinds of financial / fiscal tools. In some cases though, the state support towards a given scientific field has to be in-kind, for instance when a large RI is needed to make radical progress in a given field: "Money is not the only fertilizer; sometimes in-kind assistance, such as use of specialized equipment in government laboratories, is critical" (Block, 2008). Therefore, in some cases a government deciding to support the implementation of a RI becomes the first "innovation user", stimulating technology transfers and creating at least a new "public procurement market" for technology (Dalpe & DeBresson, 1989).

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

From there, it is always a challenge to measure the effects of a given actor's activity on firms, and even more so when its core activity is to produce or support knowledge creation. This is indeed the case for RIs whose main objective is to support scientific progress by providing highly complex instruments to the scientific community.

Therefore, to get a better picture of the overall economic effects from this type of facility, not only direct but also indirect effects have been explored. Indeed, the analysis has shown that the indirect effects are much more visible than the direct ones. However, one has to bear in mind that the demand created from an RI procurement market is derived from the government action and relies on an informed guess that funding a project in a given scientific field would eventually induce useful new technologies as well as spillovers onto the economy.

From this chapter's analysis, I have found evidence of the use of knowledge developed in collaboration with RIs for producing patents but this channel of technology transfer remains limited. The interesting fact being that not firms but mostly PROs and universities are the most

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

important users. Concerning the indirect effect, high tech firms of all sizes are involved, roughly split between small service-oriented firms and larger industrial firms. A strong finding is that firms diversify their markets between RI and non-RI market. The interpretation of this chapter is that this pattern originates from the "one shot" nature of the RI market where contracts will mostly take place during the early phase of the RI development, therefore inducing a large variability of supplies. To balance this risk, firms deeply involve themselves in other, more commercial markets.

To conclude, this chapter aimed at shedding some light on the under-studied topic of RIs in general and their relation to firms in particular. It has been shown that in order to see the whole effects, one had to consider different channels, upstream and downstream, through which RIs enhance the economic activity. And although the available data still happens to be a significant hurdle for analysing RIs economic effects, simple methods in which the available material can be used have demonstrated the existing link between RIs and firms through two channels: technology transfer and procurement market.

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.

Annex: EPO-Scopus correspondence

Patent No	Article No	Author Corr.	Field Corr.	Geo. Corr.	Applicant nat.
1	1	All	Yes	Yes	University / PRO / Individual
2	2	None	Yes	No	University / PRO / Individual
3	3	None	Yes	No	University / Individual
4	4	None	Yes	Partly	PRO / Individual
5	5	Partly (1/4)	Yes	Partly	PRO / Individual
6	6	None	Yes	No	Individual
7	7	None	Yes	Partly	Firm / Individual
8	7	None	Yes	Partly	Firm / Individual
9	8	Partly (1/7)	Yes	Partly	University / Individual
10	9	None	Yes	No	Firm
11	10	Partly (3/7)	Yes	Partly	University
12	11	None	Yes	No	Firm
13	12	Partly (1/4)	Yes	No	Firm
14	12	Partly (1/4)	Yes	Partly	Firm
15	13	Partly (1/10)	Yes	Yes	PRO / University / Individual

Tesi di dottorato "The Role and Importance of Instruments in the Scientific Process, and their Implication for the Emergence of New Technologies" di PERO MICKAEL
discussa presso Università Commerciale Luigi Bocconi-Milano nell'anno 2013
La tesi è tutelata dalla normativa sul diritto d'autore(Legge 22 aprile 1941, n.633 e successive integrazioni e modifiche).
Sono comunque fatti salvi i diritti dell'università Commerciale Luigi Bocconi di riproduzione per scopi di ricerca e didattici, con citazione della fonte.