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Unraveling the R&D-Innovation-Productivity relationship - a study of an academic endavour

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Unraveling the R&D-Innovation-Productivity relationship - a study of an academic endavour

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Abstract: This paper accounts for the development of the academic endavour to determine the firm-level relationship between investments in R&D and productivity. The impact of 28 highly cited publications within this line of study is investigated using a combination of bibliometric techniques and citation function analysis. We show how the attention paid to this line of research broadens and deepens in parallel to the diffusion of innovation as a research theme during 2000s. Our findings also suggest that the attraction of scholarly attention is driven by combination of broadening interest in the central research question under study and boundary-pushing methodological contributions made in the key contributions.

Keywords: innovation; productivity; R&D; citation analysis; bibliometric analysis

JEL codes: B23; B41; B21; C38; D24

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1. Introduction

Following a surge of interest in innovation and its consequences, academic researchers came to pay significant attention to the question of to what extent and under what conditions firms' investments in research and development (R&D) activities increase their productivity by means of successful innovation. Reviews of this literature are found in Griliches (1979), Hall (2011), Mohnen and Hall (2013). The present paper complements these traditional reviews by providing a bibliometric description of the how the literature addressing this particular theme has evolved in terms of contribution, recognition and impact.

Our analysis paints a portrait of how research on the R&D-innovation-productivity relationship (henceforth: RIP research) has evolved in a context of growing academic interest in each of these three themes, and an explosion of interest in innovation in particular. We document how RIP impact is concentrated to the discipline of Economics but also how, over time, impact disseminates across scientific fields and extends to new communities. In particular, we detect a shift in the years around the turn of the century where RIP research received wider attention, riding on the wave of increased interest in the theme of innovation across the social sciences.

The present study contributes to the growing literature which attempts to write the history of specific academic developments utilizing bibliometric tools. Deploying cross-citation analysis techniques, such studies of the social sciences have primarily sought to document and describe the development of interdisciplinary themes and emerging fields of studies such as evolutionary economics (Dachs et al., 2001; Meyer, 2001), innovation (Martin, 2012; Shafique, 2013) and entrepreneurship (Cornelius et al., 2006). Ferreira et al. (2014) apply similar techniques to a more narrowly defined object of study, as they describe the impact of transaction cost theory on international business research. As far as we are aware, however, this study is the first to apply bibliometric analysis to study the treatment of a particular research problem in academic literature. Our methodological approach is also novel in that we demonstrate how a research approach where bibliometric analysis is combined with direct confrontation with key academic texts allows us to provide a broader view of the impact and diffusion of research than a traditional literature review, but also allows a more in-depth discussion than a traditional, strictly quantitative, bibliometric analysis.

This paper proceeds as follows: Section two defines the research domain which is the subject of study. In section three, the bibliometric methodology of the paper is accounted for. Section four outlines the wider development of economic literatures related to the RIP domain. Sections five, six and seven proceed to delineate the impact of RIP research, through the identification of core publications within the domain and of citations to these publications. Section eight concludes.

2. RIP: the pursuit of a research question

The identification of prioritized research questions is a central aspect of scientific activity. In Kuhn's (1970) account of the history of science, each 'paradigm' is associated with shared norms and ideas which suggest a set of puzzles for scientists to solve and a set of tools by which to solve these puzzles. Trying to improve the precision of solutions to these puzzles through advances in methodology and theoretical refinement – activities which Kuhn refers to as "normal science" – is what engages most scientists throughout their careers.

The object of this study – the RIP domain of scientific study on the research-innovation-productivity relationship – can be defined through the following central research question: What are the elasticities of firm-level productivity to the firms' R&D investment, channelled through innovation? The demarcation of the domain as encompassing these three research teams is inspired by the seminal CDM paper (Crepon et al., 1998), which established the methodological imperative to study the three RIP themes in conjunction in order to obtain unbiased estimates of the elasticities. Studies on a wider set of capabilities of innovation which do not directly address R&D investments are not considered to lie in this domain. Studies on marketing or organisational innovation are furthermore not included, unless they also study technological product or process innovation. While productivity can be measured in levels or in terms of change over time, studies which solely address other dimensions of firm performance such as market value are furthermore not considered to belong to the RIP domain.

The RIP research domain is embedded in the tradition of neo-classical production economics and in the field of the (neo-classical) economics of innovation. In the terminology of Lakatos (1970), both of these areas of study can be classified as theories in the "protective belt" surrounding the hard core of the scientific research program of neoclassical economics (or, as suggested by Heijdra and Lowenberg (1986), as sub-disciplinary demi-cores). As such, there appears to be widespread acceptance of the general relevance of RIP research among economists. Martin (2012), for example, writes about the problem of understanding the returns to R&D as "a central building block" for studies on innovation. The publication of RIP contributions such as Mansfield (1980) and Griliches (1994) in the leading journal American Economic Review also signals that the problem has been considered broadly relevant. It is also noteworthy that even in leading early contributions to the literature by authors such as Mansfield, Griliches, Hall and Mairesse (see references in Appendix), motivations for the relevance of the RIP research problem(s) are – where at all touched upon – limited to a general acknowledgement of significant scholarly interest in the issue. This is indicative of RIP research as being strongly embedded in the research program which has held a dominating position within the economic sciences for several decades.

As an integral part of a successful research program and a line of research with a history spanning several decades, the RIP domain constitutes an interesting example of scientific activity in the social sciences. The research problem of determining elasticities is also somewhat unusual in character for the social sciences, in that it concerns a problem of assessing a magnitude. Even in the field of Economics, theories and their empirical evaluations are typically more concerned with the direction of causal influence than with the level of impact (Wade, 2007). The interest in establishing magnitudes have seemingly spurred scholars to continuously re-visit the central research questions of the RIP domain equipped with new empirical data and updated estimation methodology. In what follows, we will apply bibliometric methods to analyse the imprint of RIP research on the scientific literature.

3. Bibliometric methodology

We utilise bibliometric techniques to study the context within which RIP research has evolved and the impact of RIP research on the wider scientific literature. The domain as such is for this

purpose represented by a set of "core" papers, which are identified as the most frequently cited contributions in the domain. Citations to these papers were used to track the impact of RIP research on the wider scientific literature.

The Web of Science (WoS) database was chosen as the main material for analysis, as it has good global coverage of scientific publications, relatively strict quality threshold criteria for inclusion of scientific journals and a widely recognised categorisation of scientific fields. The searches in Web of Science were restricted to 1990 to 2012. When using key-word searches, the starting year 1992 was selected since abstracts were introduced in the database this year.[3]

The citation rates where field normalised, i.e. the mean number of citations to a paper were divided by mean number of citations for all papers in the same field in the same year. Here we used the 251 subject fields of Web of Science for normalization. This means that a mean field normalized citation rate of all papers in a field is 1 and e.g. a citation rate of 1.50 means a citation rate 50 % higher than world average.

Collaboration network layouts are created using the Pajek software (http://pajek.imfm.si/) and the Kamada-Kawai separate-components algorithm. Terms are extracted and mapped using the VOSviewer software (http://www.vosviewer.com).

4. A wave of innovation research

Our analysis of RIP research starts in a bibliometric analysis of how the interest in the three core themes of R&D, innovation and productivity has shifted over time. Figure 1 demonstrates the growth of innovation and R&D as research themes in bibliometric terms. Panel B shows how, between 1990 and 2012, the number of papers addressing innovation or R&D has increased 15-fold. While this development certainly is impressive by any measure used, it has to be related to the general volume growth of research output during this period. As worldwide spending on academic research has increased, publishing patterns have changed towards increased emphasis on publishing in international rather than national journals and in papers rather than monographs, the number of journals and papers have risen throughout the social sciences. Parallel to this development, the number of journals indexed in the Web of Science database in general and the number of papers in the field of Social Sciences and in Business and Economics has increased substantially (see panel A). This growth, however, is dwarfed by that of scientific attention to innovation and R&D, which grew eight times as much as the Business & Economics field in total. The proportion of papers addressing innovation or R&D in Web of Science has increased, from less than 2 % of B&E in 1990 to almost 13 % in 2012 (Figure 1, panel C).

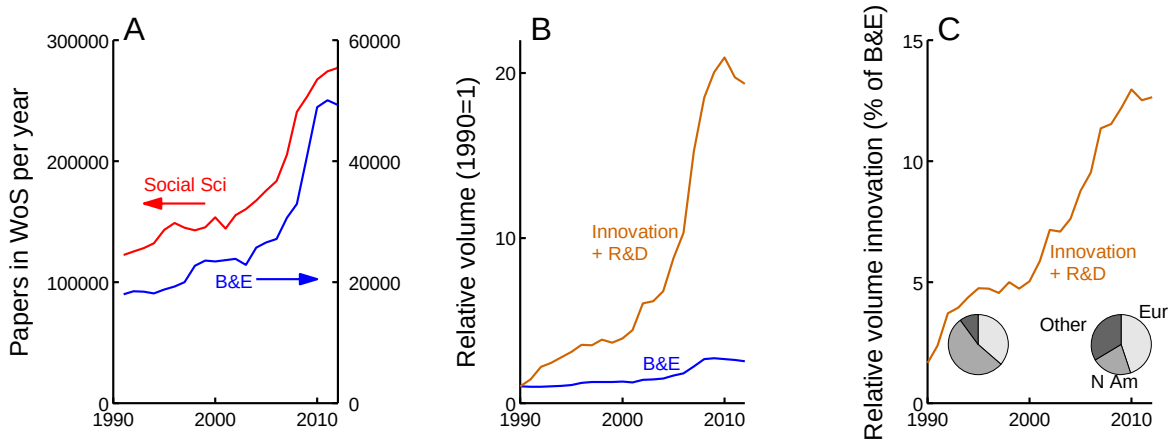
In parallel with this increase there has been a global shift in where the papers are produced.[4] In the 1990's USA and Canada produced more than half (53 %) of all papers in this field, followed

[3] In 1992, 64 % of all papers in the field "Business and Economics" in Web of Science had an abstract, this value increased successively to about 96 % in 2012. Before 1992, keyword searches resulted in very few found records.

[4] Changes in global paper production is expressed as the proportion of fractionalized papers coming from Europe, North America (US or Canada) or other parts of the world. The

by Europe (with 36 %) while the rest of the world contributed 11 % of the papers. Currently (2010-2012), one third of the papers are produced in countries outside North America and Europe. This relative increase comes at the expense of North American dominance (22 %) while the European proportion increased slightly (to 45 %).

Figure 1. The general development of Social Sciences, the Business and Economics field and innovation- R&D-literature in Web of Science since 1990. The inserted pie charts show the geographic distribution of the papers among Europe (light grey), North America (medium grey) and other parts of the world (dark grey) in the two periods 1992-1999 and 2010-2012.



In Figure 2, the development of the three main key-words of the R&D-innovation-productivity research theme is shown for each term separately.[5] While all three keywords show a growing trend over the studied period, suggesting an increasing attention paid to all three concepts by scholars in the Business & Economics field, there are marked differences in terms of growth. In 1990, about 2% of all papers in the B&E field addressed issues of innovation and of productivity, respectively. By 2012, the interest in productivity has steadily grown so that over 3% of all B&E papers list this term as a keyword. The term innovation, however, was by then provided as keyword on about 8% of all B&E papers. All three key-words show the same shift in the geography of the paper production from USA to other parts of the world, Europe maintaining a fairly constant fraction over time.

Figure 2. Frequencies of three main keywords.

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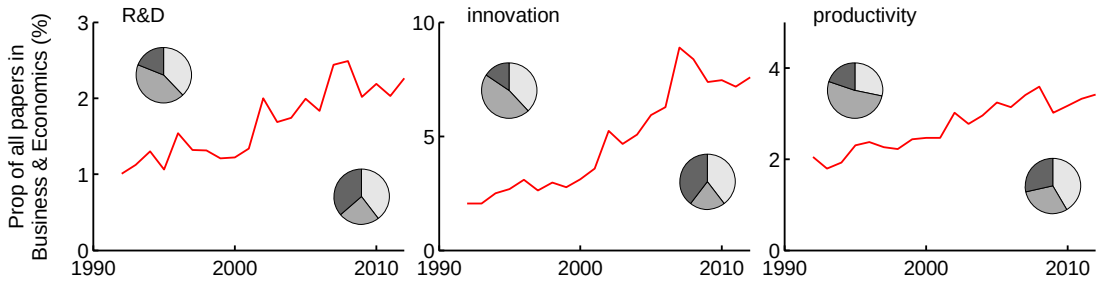
fractionalization means that when there are authors from several countries on a paper, each region is credited a fraction of each paper in proportion to the number of addresses to each region.

[5] Notably, only a small fraction of the WoS papers identified above refer to all of the three keywords. For the publication year 2012, 130 such articles can be identified within the B&E domain, with an additional 100 articles in the wider WoS database.



Behind these growth patterns, a difference in how broadly the respective themes have been picked up across disciplines in the B&E field can be surmised. The study of productivity remains strongly concentrated to the sphere of Economics. The interest for innovation, on the other hand, has penetrated the entire business studies community, surfacing in studies of economic geography, business history, industrial dynamics and several other sub-disciplines. As a widely recognised research theme, the study of innovation has developed along tracks where the connection to the other two concepts is less often in focus. Prominent examples are the focus on analysis of the systemic nature of innovation (Freeman, 1987) and the strand of literature which explores antecedents of innovation other than that of formal R&D (Pavitt, 1998). Notably, both of these strands of literature were partly motivated by perceived needs to challenge and extend the "linear" model of innovation (Godin, 2006), which underpins studies on the R&D-innovation-productivity relationship. Nonetheless, the growth of general interest in innovation as a research theme has certainly had an impact on scholars' interest in conducting research in the RIP domain and paved the way for increased impact of the domain across the social sciences. In what follows, we analyse the volume and nature of this impact.

4. A bibliometric representation of the RIP domain

The bibliometric analysis of the RIP domain is based on the identification of a set of key papers within the domain. For this purpose, the Web of Science data source was judged to be too restrictive in terms of content, as several papers widely acknowledged as key contributions in RIP research have been published as working papers or in journals hitherto not included in Web of Science. Therefore the databases SCOPUS and Google scholar were used to identify key RIP papers. SCOPUS has the advantage of including a larger journal set than Web of Science, while also including many books and conference papers. Google scholar is by far the broadest of the three sources considered here, listing individual chapters in books and working papers. Searches on well-known RIP contributions also suggested to us that Google scholar complemented SCOPUS limitations on records from before 1996 (c.f. Jasco, 2005).

In view of these database characteristics, two complementary search methods were use. First, we searched SCOPUS for all papers with more than 100 listed citations by February 2015 featuring at least two of the terms "R&D", "innovation" and "productivity" in their title, abstract or among listed keywords. In complementary searches, "R&D" was substituted by "research", innovation by "patent", "technical change" and "technological change" and productivity by

"performance". In total, the 19 searches on combinations of the above terms restricted to the three SCOPUS subject fields "Economics, Econometrics and Finance", "Social science" and "Engineering", rendered 79 papers fulfilling the citation threshold criterion. Out of these, 15 were found to belong to the RIP domain.

Second, we searched Google scholar for all papers on the reference lists of four RIP reviews: Griliches (1979), Mairesse and Sassenou (1991), Hall (2011) and Mohnen and Hall (2013). Papers with more than 500 citations in the Google scholar database by February 2015 were selected, whereof five were identified as RIP-papers not identified through the first search method. Repeating this procedure on the references listed in the RIP papers identified so far, another set of seven publications with more than 500 Google scholar citations was identified.

In total, searches thus rendered 28 publications. In ten instances, a working paper version (often separated in time) with an identical name was identified. These references were also added to our list. The complete list of identified papers is provided in the Appendix.

5. Impact of RIP research: journals, authors, disciplines

To map the influence of RDIP research, we next identify a set of 3274 papers in WoS which cite at least one of the 28 core papers. The annual number of citing papers increases strongly and continuously over the studied period, from an average of 17 papers per year in 1990-1994 to 390 papers per year in the period 2008-2012. This increase strongly outperforms the general growth of economic literature included in the WoS which, as shown in Figure 1, grew about 150 percent in volume over the same period. The selection of "core" publications was not designed with the primary purpose of studying temporal patterns, and we acknowledge that the volume of citations to the full set should be expected to increase over time as the number of publications attracting citations grows. [6] Nonetheless, the growth of citation to the core RIP publications indicates a strong and persistent increase in attention to the domain during the studied period.

The set of citing papers have 4916 unique authors and are published in 745 different journals. Table 1 shows the names of the ten most prolific of these authors. Table 2 lists the 20 most frequently occurring journals, accounting for about a third of all publications. Publications are fairly broadly distributed across journals, but with a significant concentration to the journal Research Policy, which alone accounts for 9% of the publications.

Författare	Count
Yang, C.H.	24
Czarnitzki, D.	19
Hall, B.H.	18
Lerner, J.	15
Van Reenen, J.	16
Vivarelli, M.	15
Roper, S.	14
Tsai, K.H.	14

[6] Of the 28 papers listed in the Appendix, 8 are published before 1990, 9 are published in the 1990s and a further 11 in the first decade of the 21st century.

Gamberdella, A.	13
Love, J.H.	13

Table 1: Top 10 authors of papers citing core RIP contributions

Journal	Count
Research Policy	280
Strategic Management Journal	67
Industrial and corporate change	62
Small Business Economics	59
Scientometrics	57
Applied Economics	56
Technovation	49
International Journal of Industrial Organization	44
International Journal of Technology Management	42
Management Science	42
Technological Forecasting and Social Change	42
Review of Economics and Statistics	40
American Economic Review	37
Industry and Innovation	31
Journal of Evolutionary Economics	30
Journal of Technology Transfer	30
Organization Science	30
Journal of International Business Studies	28
R & D Management	28

Table 2: Top 20 journals publishing papers which cite core RIP contributions

Table 3 shows how these papers are distributed across WoS subject classifications. We find that a lion's share of all papers drawing on RIP research have been published in journals classified as belonging to the field of Economics. Furthermore, significant shares of the papers are published in journals which are classified as belonging to other economic disciplines (Management, Business, Planning & Development). Temporal analysis (not showed in the table) identifies a shift in patterns occurring around the year 2000. After this year, the share of citing papers published in journals classified as Economics and as "Social Sciences, Mathematical Methods" fall back. The share of papers originating from Management and Business publications increase correspondingly.

Field	Map code	Number of papers	Mean cit rate
Economics	1	1638	1.45
Management	2	1230	1.59
Business	3	681	1.44
Planning & Development	4	422	1.65
Operations Research & Management Science	5	215	1.66
Engineering, Industrial	6	204	1.13
Business, Finance	7	160	1.58

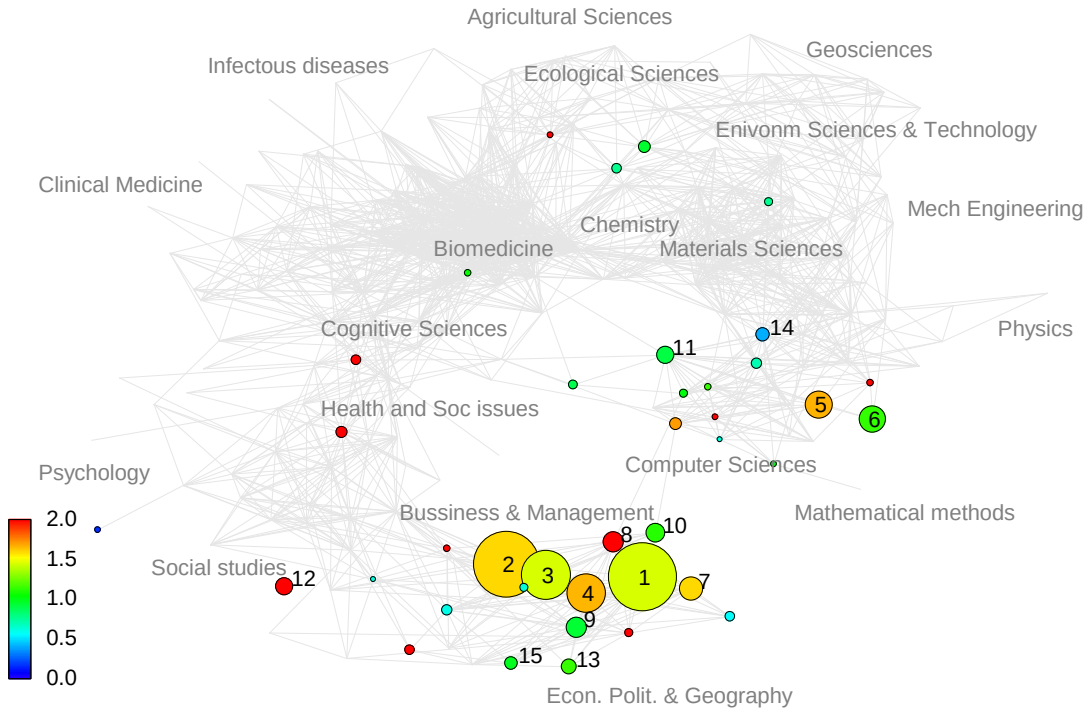
Social Sciences, Mathematical Methods	8	117	2.07
Environmental Studies	9	117	0.94
Information Science & Library Science	10	103	1.11
Computer Science, Interdisciplinary Applications	11	91	0.91
Law	12	89	2.25
Geography	13	68	1.14
Engineering, Multidisciplinary	14	54	0.41
International Relations	15	51	0.98

Table 3: Top 15 fields from which core RIP contributions are cited

In Figure 3, the different subject fields are visualised in relation to each other using Rafols & Leydesdorff (2009)'s World Map of Science. The layout of this map is based on a cluster analysis of citation links between subjects and grouped into 19 broader subject areas indicated on the map. While a vast majority of impact is within economic fields, we note that citations are found across the map, received from 94 out of 222 subject fields used by Rafol and Leydesdorff. We note that the average citation level is significantly higher for papers published in journals which are classified as oriented towards the methodological aspects of RIP research ("Mathematics, Interdisciplinary Applications", "Social Sciences, Mathematical Methods" and "Statistics & Probability") than for papers published in journals with a more traditional social science orientation. We suggest that this pattern demonstrates that the core of the RIP research program has been pushing the methodological frontiers, attracting attention and creating impact in research communities where development of quantitative analysis of economic activity is of greater interest than the issue of estimating the elasticities of the R&D-innovation-productivity relationships.

From figure 3 it is also clear that the citation impact of the paper set used for this analysis is highly cited, with publications in the five most frequent fields cited between 45 percent and 66 percent above world field average. The papers citing the core-set of papers are thus themselves making a significant impact in a range of subject fields.

Figure 3. Subject distribution and mean impact of the papers citing the 27 core publications, across field classifications.



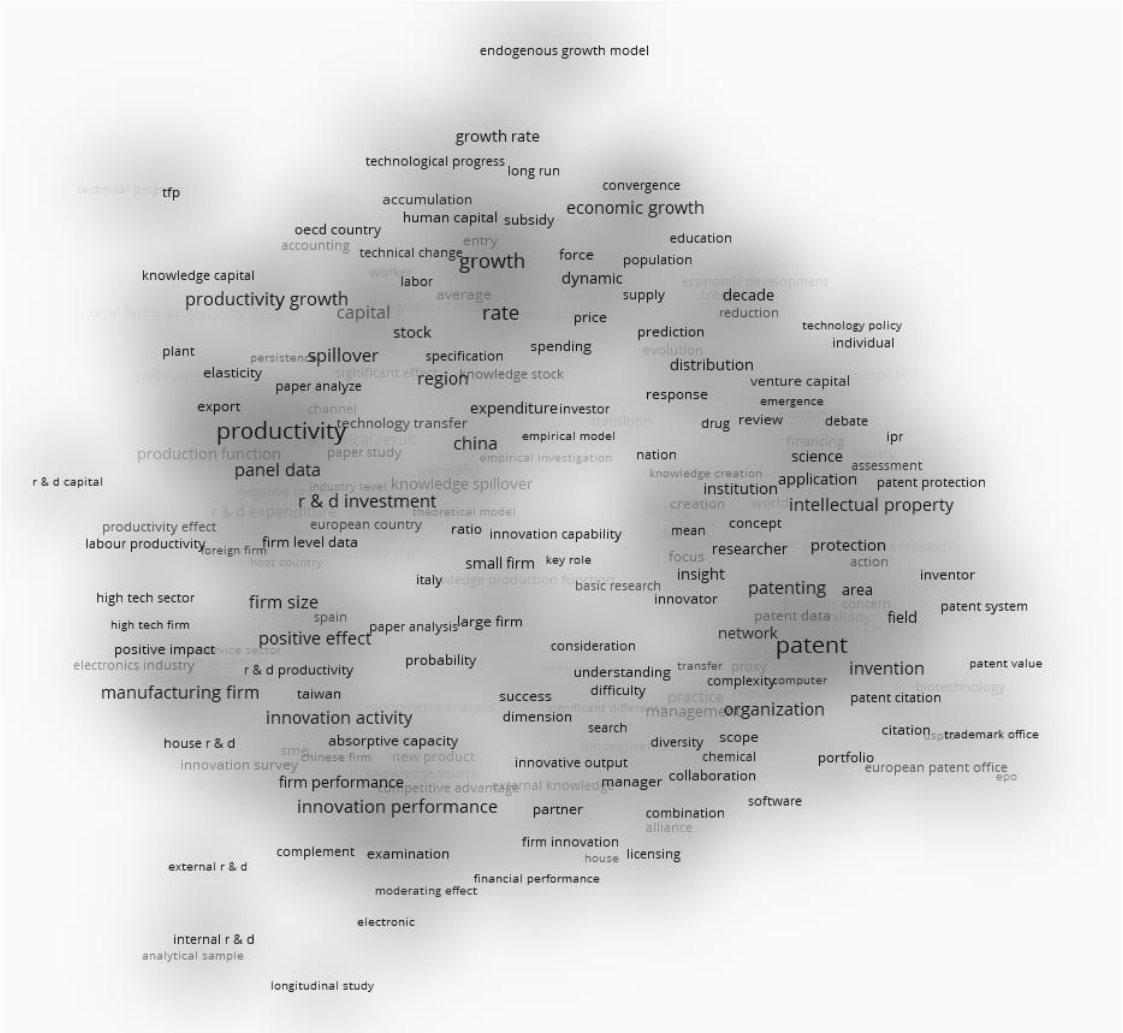
Legend: *The size of circles reflects the number of papers classified as belonging to each subject field. The colour of the circles reflect mean citation impact of all papers in that subject field (the scale on the right side). The numbers in/beside the larger circles refer to the table below.*

6. Impact of RIP research: thematic clustering

We next characterise the set of citing papers by means of analysing which terms are most frequently occurring in titles and abstracts. Using a threshold of minimum 30 occurrences for terms to be included, 353 terms where identified using the VOSviewer software (Van Eck and Waltman, 2011). As expected, the terms used to identify the gross list of core RIP papers also feature prominently. "Productivity" appears in 21 percent of all papers, "R&D" in 36 percent, "patent" in 29 percent and "innovation" in 38 percent. The occurrence of these terms over time is reasonably stable, with one notable exception. The term "innovation" features in 15 percent of the 300 papers in the set which are published before 2001, and in a whopping 47 percent of the 1984 papers published after 2007. This finding supports the claim (see section 4 above) that the broadened interest in RIP research has been carried by a surge of interest in the notion of innovation during the first decade of the 21st century.

The extraction of terms from the title an abstract of papers can also be used to establish relatonships between papers in the set of citing papers. Figure 4 shows a term-density map created using the VOSviewer-software. Terms occurring in the same document are placed close to each other and frequently mentioned terms are displayed in a larger font size than more infrequently occuring terms. Only terms which effectively identifies clusters of papers are shown on the map.

Figure 4.Cluster analysis of papers citing the set of 27 core RIP publications, by terms featuring in



A first interesting observation is that the term "innovation" is not found to define a demarcated cluster of publications, but occurs in various terms scattered across the lower left quadrant of the map. This likely reflects that the concept of innovation has been widely adopted and occurs in such a broad set of publications that it does not meaningfully define specific research niches in bibliometric analysis.

The term-density map shows three particular concentration points, which define separable cluster of publications. On the upper left side of Figure 4, the terms "productivity" and "r&d investment" feature together. Papers who are themselves in the RIP domain constitute an important part of this cluster, together with highly related studies on industry-level elasticities between research, innovation and productivity. The central upper cluster is focused on the terms "growth" and "rate". This cluster is closely tied to the first; the composite term "productivity growth" features in the title or abstract of 9% of the citing papers. That this cluster is identified as a separate group by the algorithm reflects how RIP core papers have been cited in works discussing the role of R&D and innovation for macroeconomic development. The composite terms "economic growth" occurs in as many as 8% of all citing papers.

Finally, in the lower right hand side of the figure we find a clearly separated cluster of papers linked together by the occurrence of terms related to patenting. Some of the papers in this cluster are in the RIP domain, where the count of patents or patent applications has become the most common measure of innovation output. But interestingly, we also find a broad set of papers relating to RIP research though citation of at least one of the "core" paper in connection to research analyzing the patent system as such and the immaterial property rights strategy of firms.

7. Impact of RIP research: citation function analysis

Classification of publications by means of bibliometric tools and techniques such as those applied above provide good overview and orientation of a set of scientific papers, but clearly also leave many questions unanswered. In order to provide a more in-depth analysis of the impact of RIP research, we next turn to analysis of in what context the set of 27 core RIP is cited by other papers. For this purpose, we extract all papers in the Web of Science (Wos) database citing at least one article in the set which themselves have received at least 100 citations from WoS papers. Citations between two papers within the core set (5 papers with 9 citations to other core papers) are excluded. 126 citing papers, and 184 unique citing-cited paper pairs are identified in this manner. Several citing papers contain multiple references to the same cited paper. In parallel to the bibliometric analysis of the previous two sections, we do however in what follows refer to each of the 184 pairs as a citation.

A first finding, after manually reading and categorizing these papers, is that only 12 papers (9 %) are themselves within the RIP domain. This finding complements the disciplinary and thematic analyses of the influence of RIP research, as presented above, in providing a picture of RIP research as highly relevant outside the RIP domain itself.

We also carefully study all citations to the 27 core RIP papers in the 126 citing papers in order to analyse the function of the cited paper in reference to the citing paper. In the literature on the practice of scientific citation, several categorization schemes for such analysis have been suggested and applied. Peritz (1983), for example, presents eight functions in which citations are used in empirically oriented social sciences. For the purpose of characterizing the impact of RIP research by citation function, we apply a simplified scheme of analysis structured around the following two questions:

Question1: Does the citing paper build on results and arguments from the cited paper to establish a position about a real-world phenomenon relevant to the present study?

From a position of what in the philosophy of science is referred to as realism, we refer to such citations as filling an *evidential* function. The cited paper is referred to has having advanced a specific idea, to have shown/suggested a causal relationship (i.e. establishing which control variables to use in econometric modelling exercises) and more generally as presenting arguments or findings which are directly relevant for the scientific work of the citing paper. The citing paper references the cited paper in relation to an affirmative statement.

Question 2: Does the citing paper build on the cited paper in order to establish how something can or should be researched?

We refer to such citations as filling a *methodological* function. In the context of papers citing RIP research, a vast majority of such citations are related to the empirical issues such as the choice of estimators, modelling techniques, and data. Citations with a methodological function are also used in problematizing (e.g. in reference to measurement problems), conceptualising (e.g. in reference to the relationship between theoretical constructs and empirical measures) or explanatory statements (e.g. in discussing alternative theoretical mechanisms behind an observed empirical regularity).

Following Moravcsik and Murugesan (1975), we refer to citations which fill neither of these two functions as *perfunctory*. Such references are for example used to acknowledge the general existence of a paper without further explaining how or to what extent the citing paper relates to the cited paper. A handful of perfunctory references are also provided to papers cited as having neglected to study a specific aspect of a phenomenon.

Table 4 shows how citations are distributed between the three categories of citation functions listed above. We note that the percentage of perfunctory references is relatively low, at least in comparison to previous studies of the physical sciences where about 50 percent of all citations are typically found to fall into this category. The lack of available studies of citation functions in the social sciences makes it difficult to draw strong conclusions about whether this result is a particularity of the RIP domain, or if this number is representative for the economic field. We may, however, conclude a large majority of the citational linkages identified in sections 5 and 6 are indeed to be understood as an indication of intellectual debt to RIP papers, not merely as an acknowledgement of their existence.

	Percentage of citations
Evidential function only	48.9 %
Methodological function only	25.5 %
Both evidential and methodological functions	8.7 %
Perfunctory citation	16.8 %

Table 4: Function of citations to core RIP papers

The central research question RIP research domain is of an evidential nature[7]. It is therefore somewhat remarkable that over a third of all references to the core RIP papers fill a methodological function. In order to obtain a point of reference, we analysed the last issue (No 8) of 2014 of Economics of Innovation and New Technology in a parallel fashion to the analysis presented in Table 4. In the six regular papers of this issue, one out of four references was categorised as having a methodological functions.

We interpret the relatively high frequency of methodological references as an indication that RIP research has made significant methodological contributions. As an illustration of this phenomenon, we conduct a third wave of citation function analysis, this time with a particular core RIP paper in focus. Crepón et al. (1998) is widely acknowledged as a methodological milestone paper both within the RIP domain per se and in the wider fields of production

[7] The central research question of the domain may be stated as follows: "What are the elasticities of firms' R&D investment and increases to their productivity, channeled through innovation?". See section 2.

economics and the economics of innovation (see Lööf et al., this issue).[8] We find that 61.0 percent of all citations to either of the two versions of this paper have a methodological function. Two indications of the Crepón et al.-paper's central importance for the work presented in many citing papers is that we find many instances of extensive referencing among the citing papers and that a full 26.8 percent of all citations have both evidential and methodological functions.

7. Conclusions

Research on the relationship between a firm's investment in R&D, its success in introducing innovations and it's performance in terms of productivity have a long history. Utilising a novel combination of bibliometric analysis and direct engagement with academic texts, this paper has accounted for the impact that this area of study ("the RIP domain") has had on the scientific literature over three decades. We show that the share of papers within the economic sciences with the term "innovation" featured in the title or abstract increased fourfold between 1990 and 2012, with a clear trend shift occurring around the turn of the millennium. In this intellectual environment, interest in the RIP domain was increased and broadened across scientific fields.

We argue that the strong embeddedness of the domain in the tradition of neo-classical production economics and the (neo-classical) economics of innovation provided a basic academic legitimacy for RIP research, but the theory-independent nature of the core RIP research question may have increased the wider accessibility of research results originating from the domain. The interest in RIP research was probably also positively affected by a simultaneous increase in interest in the causes of inter-firm productivity across the entire field of Economics (Syverson, 2011) and fuelled by significantly improved availability of firm level data of high quality in many countries, e.g. though the diffusion of the CIS surveys (Arundel et al., 2008).

Indicative of this broadened interest in the research-innovation-productivity relationship, we find indications that macroeconomic studies and industry-level analysis has drawn rather extensively on RIP research. We also find that 58 percent of citations to RIP research are made in a context where the author(s) build on empirical results or theoretical ideas about economic realities presented from the cited paper. Only a limited fraction of citations are made in general acknowledgement of the field and its central papers.

RIP research has moved forward through constant refinement of estimation methodology, careful re-interpretation of the conceptual linkages between theoretical constructs and empirical measurement and though the collection of richer data sets. Thereby, research within the domain has made a number of important contributions to the wider scientific literature. We show that about one out of three citations to RIP papers are made in reference to methodological issues. Cluster analysis depicts studies analysing the institutions of immaterial property rights (IPR) and the IPR strategies of firms as constituting an important group among all papers citing RIP research. We also find that papers from journals which, judging by their classification, are oriented towards the methodological aspects of RIP research is significantly higher than the

[8] Citing papers are as before identified through WoS. In order to obtain a larger set of analysable citing papers, we lower the threshold inclusion criteria from 100 WoS citations to 30 for this analysis. 43 paper citing Crepón et al (1998) were identified in this manner.

average impact of citing papers. Together, these findings suggest that the methodological contributions of RIP research have broadened the interest in the domain.

The main contribution of the present paper is to provide a comprehensive overview of academic research into the research-innovation-productivity relationship. In doing so, we have however made one or two methodological contributions which we hope may stimulate further research. We hope to have shown that specific research problems and research domains may be subject to analysis of a kind previously applied to wider fields or theories, and that such study can provide important insights into the workings of the international scientific system. We also hope to have illustrated that a combination of bibliometric techniques and direct study of academic texts is a valuable complement both to the traditional research review and the traditional bibliometric study.

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Appendix: Key papers

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