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Appropriating the returns of patent statistics:

Take-up and development in the wake of Zvi Griliches

Sandro Mendonça, Hugo Confraria, Manuel Mira Godinho

September, 2021

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Abstract

Three decades after the publication of Zvi Griliches' (1990) influential survey on "Patent statistics as economic indicators", the uses and limitations of patent statistics remain a core issue in the field of innovation studies. This paper follows through Griliches' seminal work to understand how the literature using patents as an empirical resource developed over time. How has this indicator been adopted and how has it been adapted to different research challenges? We address this question by examining the citation tree of nearly 2000 articles published in almost 400 journals found to refer to Griliches' seminal contribution between 1990 and 2019. We combine bibliometric techniques and qualitative analysis to provide a close-up moving picture of patents as a data resource: growth and variety of usage, impact on disciplines and journals, driving institutions and geographies, major topics and research issues. We find that five main themes emerge: 1) *Economic growth*; 2) *Geography of innovation*; 3) *Innovation management/performance*; 4) *Pat-methods*; and 5) *Green innovation*. Shouldered by these findings, we discuss potential pathways for future patent-based research.

Keywords: patents, innovation indicators, bibliometrics, survey, Zvi Griliches

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"I think patent statistics are interesting in spite of all the difficulties that arise in their use and interpretation", Zvi Griliches (1990, p. 1661)

1. Introduction

Patents point to progress. Or at least that is the assumption of many economists, given that the temporary monopoly provided by a patent grant incentivises the production of new technological knowledge (for classic textbook treatments see Tirole, 1988 p. 390, and Carlton and Perloff, 2015, ch. 16). However, it is well known that patents transcend simplistic accounts. This institutional device was set-up for different purposes long ago (an exclusive privilege designed originally to promote imitation in 14th century Venice, not invention); it can have diverging effects in terms of social welfare (whenever trade-offs between protection and diffusion are not properly balanced); and it can even be harmful to socio-economic development by crowding-out other mechanisms of knowledge governance (like unimpaired scientific discovery and norms-based informal collective appropriation solutions) (see Bessen and Meurer, 2008; Cabral, 2017, pp.391-5; Gilbert, 2011; Machlup, 1962). However, and as noted by (Arrow, 2012, p. 47), there is only one perspective more influential than the whole question of incentives in the literature: the role of patents as a "measure of inventive activity".

In addition to the study of their actual implications, patents constitute an interesting source of insight since they are carriers of substantive information (technical knowledge content) and meta-information (of empirical value for competitive intelligence purposes, technology strategy, science governance, etc.). Patents have become the object of a sprawling empirical-quantitative literature that emerged in tandem with the enormous rise in global patenting activity and the availability of computerised databases from the 1980s onwards (see, e.g., Granstrand, 1999, Ch. 9). Their use for analysis is certainly associated with what has been called the Schumpeterian *revival* (Fagerberg, 2003) or *renaissance* (Freeman, 2008), that is, the rise of the subject of research and technical change as a subject worthy of scientific pursuit. The question of how patents have been developed and actioned in the study of innovation phenomena is the focus of the present paper. Understanding the absorption and adaptation of patents in academic work has implications for science studies and innovation scholarship, but it also has implications for the formulation of actual innovation, industrial and development policies and management.

Over the last decades, the body of work drawing on patents as a research resource markedly increased and any attempt to summarise is now a heroic task. In sketching the generative process behind the usage of patents, we decided on an analytic overview: we approach the patent indicator from a bibliometric perspective. We study all the academic journal literature published (retrieved from Web of Science Core Collection) between 1990 and 2019 that cite the survey published by Zvi Griliches in the *Journal of Economic Literature* (JEL) in 1990. The work of this economist was a particular source of inspiration for innovation studies and his 1990 instalment was a pivotal piece that did a lot to establish patents as a legitimate and promising mainstream data source for economics and innovation studies (see Fagerberg and Verspagen, 2009, who found him at the top 10 of the most influential scholars named by researchers in the field). His JEL paper was by no means the first to propose or even to assess this indicator (see Basberg, 1987; Comanor and Scherer, 1969; Acs and Audretsch, 1989; Narin et al., 1987; Pavitt, 1985; Schmookler, 1950), but it surely came to be the most salient work to which most authors refer when acknowledging that patents can be used as a proxy of inventive activities and a metric of technological change. Griliches (1990, p. 1662) asked: "What can we use patent statistics for?". In turn, 30 years on, our interrogation is: *What were patent statistics actually used for?* Given that by then the question was "already too large for one article and one person to deal with", we will thus concentrate on what the impact of Griliches' influential paper can tell us about the appropriation of patent statistics for the sake of academic analysis. In doing this we aim at making two contributions, a methodological one and a substantive one. First, we trace the scientometric life of an indicator. There has been some work on the publication profile of leading scholars of innovation studies (Fagerberg and Verspagen, 2009; Meyer et al., 2004) and on the impact of some concepts (Kovács et al., 2015; Rakas and Hain, 2019), but so far less so on the flurry of scholarly work building upon an innovation indicator. Second, we investigate the actual efforts of adoption and adaptation of patents in shifting research agendas over the long run (Keuchenius et al., 2021), something that matters also for understanding the evolution of innovation studies themselves (Martin, 2019).

This exercise, which takes as a yardstick a single but agenda-setting reference[1], offers a timely opportunity to take stock and investigate how patents were put to purpose and further developed. While in the beginning of our period patents were not a mainstream tool of the trade, today they are commonplace. We will chart the citation trajectories, the thematic fields of application, the networks of tributary scholars, and track the life-cycle of the reception of patents as part of the scholarly toolbox, including from the institutional and international perspectives. A major

[1] Griliches himself was aware of this. The paper figures in his collection of essays (Griliches, 1998, p. 10), and the author was not shy in underlying just how influential it had been already: "A number of very interesting studies of patents, their role in innovation, and what they can teach us about it have followed [his 1990 paper]…".

outcome of the analysis is the organisation of the bibliometric stylised facts in the form of a taxonomy of patent data uses.

In this paper, we take into account 1,800 articles published in 394 WoS-indexed journals. Our approach, however, is not reducible to "metrics"; we complement and supplement the quantitative perspective with qualitative research (like probing into the acknowledgements of papers, examining biographic assessments of Griliches by his colleagues, or studying what the author himself said referring to his work in interviews, public events or in the retrospective reflections available in the preamble materials of essay collections) so as to provide a more granular, multidimensional and robust assessment of the meaning and significance of Griliches' key contribution. In sum, we find that pooling the quantitative and qualitative perspectives allows for an "augmented review" or "integrative appraisal" (Mendonça, 2017).

In what follows, we present evidence indicating that patent-based empirical analysis grew rapidly in the wake of Griliches (1990). We show that his contribution is salient in the context of economics discipline but that its influence spread ever more widely over time in what can be described as a succession of overlapping research streams, namely: 1) "Economic growth"; 2) "Geography of innovation"; 3) "Innovation management/performance"; 4) "Pat-methods"; and 5) "Green innovation". While the US authors traditionally dominate the literature, the recent story has been the rise of China to second place as a player harnessing the power of patent data. Publications have appeared in no less than 394 indexed academic outlets, among which the leading journal of innovation studies "Research Policy" came to be the most prominent. Patents proved to be a rich raw material, an elastic empirical resource able to serve different and not easily compatible agendas (from competitiveness to sustainability). The diverse and evolving analytical uses of patents allows us to argue that there was a transition from narrow "economic statistics" to a multi-purpose "innovation indicator". As a source of discovery, patents went beyond what Zvi Griliches originally envisaged and are likely to remain so as their potential continues to be creatively stretched.

Section 2 proceeds to explore the measurement issues that surround innovation as a research topic. Section 3 details the approach and the evidence. Section 4 presents the findings and critically elaborates on their substantive significance and robustness. Some conclusions, acknowledgement of limitations, as well as implications for future scientometric research and innovation strategy are presented in section 5.

2. Measuring innovation: Background

2.1 The measurement agenda in innovation studies

Measurement implies commensurability, i.e. that there is at least some level on which objects are structurally similar, so that meaningful comparisons can be made in quantitative terms. The challenge is that innovation is about quality and new qualities[2], via always unique pathways of learning and knowledge-building. Since innovation usually involves multidimensional novelty and brings a degree of discontinuity along with it, aspects of standardisation and comparability regarding indicators of science and technology were acknowledged as paramount from early on. In his review of innovation indicators, Smith (2005, p. 149) highlighted that the "key problems" indeed "concern the underlying conceptualization of the object being measured, the meaning of the measurement concept, and the general feasibility of different types of measurement."

In what became the first journal special issue dedicated to science, technology and innovation "output" statistics (*Research Policy*, edited by Chris Freeman in 1987, in honour of Yvan Fabian who at the OECD had spearheaded the Frascati Conference), it is also clear that researchers were actively pursuing other measures beyond research and development (R&D) as part of a portfolio approach. In the Preface of the book version that followed, Freeman (1987, p. v) in the forward note:

> "From the very beginning in 1963 at the first Frascati Conference, Yvan Fabian recognised that the official R&D statistics were only the first step. He was more aware than anyone else of their limitations and understood the importance of other scientific and managerial activities in bringing about technical innovations. Most important of all, he knew perfectly well that R&D expenditures and personnel statistics were only measures of inputs and that it was the measurement of outputs which was the real challenge."

As the field matured, the endeavour to increase the scale and scope of innovation measurement beyond "input" indicators (namely, R&D investment) kept its momentum. A set of examples of steps taken to push the boundaries of innovation indicators can be summed up: patent counts (Griliches, 1990; Pavitt, 1985); direct technometric observations (Saviotti, 1988); patent citations (Trajtenberg, 1990); questionnaire-based inquiries (Acs and Audretsch, 1990; OECD and Eurostat, 2005; Pavitt, 1984); technological alliance announcements and new product reports in the press (Hagedoorn and Schakenraad, 1994; Hitt et al., 1996); composite indicators (Hagedoorn and Cloodt, 2003; Patel and Pavitt, 1995); trademarks (Schmoch, 2003; Mendonça et al., 2004); fair

[2] "An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organization or external relations." (OECD, 2005, p. 46).

exhibits (Moser, 2005), among others. A recent literature review (Dziallas and Blind, 2019), identified 82 unique indicators throughout the innovation process.

Today, patents are only one of a diverse portfolio of possibilities; that is to say, they are a partial indicator of technological progress (Martin, 2019; Martin and Irvine, 1983). What is remarkable is that their rise to prominence in the 1980s as an official statistic at the OECD happened while other output indicators were being promoted and trialled (Godin, 2004, p. 124). The remarkable, sometimes obfuscating, success of this indicator among the expanding range of other options ever since seems not pre-determined from the outset and calls for further inspection.

2.2 Patents as an economic indicator

The interest around patents as indicators of economic activity is not new. Already in the 1930s, 1940s and 1950s researchers like Gilfillan (1935), Graue, (1943), Plant (1934) and Schmookler (1950) were starting to interrogate patents about the underlying dynamics of invention.

In what was an early systematic appraisal, Simon Kuznets (1962, p. 37), who got a Nobel prize for his pioneering work on economic statistics, had the following to say of patents: "Obviously, we cannot assume that one patented invention is, in any meaningful economic sense, equivalent to another." Nonetheless, works by Schmookler (1966, 1962), Griliches and Schmookler (1963), and Scherer (1965) began explicitly to evaluate the potential of large patent datasets to test hypotheses. The increasing microeconometric efforts in the 1960s and 1970s related variables like R&D and patents to understand the most favourable industrial structure for rapid technical progress. The overall spirit at the time was that although differences in the magnitude of inventions between patents existed, they did not, however, "overwhelm any association between patents and technical change" (Comanor and Scherer, 1969). Griliches, who was heavily involved in these efforts from the outset (Nerlove, 2001), also kept the view that "in spite of all of the difficulties, patents statistics remain a unique resource for the analysis of the process of technical change" (Griliches, 1990, p. 1702).

A pioneering appearance of patent statistics in a textbook was on *The Economics of Industrial Innovation* by Chris Freeman, who devoted a section to "patents as a measure of inventive output". While acknowledging patents were not to be considered entirely satisfactory, as they are not the same as numbers of innovations, he stated that these would not be employed "if better information were available." Freeman, who was one of the drivers behind OECD's pioneering travaills to define and harmonise input indicators like R&D statistics, emphasised that difficulties with patents were even more overwhelming. Labouring too much on the nexus between input and output indicators would thus be futile. Patents, he stressed in a way that would become the hallmark of the neo-Schumpeterian SPRU tradition, should not be used alone as they do not convey the whole story of innovation, which for him encompassed the complex process of introduction in the economy of products and methods of production incorporating new knowledge (Freeman, 1982, p. 4).

During the 1980s there was a marked increase in interest in patent statistics. According to Keith Pavitt (1985), who also had worked at the OECD and was by then at SPRU, the rising interest in this statistical artefact was clear from the outset due to three main reasons. First, there was a new social and political recognition of the importance of science and technology for the growth of firms and national economies. Second, there was a spread of technological activities among a wider range of firms and countries, which required statistical evidence to be more systematically understood and assessed. Third, improvements in information storage and computational capacity were enabling patent offices (and international agencies) to better organise and retrieve the data contained in patent documents. By this time, increasingly comprehensive reports on patent activity in time and space were already forcefully demonstrating the feasibility of this indicator for purposes of industry analysis and international comparison (Scherer, 1983; Soete and Wyatt, 1983).

During the 1990s and 2000s this trend continued, and a survey in fact argued that during these years "research papers that use patent statistics, have been increasing at a faster rate than patents themselves" (Nagaoka et al., 2010, p. 1085). Recent indicator-oriented surveys converge in recognising the prominence presence of patents among the various metrics of science and technology (e.g. Hall and Jaffe, 2018; Lhuillery et al., 2017).

2.3 What is in a patent

While the detailed explanation of technology itself lies in the main text of the patent document, most of the information economists tend to find most useful is included on the front page. It usually includes the inventor's name and address, the identification of applicant or assignee, key dates such as the priority date, application date, grant date, and, importantly, technology classes (usually based on the International Patent Classification). Patents also include references to patent and nonpatent documents such as scientific publications.

Although such information has not changed much over time, and is basically the same across different patent offices, the potential of patents as empirical material seems hard to exhaust and indeed expansive as they are exploited. Several authors have provided encompassing discussions how this information can be used analytically (Archibugi, 1992; Basberg, 1987; Griliches, 1990; Nagaoka et al., 2010; Narin et al., 1991; Pavitt, 1985). According to these surveys, patent statistics can be used to conduct research on a variety of topics, from firm strategy to industrial dynamics, from R&D spillovers to university- industry knowledge transfer, from productivity analysis to stock-market valuation, etc. New uses are contingent of new research questions coming to the fore, and somehow patents seem to be amenable to provide new answers.

The growing experience with patent statistics has also produced an awareness of a long list of limitations (e.g. Arundel and Kabla, 1998; Brouwer and Kleinknecht, 1999; Griliches, 1990; Torrisi et al., 2016). First, patents protect inventions and not innovations. Second, not all innovations are patented. Third, the value of patents is highly skewed. Fourth, different sectors and firms of different sizes have different propensities to patent. Fifth, patents are used for strategic purposes, such as to block other patents with unused patents or to receive licensing fees. And the examples could go on, always stimulating new countermeasures in a feedback mechanism that further stretches the methodological mileage of the indicator. Hence, the perceived advantages and shortcomings have not remained frozen over time: they co-evolve.

More than other single contribution, Griliches' (1990) well-known survey introduced a discontinuity in the field. As Griliches (1989, p. 314) said in a Brookings Institution seminar just before his seminal paper was published: "What I have just discussed is the fundamentally unobservable quantum of 'invention', or 'an advance in knowledge." His survey was programmatic and put knowledge, and its patent proxy, at the heart of economic analysis. How the ensuing literature made the most of his insight is what we want to find out.

2.4 Why Griliches (1990)?

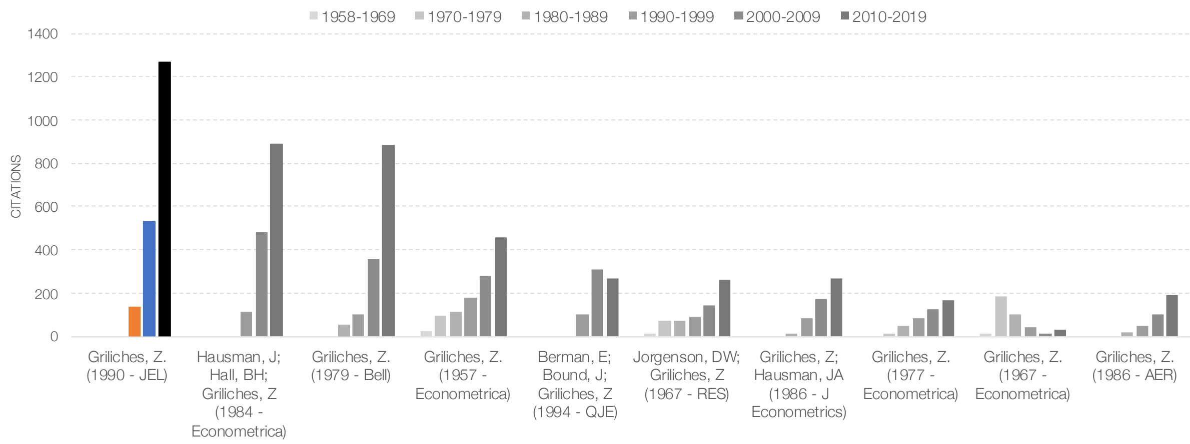
Our research strategy is to produce a comprehensive overview of the patent indicator by taking Griliches (1990) as the turning point in the literature. We choose this approach because the paper is the most highly cited paper of its kind (discussing patent statistics as data) and probably the one that decisively established patent indicators in mainstream economics.

Griliches' publications, including books, articles, notes, comments, reviews, and congressional testimonies, total approximately 221 documents (Diamond, 2004). Out of all his work, Griliches himself saw his career goal as trying to explain Solow's residual, namely, accounting for economic productivity growth after the standard tangible variables of capital and labour are correctly measured (see interview Krueger and Taylor, 2000; see also Nerlove, 2001). He made widely acknowledged contributions to many areas of economics, most notably the economics of technological diffusion, measurement of R&D returns, growth accounting, and the econometrics of dynamic phenomena. In a review of Griliches' legacy, Paul David (2005) singles out his three "biggest hits": (1) the diffusion of innovations (Griliches, 1957, 1958), which laid the foundation for rigorous empirical studies of the private and social returns to research activity, and hence for the role of formal research activities in generating growth; (2) the explanation of changes in total factor productivity (Jorgenson and Griliches, 1967), which transformed the study of productivity growth from the study of the residual to a study of the measurable factors that caused increases in the output available from given configurations of inputs; and (3) the work on distributed lags econometric frameworks (Griliches, 1967), in which he aimed to solve the problem of having too many omitted characteristics in R&D models. James Heckman (2005, p. 6) agreed and complemented by stating how he:

> "...had a major impact on research in economics and on the practices of statistical agencies of governments. As a result he is one of the most influential empirical analysts in the history of economics."

A bibliometric appraisal can put these views into perspective. Although citations are only a rough measure of intellectual influence they do, however, testify to the scholarly repercussion of individual achievements (Martin and Irvine, 1983; Moed, 2005). Although his JEL 1990 survey came at a later stage of his academic career, and has not been seen as one of his top acts, it does currently stand out as the research piece for which Griliches got more impact vis-à-vis all his other contributions (Fig.1).

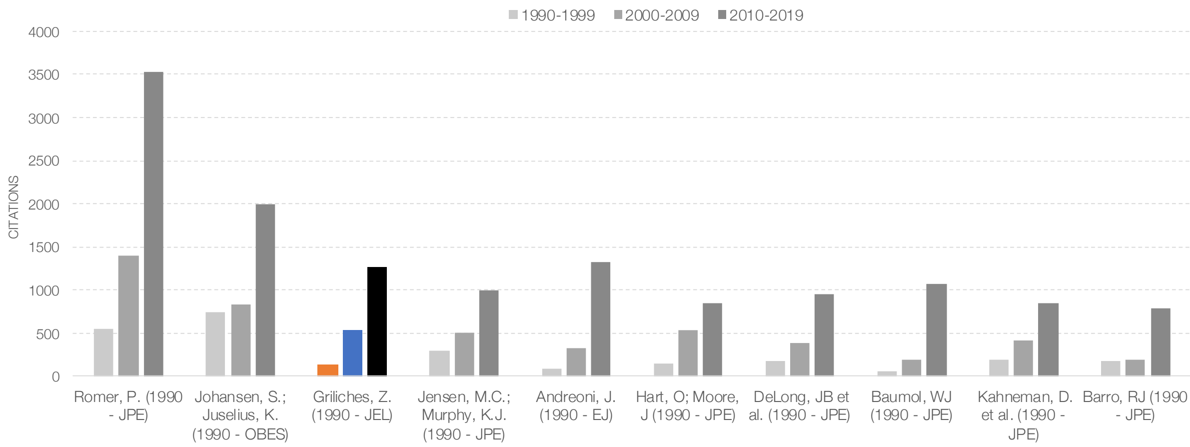
Figure 1. Griliches' top 10 highly cited contributions



Source: Web of Science (WoS), the same for following figures and tables

Being Griliches' most cited paper, it would seem to follow that his 1990 contribution would have also been significant in the field of "Economics" as a whole (see Nagaoka et al., 2010, p. 1085). To check this conjecture, we compare in Fig. 2 the citation numbers of his 1990 survey against other papers in the "Economics" WoS category for the same year of publication (to normalize by the year).

Figure 2. Griliches (1990) versus the top 10 highly cited publications in "Economics" published in 1990



Indeed, we find that Griliches (1990) is the third in terms of more citations in the field of "Economics" (up to December 2019) from a total of 6237 papers. The two papers from that year which have received more citations than Griliches' survey are Paul Romer's endogenous growth model (Romer, 1990), which was credited for his Nobel Prize of 2018[3], and Johansen and Juselius, (1990), which is widely used in econometrics for pointing the way to detect multiple cointegrating relationships. The remaining top 10 papers cover subjects ranging from financial economics (Jensen and Murphy, 1990; Long et al., 1990), public economics (Andreoni, 1990), property rights (Hart and Moore, 1990), entrepreneurship (Baumol, 1990), behavioural economics (Kahneman et al., 1990), back to economic growth (Barro, 1990). Hence, it becomes clear that Griliches (1990) was an important paper in a year when a number of marked advances were made in Economics.

In addition to comparing Grilliches (1990) with the WoS 1990 Economics cohort, we assess its relevance within the specific literature advocating and deploying patents as economic indicators. For this, we use a search query[4] that combines the word "patent(s)" with related keywords within this specific literature, namely "technolog*", "innovation", "economic*", "R&D". Applying this to the Social Sciences Citation Index from WoS (SSCI) since 1900 yields 9285 papers; by

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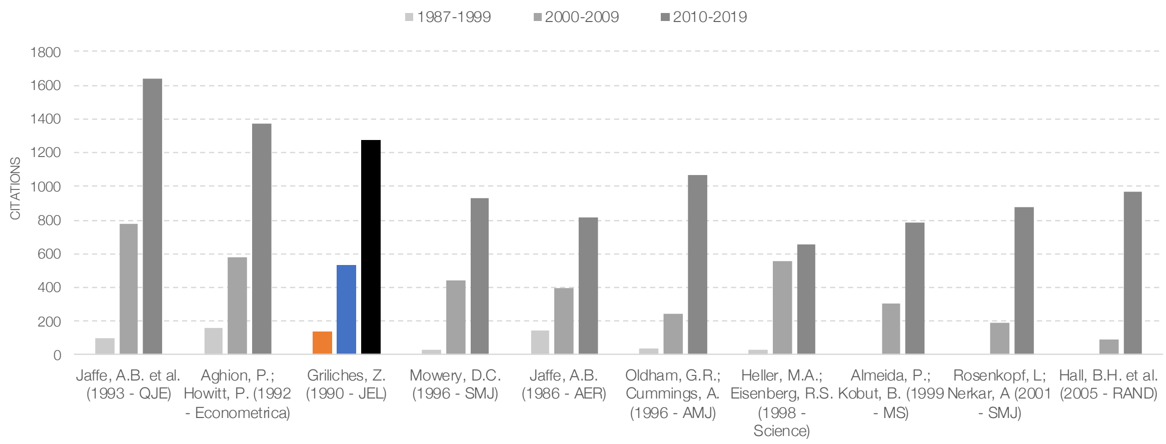
[3] https://www.nobelprize.org/prizes/economic-sciences/2018/romer/facts/

[4] (("Patent*" AND (economic* or "creativ*" or industr* or Innovat* or "knowledge" OR "residual" OR "R&D" OR "research and development" OR Statistic* OR Technolog* OR "tfp" OR "total factor productivity")) OR "patent data" or "patent indicator*")

considering Griliches' (1990) against this population of related research available, we find it to be the third most cited paper (Fig. 3).[5]

Figure 3. Griliches (1990) versus top 10 highly cited patent-related publications



The paper ranking #1 in this set of work focuses on geographical knowledge spillovers using patent citations (Jaffe et al., 1993). That paper compares the geographic location of the inventors identified in a given patent with the geographical location of the inventors of the patents that cite the originating patent, and checks if citations come disproportionately from the same state or metropolitan area as the originating patent. The authors find evidence that indeed knowledge spillovers are geographically localised. Zvi Griliches is mentioned in the acknowledgements section. Interestingly enough, all three authors from this paper were his doctoral students.[6]

Paper #2, by Aghion and Howitt (1992), provides a theoretical model of economic growth based on a Schumpeterian process of creative destruction and is widely cited in the literature on endogenous growth. Again, Zvi Griliches appears in the acknowledgements.

It is worth noting what is found by gleaning through these non-content sections, which often appear to pay an intellectual debt to individuals and institutions that have provided some sort of assistance during the research or in the preparation of the final version of the paper. Despite Griliches' own paper coming #3 in the ranking, these observations show that his powerful influence is imprinted in the two most cited papers.

[5] The 9,285 publications identified by our search were ranked by the number of citations received until 2019. Next, to ensure the relevance of each of the top10 highly cited publications for our purposes, the abstracts, keywords and introductions of each top20 publications were checked manually. This allowed identification and elimination of two false-positive articles (i.e. articles not related to our topic of interest) in our top10, which were replaced by the following two with more citations in the list.

[6] Griliches (1998 p. 10) was indeed keenly aware of how, in his words, "my students and their students" were instrumental in further opening-up the subject, establishing new facts and making methodological breakthroughs.

The other papers in this ranking cover issues such as interfirm knowledge transfer within strategic alliances (Mowery et al., 1996), R&D spillovers (Jaffe, 1986), employee creativity (Oldham and Cummings, 1996), how excess privatisation of R&D can deter innovation , mobility and spillovers (Almeida and Kogut, 1999), mechanisms facilitating techno-organisational learning (Rosenkopf and Nerkar, 2001), and the relation between patent citations and firm market value (Hall et al., 2005). Four out of these seven papers cite work by Griliches, which goes on to underscore his disproportionate influence among top research focusing on innovation and economically useful knowledge.

Taken together, this evidence sets the scene in terms of the innovation measurement research programme. Patents have prominence as an innovation indicator, either when compared with all other economics contributions published in the year 1990 or in the context of full range of work published in that year on technical change. Incidentally, Griliches (1990) is the publication most cited ever in the *Journal of Economic Literature*, one of the most prestigious economics outlets in academia. In other words, the impact of this work and the agenda it synthetises can only be underestimated and amply justifies its employment as a focusing device to drill into the significance and influence of the patent indicator.

3. After Griliches (1990): Data, methods, caveats

3.1 Research strategy and data constraints

Our research addresses the evolution of the journal-based literature on patents as economic indicators by looking at the corpus of publications (articles and reviews) citing Griliches (1990) in Web of Science Core Collection (WoS) until 2019.

With this source, we can evaluate the influence of the target paper on academic knowledge production independently of disciplinary boundaries. However, it should be kept in mind that this approach does not capture all relevant scientific work on patents as economic indicators. First, authors impacted by the ideas that appear in Griliches (1990) may not cite it but rather other surveys (e.g. Pavitt, 1985). Second, Griliches (1990) is cited in many other documents beyond peer-reviewed papers available in WoS; Google Scholar during the year 2020, for example, yielded slightly over 8100 for the period until 2019, while in WoS counts 1,800. Third, some ideas seep in to become common sense and, as generations go by, researchers stop using explicit references to indicate what became a pre-acquired belief (see Merton, 1973). We choose WoS instead of other bibliometric databases like Scopus, Dimensions, Lens or Google Scholar[7] due to its reliability in historical citation links, quality of abstract and keyword data for topic modelling, and availability of the "organization-enhanced" function that allows for consistent institutional collaboration analysis.

While this bibliometric approach offers unique insights and has distinct advantages, there is a number of drawbacks to our study. To start with, we are only dealing with citations from publications in WoS journals, meaning that PhD theses, books, grey literature, and scientific publications in proceedings or non-indexed journals in WoS are absent.[8] This might lead to some disciplinary and geographical bias (Chavarro et al., 2017; Mongeon and Paul-Hus, 2016). Another limitation is that, although we used clustering techniques to identify groups of literature within our set, we rely also on interpretive methods to identify the key research streams.

The present study takes on board WoS data in three major steps, which we detail below. First, we use the affiliation data from publications citing Griliches (1990) to analyse what institutions, countries, and collaborations appear. This allows us to trace the communities (geographies, organisational players, groups of scholars) that have been influenced by his work and how his

[7] Data in Google Scholar, for example, is unstructured and many of the citing documents do not reflect academic impact (Martín-Martín et al., 2018).

[8] For citation numbers it would be interesting to do all types of documents to assess general impact. However, for the disciplinary section, since only scientific journals are associated to WoS categories, and since only article and review keywords (and references) are consistently available in WoS to perform keyword analysis (and bibliographic coupling), we decided to be coherent and only use articles and reviews for all analyses done.

influence changed over time. Second, in order to have a better overview of the disciplinary impact of Griliches (1990), we analyse the disciplines of those journals in which citations appear as well as the keywords and topics surfacing in the citing publications, including the most influential citing publications. Third, we combine, complement, and supplement this bibliometric analysis with an historicist component to construe a taxonomy of the actual trajectories of research that have developed and deployed patents as indicators.

3.2 Geographical and institutional influences

The first step of our analytical section makes use of affiliation data (1) to check which authors in what institutions and countries are responsible for the citations, and (2) to identify the co-authorship networks mostly influenced by the paper. This helps us to understand which actors and networks have been active in appropriating the analytical and empirical value of Griliches' contribution.[9] Collaboration (co-authorship) networks are built using Gephi's "Fruchterman Reingold"[10] algorithm.

3.3 Disciplinary and thematic influences

The second step involves identifying and outlining (1) bibliographic information to depict the broad disciplinary areas that are making use of the insights contained in the target paper, (2) keyword data to identify the most frequent topics and research problems studied in the citing publications, (3) the most influential citing articles, and (4) groupings based on the commonality of references that they cite.

By analysing the (394) journals and WoS categories[11] that cite the target paper, we are able to derive an understanding of the diffusion and disciplinary boundaries of the literature on patents as indicators. This in turn helps us with other inferences, for example, whether studies in this area are exclusively performed in economics or are likewise done in other fields (Angrist et al., 2020).

Also, by analysing the most common keywords in papers that cite Griliches (1990) we will have a more fine-grained analysis about the contents driven forward by this classic survey, and what are the emerging topics that are appearing. Keywords are obtained both from the keywords provided by the authors of each paper and those created by KeyWords Plus[12]. We generate the co-occurrence matrix of keywords, frequencies and map of relations between terms using the VOSviewer "LinLog/modularity" layout procedure (for more info see Newman, 2003; van Eck

[9] We use the full-counting method, that is to say, counts are not weighted by number of authors and addresses in a publication.
[10] https://github.com/gephi/gephi/wiki/Fruchterman-Reingold
[11] https://images.webofknowledge.com/images/help/WOS/hp_subject_category_terms_tasca.html
[12] KeyWords Plus are words or phrases that frequently appear in the titles of an article's references, but do not appear in the title of the article itself. They are created based upon a proprietary algorithm from Clarivate Analytics.

and Waltman, 2020). Keywords that co-occur more often in the same publications appear closer together in the maps of keywords. For all keywords in our set, we also calculated the average year that they appear in different papers during the period 1990-2019, which allows us to assess the timeline of different intellectual returns derived from Griliches.

Moreover, by analysing the reference commonalities of the citing papers we are able to identify academic groups/clusters. For this, we carry out a bibliographic coupling analysis, a technique that computes the similarity of sources of a set of papers (Kessler, 1963). The "coupling strength" between publications is determined by the number of references they share, assuming that a common pool of references points a resemblance in terms of aims, background, methods, or theory (Rakas and Hain, 2019). The higher "coupling strength" is therefore an expression of a scholarly community (for more info see Perianes-Rodriguez et al., 2016; van Eck and Waltman, 2009, 2020). This technique will also allow us to analyse how the themes have evolved in size through time. After fleshing out the structure of the literature using this technique, we improve the visualization of the most relevant articles by highlighting the publications that have higher normalized citation impact by year (Waltman, 2016).

3.4. Taxonomy of research streams

The final step of this paper is to describe the different kinds of literature that use patents as economic indicators, and how they changed in time. The procedure is designed to provide crosschecks to the clusters and thus enhance the robustness of our findings. We go about this analysis by (1) using the previous results so as to discern major issues of interest in the literature, (2) using VoSviewer clustering algorithms to sort out developing themes, which we call *research streams*, and (3) tabulating the key characteristics of the research streams, i.e. the defining terms and focusing questions, and producing a classification (a taxonomy) of patent uses as empirical inputs. In order to capture the latest developments and emerging topics, the last empirical sub-section is dedicated to the analysis of papers citing Griliches (1990) or found using the same query as in Fig. 3 published only in 2019 and 2020 in a way akin to an out-of-sample sensitivity analysis. We appraise these recent articles by considering their novelty in relation to all the literature previously discussed.

Overall, and by means of pooling different evidence bases (including qualitative data and emerging trends), our research design allows us to augment and buttress what would otherwise be a purely quantitative/descriptive paper (Mendonça, 2017).

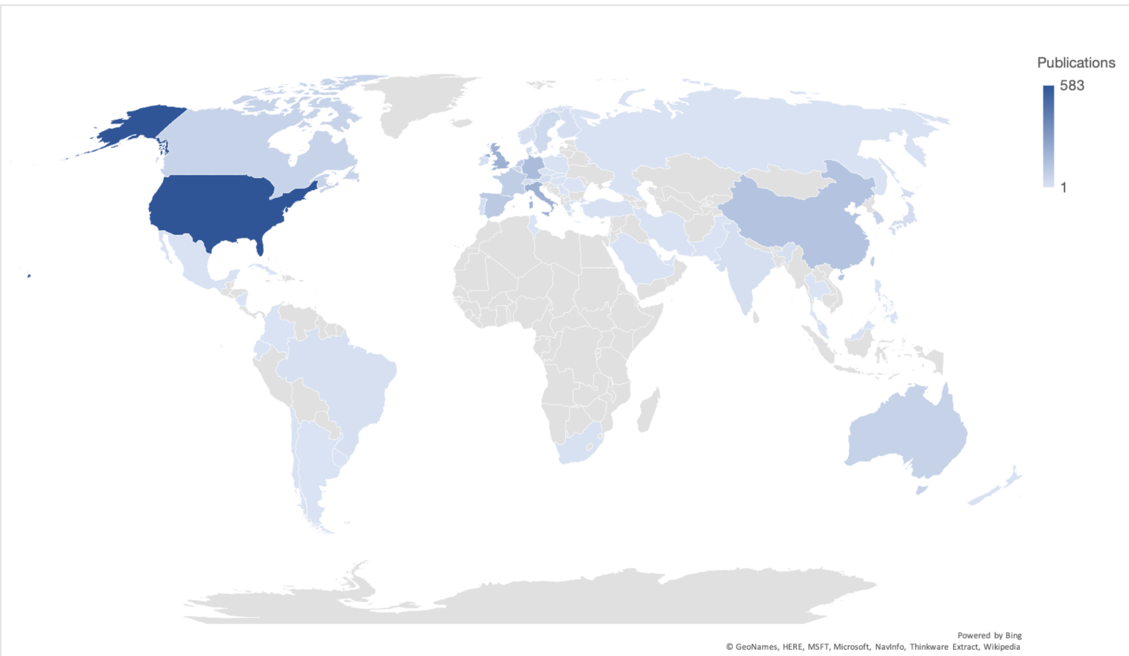
4. Results

4.1. Geographical influence

According to WIPO (2019) from 1970 to 2000 US, Japan and Western Europe accounted for 90 percent of all patent applications worldwide. However, in recent years the patenting take-off of new players like China and India has contributed to innovation becoming more evenly distributed globally (Confraria et al., 2021; Godinho and Ferreira, 2012). At the same time, paradoxically, it is argued that patenting activity is getting geographically concentrated in a limited number of innovation hotspots based on a few large, cosmopolitan and prosperous urban areas inside each given country (e.g. Bergquist et al., 2018). In other words, given that patenting patterns have changed over recent decades; likewise, looking into how the study of patents as an empirical window into innovation phenomena has itself changed becomes a compelling endeavour.

In this section, we analyse the geographical distribution of the literature citing Griliches' 1990 survey. In Fig. 4 we can observe that the US is the country where most authors citing Griliches (1990) are located. These US-based papers represent around 32% of all Griliches-citing publications, in line with the 34% US global share of total publications over the same period (also computed from WoS). Not only US-based researchers have an historical record of dominating "innovation studies" (Fagerberg and Verspagen, 2009), it should also be pointed out that Zvi Griliches was based in the US for most of his career; since researchers tend to disproportionately cite papers from their own country (Jaffe et al., 1993; Larivière, Gong, and Sugimoto, 2018), this is indeed an expected result.

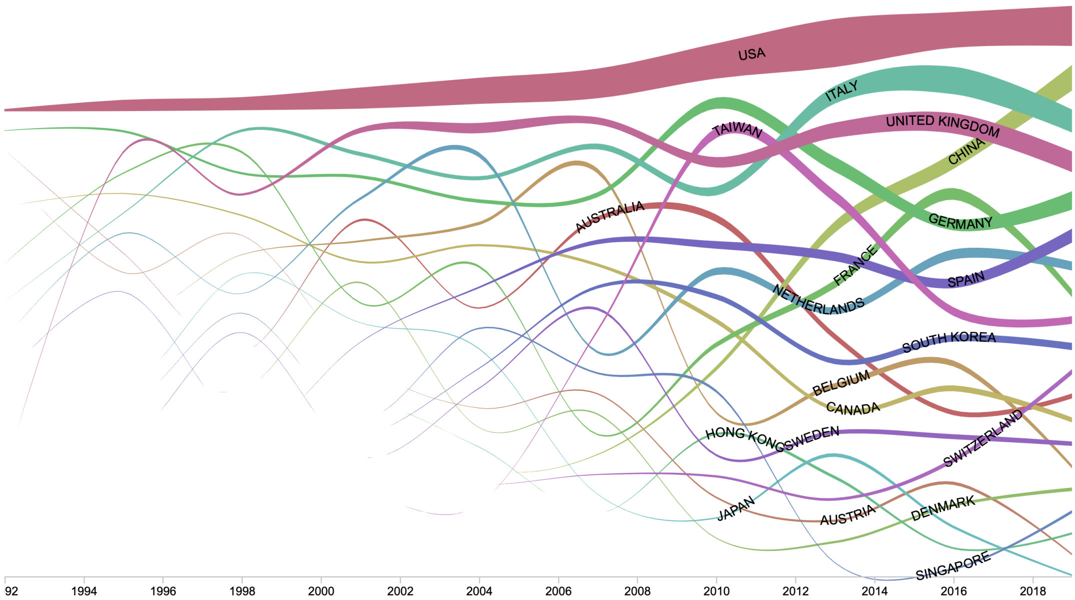
Figure 4. Countries of citing articles of Griliches (1990), 1990-2019



The next countries with a higher share of citing documents are Italy and the UK, each with 12%. Italy's position comes as somehow surprising since its global research share is substantially lower (5%). However, since Italian authors have a historical tradition in "innovation studies" using patent data (e.g. Archibugi and Pianta, 1996; Breschi et al., 2000; Malerba and Orsenigo, 1995, 1996), for those familiar with innovation studies this is likewise not an unexpected result. As for the UK, which is also above its global research share (9.4%), given that there are several academic institutions in which pioneering work in this area took place, this finding is also understandable: the SPRU group stands out (e.g. Freeman, 1982; Pavitt, 1985), but research done at LSE, UCL and Manchester has also been vibrant (e.g. Geroski et al., 1993a; Metcalfe et al., 2005; Mina et al., 2007). Germany (9%), China (7%), Spain (6%), Netherlands (6%), France (5%), Taiwan (5%) and Australia (4%) close the top 10.[13]

The previous world shares are static, aggregate figures. In order to understand the geographical dynamics of research on patent statistics, we computed the evolution of the top 20 countries (>1% of total share) with more publications citing Griliches (1990) over 1990-2019 (Fig. 5). The feature story here is China: this country rose substantially in the ranks and recently become the second country with publications citing Griliches (1990). Chinese scholars tend to focus on Chinese patenting, both at the macro (e.g. Guan and Chen, 2010; Li, 2009, 2012) and micro levels (e.g. Guan and Yam, 2015; Li, 2011).

Figure 5. Top 20 countries citing articles of Griliches (1990), 1990-2019



13 It should be pointed out that if the data in Fig. 4 and Fig. 5, were normalised relative to population, we would perceive the Netherlands, Switzerland, Belgium, Denmark and Taiwan would come as the top performers in this field.

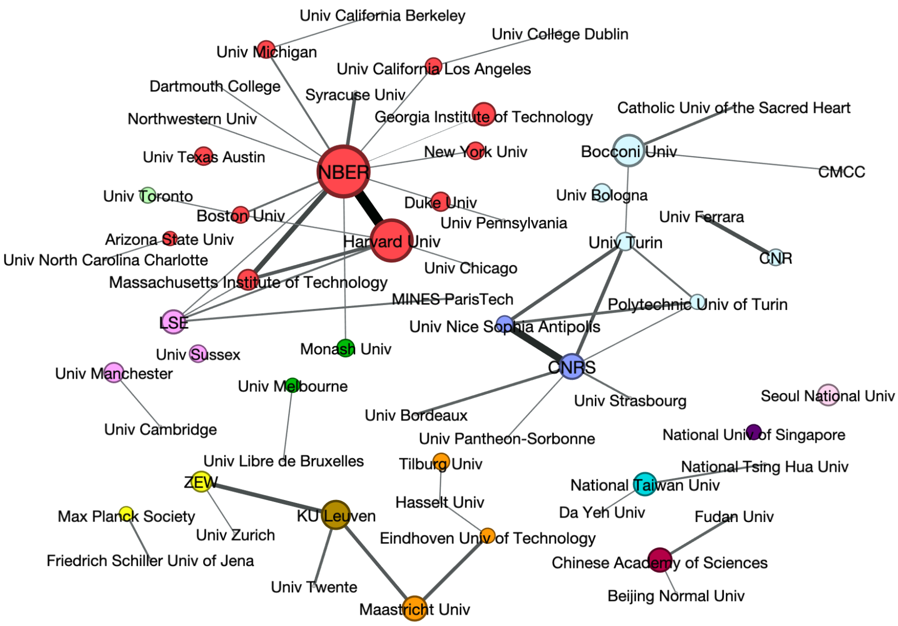
4.2. Institutional influence

To have a better understanding of the research groups and universities that are more active in citing Griliches (1990), we analysed the institutions that produced more publications and how they collaborated. Fig. 6 reports the academic players citing Griliches's survey between 1990 and 2019 (>14 pubs), and the pairing institutions that collaborated more often (>2 pubs).

Harvard University and NBER provide the organisational settings for papers citing Griliches (1990) more often. As this was precisely the framework out of which Griliches influenced, collaborated, and supervised (e.g. Ariel Pakes, Mark Schankerman, Rebecca Henderson, Iain Cockburn, Manuel Trajtenberg, Adam Jaffe, etc.)[14] in topics related to the economics of innovation, it is justifiable why those are the institutions producing more research citing his landmark work.

The collaboration network also shows two European clusters, a Belgium-Dutch-German one (including Maastricht, Eindhoven, Leuven, ZEW and Max Planck Society, among others), and an Italian-French one (including Bocconi, Turin, and Nice plus the CNRS).[15] From the UK, the LSE, Sussex and Manchester are also important universities in the network, but seem not to cooperate a lot among themselves. Conversely, Asian institutions seem to collaborate mostly within their own countries.

Figure 6. Collaboration network of most productive institutions citing Griliches (1990)



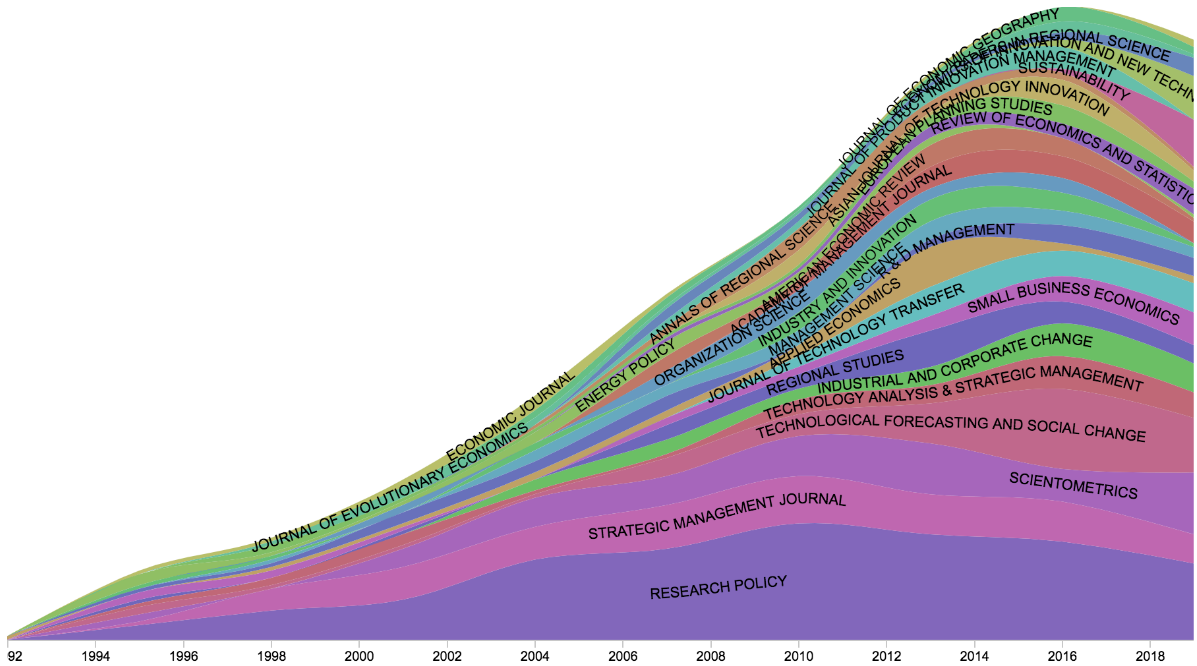
[14] http://people.bu.edu/cockburn/tree_of_zvi_4_generations.pdfaghio

[15] The first of these two clusters includes scholars like John Hagerdoorn (Maastricht) and Bart Verspagen (Maastricht and Eindhoven), Koenraad Debackere, Bart Van Looy, Rene Berderbos and Dirk Czarnitzki (KU Leuven), Dietmar Harhoff (ZEW and Max Planck Society) among others, while the second cluster includes scholars like Franco Malerba, Stefano Breschi, Luigi Orsenigo (Bocconi), Cristiano Antonelli (Turin), Francesco Lissoni (currently at Bordeaux).

4.3. Disciplinary impact

Following through the previous section of the most important actors (countries, institutions and authors), our aim now is in identifying the citation tree of research areas that are more pervasive. We start by analysing the scientific journals where the influence of Griliches (1990) was felt. In Fig. 7, out of the 394 journals in the database we plot the top 20 journals with more citing publications, which account for 42% of the publications in the citation tree.

Figure 7. Top 20 scientific journals with more citations to Griliches (1990-2019)



Around 10% of all publications citing Griliches appear in "Research Policy" (RP). RP, founded by Chris Freeman from SPRU, and which is generally acknowledged to be the leading journal in the field of "innovation studies" (Fagerberg and Verspagen, 2009; Rossetto et al., 2018; Teixeira, 2014). The papers here tend to deploy patents to address the interaction of innovation and policy relevant matters. The other journals with more than two percent of the global sample are "Scientometrics" (4.3%), "Technological Forecasting and Social Change" (3.7%), "Strategic Management Journal" (2.4%) and "Technovation" (2.3%), which are also core journals in "innovation journals" (see Fagerberg and Verspagen, 2009).

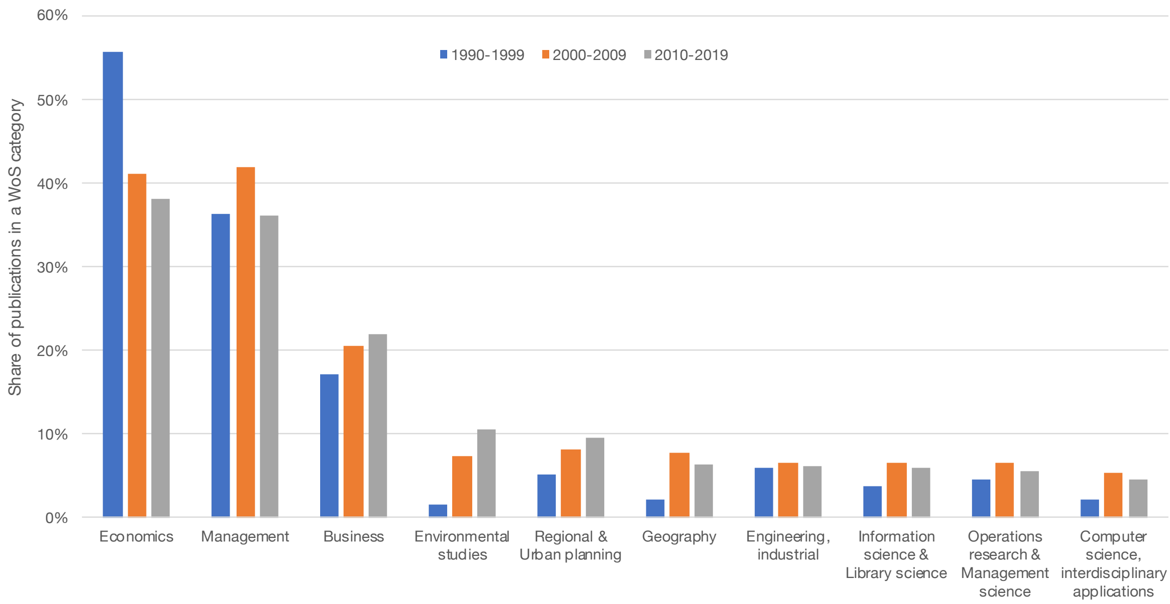
While most of the studies published in Scientometrics focus on perfecting patent analytics, many of the articles in "Technological Forecasting and Social Change" citing Griliches (1990) used patent data to analyse technological trajectories. As for the "Strategic Management Journal", a well-known business studies journal, it features many papers using patent data in relation to inter-firm knowledge flows, strategic alliances and issues related to firm performance. Closing the top

5, articles is “Technovation”, which is a journal that encompasses all facets of technological innovation, tend to use or discuss patent applications/grants as a proxy for innovation.

Interestingly, the only high-profile economics journal (Heckman and Moktan, 2020) in this ranking is the “American Economic Review”. Another remarkable aspect of Fig. 7 is that two journals seem to be “emerging” in the last period, namely “Industry and Innovation” and “Energy Policy”. This finding seems to indicate that the influence of the literature on patents as economic indicators continues to expand to new journals and specialisms.

The individual observation of journals in which the citing papers were published is a good way to assess the reach of patents as indicators in the socio-economic sciences. However, another way to assess this influence is to aggregate these journals in research areas.[16] Fig. 8 shows the distribution and dynamics of publications that cite Griliches (1990) using WoS categories in 10-year periods.

Figure 8. Top 10 disciplines taking-up Griliches (1990-2019)



The bulk of the citing papers are in “Economics”, “Management” and “Business” journals, with the relative importance of “Economics” declining, and “Management” sustaining dominance. The WoS category that has been rising mostly is “Environmental studies”, with 11% of the papers being associated to it in the most recent 10-year period (2010-2019). Other WoS categories like “Regional and Urban planning”, “Geography”, “Information science and Library science” and “Computer science, interdisciplinary applications” have also been on the rise. These results clearly

[16] Every journal covered by WoS is assigned to at least one of 252 WoS subject categories. There are journals that belong to two, three, or even four categories, but for our sample the majority of journals (42%) are associated with just a single category (e.g. “Research Policy” belongs only to the “Management” category).

demonstrate that patent statistics have been appropriated by research agendas well beyond economic sciences and business disciplines.

4.4. Research trajectories from Griliches (1990) onwards

Our findings at the aggregate level allow for an overall perspective about the configuration of the citation tree. However, the trajectories along which the literature referring to Griliches (1990) has advanced can be further tracked by examining how the citing papers are grouped in terms of the similarity of their references (i.e. bibliographic coupling). Based on our data set of 1,800 articles and using VoSviewer bibliographic coupling algorithm[17] (see Appendix), we identified five thematic research streams, as follows: 1) *Economic growth*; 2) *Geography of innovation*; 3) *Innovation management/performance*; 4) *Pat-methods*; and 5) *Green innovation*. These research streams evolved relatively independently from each other, while publications from a sixth research group (others) comprise around 35% of total publications that share a significant amount of references with those belonging to the five other groups.

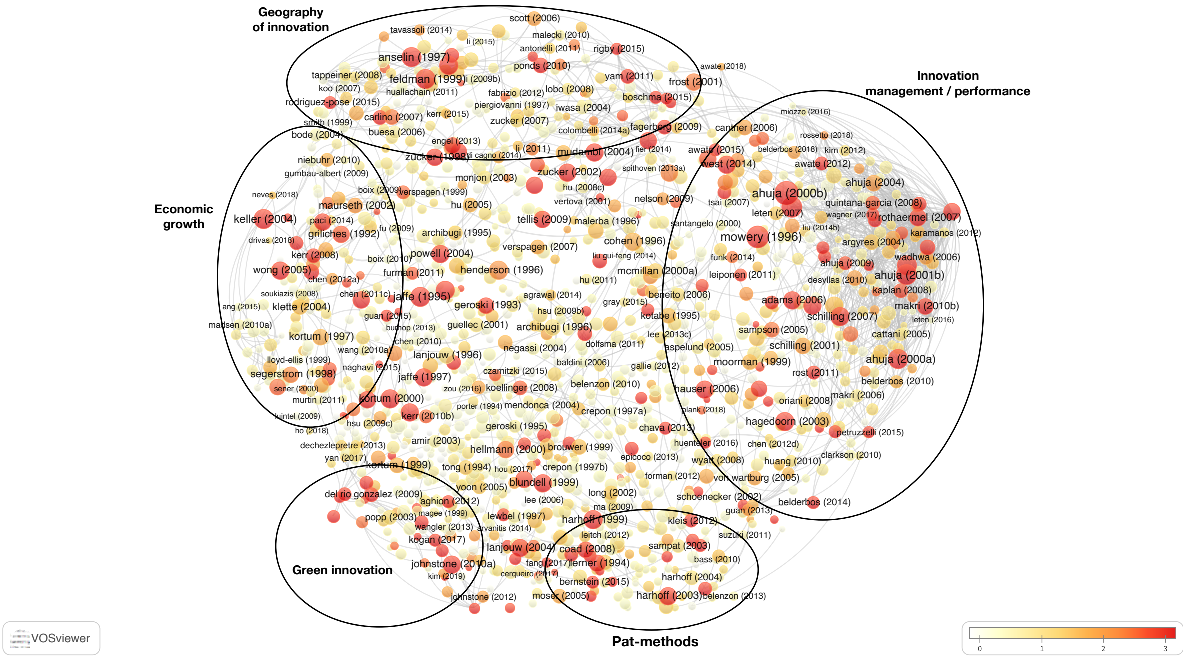
This coupling approach also facilitates the identification of the articles that are more impactful in a certain research stream. In order to control for older publications having on average more citations, we built a map of publications citing Griliches where we use both the number of citations received until 2019 for the size of the nodes, and time normalised citation impact[18] for nodes colouring (in Fig 9 red represents high impact, yellow average impact and white low impact).[19]

[17] VoSviewer software was used to build this map. VoSviewer is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations" (in https://www.vosviewer.com/).

[18] The normalized number of citations of a document equals the number of citations of the document divided by the average number of citations of all documents published in the same year and included in the data that is provided to VOSviewer. The normalization corrects for the fact that older documents have had more time to receive citations than more recent documents.

[19] This analysis was also performed by decade (1990-1999; 2000-2009, 2010-2019) in order to obtain more insights about what the most highly cited papers in each decade were and to understand if the clusters of publications were consistent over different periods. Graphs and analysis can be provided upon request.

Figure 9. Map of publications citing Griliches (1990), based on bibliographic coupling, 1990-2019



In what follows we will look into those five streams, examining at a more granular level some anchoring references within each of them.

Stream 1 (*Economic growth*) is spearheaded by econometric approaches, including the application of variations of the Cobb-Douglas production function and ways to model the macro patterns of innovation.[20] In the 1990s, this economics of R&D strand, includes Segerstrom (1998) who used a R&D-driven endogenous growth model to shed light on some puzzling economic trends of the time; Griliches (1992) which is a survey on models to capture R&D spillovers with particular attention to the analytical difficulties of coming up with robust stylised facts; and Griliches (1994), who discussed a series of issues related to productivity decline. The 2000s brought in contributions such as Keller (2004), who surveyed what is known about international technology diffusion; Wong et al. (2005) that used an augmented Cobb-Douglas production function to explore firm formation and technological innovation as separate determinants of growth; and Bottazzi and Peri (2003) who estimated the effect of research externalities in generating innovation. During the 2010s, Furman and Stern (2011) investigated how institutions shape the creation of new knowledge; Guan and Chen (2012) proposed a relational data envelopment analysis model for measuring the innovation efficiency of the national innovation system by decomposing the innovation process into a network with a two-stage innovation production framework, namely an upstream knowledge production process and a downstream knowledge commercialization

[20] The early prominent role of this research line has been greatly discussed, see Verspagen and Werker (2004) and Fagerbgerg and Verspagen (2009, p. 220).

process; and Hunt and Gauthier-Loiselle (2010) measured the extent to which skilled immigrants increase innovation in the US.

Stream 2 (*Geography of innovation*) includes several different issues such as the measurement of localised learning, university-industry relations, and technological relatedness.[21] Some crucial contributions in the 1990s include Anselin et al. (1997), who examined spatial spillovers between academic research and high-tech innovations; Feldman and Audretsch (1999) who tested whether the specialisation of economic activity within a narrow concentrated set of economic activities is more conducive to generate knowledge externalities or if diversity, by bringing together complementary activities, better promotes innovation; and Zucker et al. (1998) who studied whether the impact of research universities on nearby firms relates to identifiable market exchanges between star scientists and businesses. During the following decade, the 2000s, there were significant contributions such as Acs et al. (2002) who provided a regression-based analysis of innovation count data at low levels of geographical aggregation; Glaeser and Kerr (2009) who used Census Bureau data to study local determinants of manufacturing start-ups across cities and industries; and Carlino et al. (2007) who looked at the relation between urban density, rate of invention and knowledge spillovers. Finally, during the last decade, Ponds et al. (2010) analysed the effect of spillovers from academic research on regional innovation; Boschma et al. (2015) investigated if technological relatedness was a crucial driving force behind technological change in 366 US cities; and Rigby (2015), who mapped knowledge complexity in US cities using patent classes, and explored how the spatial diffusion of knowledge is linked to complexity.

Stream 3 (*Innovation management/performance*) one of the papers with more citations is Mowery et al. (1996), which examined interfirm knowledge transfers within strategic alliances.[22] This paper used a new measure of alliance partners' technological capabilities based on the citation patterns of their patent portfolios, which was later on taken up by many other studies. During the ensuing decade, this stream of research came to include several other highly cited papers, like those by Ahuja and colleagues (Ahuja, 2000a, 2000b; Ahuja and Katila, 2001; Ahuja and Lampert, 2001) which used a mix of network analysis and patent data to study the innovative performance of firms based on their collaboration structures. Other influential papers in this trajectory include Hagedoorn and Cloodt (2003) who studied the innovative performance of a sample of nearly 1200 companies in high-tech industries; Rothaermel and Hess (2007) who followed the dynamic capabilities perspective to test the direct effects of individual, firm, and network factors on

[21] Fagerberg and Verspagen (2009, p. 220) also detected the importance of the geographical perspective in the field of innovation studies.
[22] Meyer et al. (2004) is one of the first contributions establishing that research on innovation and industrial dynamics produced a great impact in the business school realm.

innovation output; and Schilling and Phelps (2007) who proposed that firms' cluster embeddedness was related to greater innovative output. Then, during the last decade (2010s), important contributions in this area include Makri et al. (2010) who developed a model of relatedness in high-technology mergers and acquisitions; West and Bogers (2014) who, from an open innovation perspective, reviewed how and why firms commercialise innovation springing from external; and Kaplan and Vakili (2015) who developed a text-based measure of novel ideas in patents using topic modelling to identify those patents that originate bring in new bodies of knowledge. Also, more recently, there have been many papers on the relation between financial performance of firms and patent activity (Acharya and Xu, 2017; Flammer and Bansal, 2017; Flammer and Kacperczyk, 2016; Hirshleifer et al., 2013; Kogan et al., 2017). An overarching topic within this research stream is, indeed, the relation between innovation and firm performance (e.g. Geroski et al., 1993; Blundell et al., 1999; Coad and Rao, 2008; Kogan et al., 2017).

Stream 4 (*Pat-methods*) is essentially a methodological trajectory of work, which can be seen to build upon the potential of patents as a source and a metric. There are some articles that discuss the relation between patent value, quality, and characteristics (e.g. Harhoff et al., 2003, 1999; Lanjouw and Schankerman, 2004; Sampat et al., 2003), technical issues related to the use of patent data (e.g. Jaffe and de Rassenfosse, 2017; Lerner, 1994), as well as bibliometric analysis of patent citation networks, technological trajectories and emerging technologies (e.g. Choi and Park, 2009; Mina et al., 2007; Verspagen, 2007).

Finally, **Stream 5 (*Green innovation*)** is relatively smaller and includes more recent articles. The oldest ones we could identify are from Jaffe et al. (1995), who assessed the linkage between environmental regulation and competitiveness, and Jaffe and Palmer (1997) who focus more closely on the stimuli to domestic innovation vis-à-vis foreign competitors. During the 2000s del Río González (2009) produced a review on the determinants of environmental technological change; Popp (2002) used US patent data to estimate the effect of energy prices on energy-efficient innovations; and Fischer and Newell (2008) assessed different policies for reducing carbon dioxide emissions and their impact on renewable energy. In the 2010s, Johnstone et al. (2010) examined the effect of environmental policies again on the specific case of renewables innovation; Rubashkina et al. (2015) investigated the environmental upgrades of manufacturing sectors of 17 European countries; and Costantini et al. (2017) who performed an empirical investigation policy mixes inducing innovation in energy efficient technologies.

A decade-by-decade account of the resulting allocation is displayed in Table 1. The number of articles increased almost nine times from 1990-1999 to 2010-2019. Overtime the structure of publication also got richer and more thematically balanced.[23] Regarding the classified pieces of research we perceive a wave-like succession of streams, with *Economic growth* being the first to raise steam, and *Geography of innovation* as a close second. The *Innovation management/performance* stream becomes a mainstay of patent analysis already by the early 2000s, maintaining thrust henceforth. The *Pat-methods* stream, with its focus on metrics and broader analytical issues, really jumps off in the 2000s and keeps strong momentum in the following period. The stream pursuing *Green Innovation* breaks through in the 2010s, sporting the remarkably robust dynamics in relation to the previous decade and in comparison with other streams.[24]

Table 1. Patent-based research streams over time

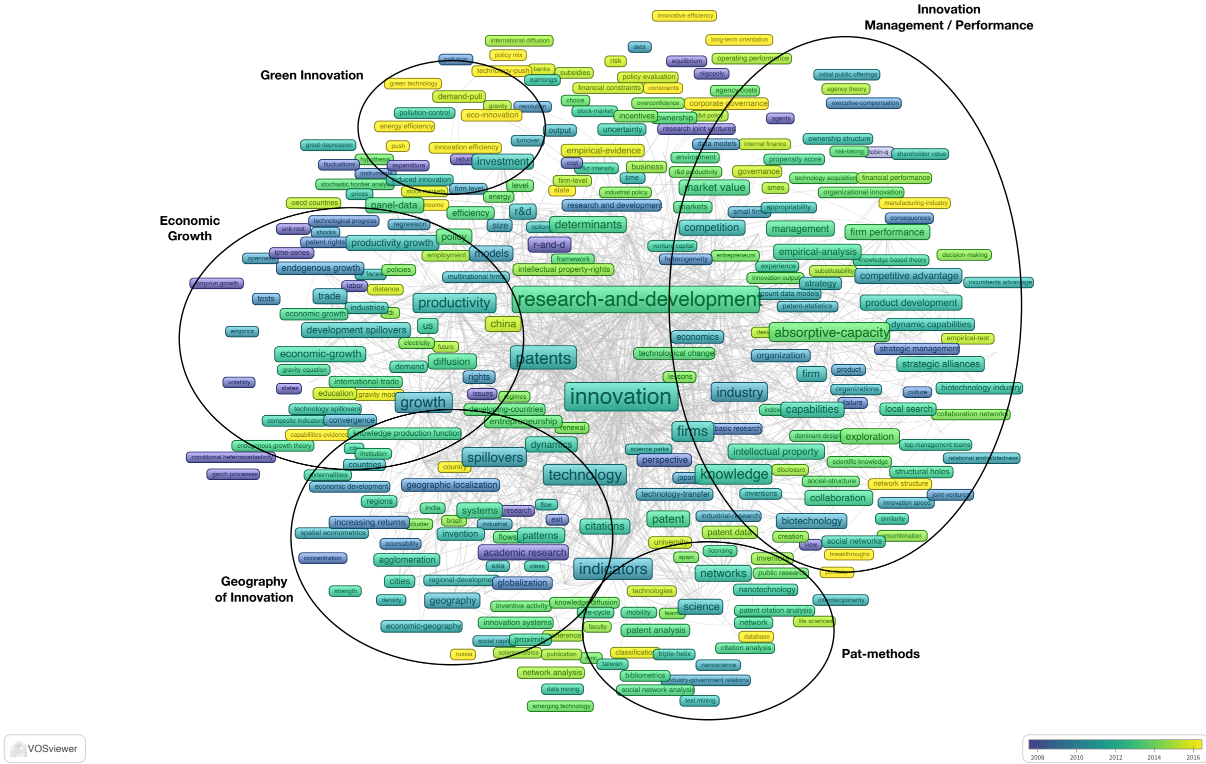
	1990-1999	2000-2009	2010-2019
Economic growth	17	64	120
Geography of innovation	12	84	162
Innovation management/performance	9	98	236
Pat-methods	3	38	188
Green Innovation	6	26	108
Others	88	190	351
Total	135	500	1165

4.5. What do keywords tell us about the major research trajectories

Our previous findings helped us identify broad research themes that unfolded after Griliches contribution. However, we are also interested in comprehending what specific research topics have been pursued (concepts, phenomena, questions), and which ones have been emerging more recently. Fig. 10 shows a co-occurrence map of keywords that appear most frequently in the citing articles. On the map, larger keywords are those that appear more often; keywords that tend to co-occur in the same publications appear closer together; and keywords with a lighter colour (yellow) are topics that, on average, appear in more recent publications.

[23] An analysis of percentage shares shows that a classic concentration indicator goes down through the years. Using the Hirshmann-Herfindahl index in five-year intervals shows it dropping dramatically until 2015, being stable after that.
[24] The chronology was established as follows: 1) the median date of publication was taken as time-anchor for every stream; 2) two ties were observed (streams 2/3 and 4/5). In these cases, the chronological order was established by defining an older stream as the one which as the older first paper per stream.

Figure 10. Map of keywords appearing in publications citing Griliches (1990), 1990-2019



Interestingly, Fig. 10 allows for the identification of the same five literature streams and suggests a further set of findings. First, keywords like "innovation", "research-and-development" and "technology" appear more often, compared with all the other keywords, and are central in the network (which means that they co-occur very often with all other terms). Second, cluster 5) "Green innovation" seem to include many emerging keywords such as "green technology", "energy efficiency" and "eco-innovation". Other frequent keywords in each of these clusters are "absorptive capacity", "competitive advantage" and "strategic alliances" in cluster 3 (Innovation management / performance); "spillovers", "agglomeration" and "economic geography" in cluster 2 (Geography of innovation); "productivity", "endogenous growth" and "growth" in cluster 1 (Economic growth); and "patent citation analysis", "patent data" and "networks" in cluster 4 (Pat-methods).

4.6. Taxonomy of literature on patents as economic indicators

The analysis in sections 4.2 to 4.5 offers perspectives about how the literature on patents as economic indicators has evolved.[25] In order to summarize it, we present a taxonomy in Table 2

[25] It should be noted that as it could be expected there are other papers covering a diversity of innovation-related matters that are not directly covered by our streams (see red area in Fig. A1 in Appendix). Some of these are highly cited articles and deal with a variety of issues ranging from theoretical (Fagerberg and Verspagen, 2009; Freeman, 1994; Powell and Snellman, 2004) to empirical

that includes information about each stream over each of the three observed decades concerning: i) the estimated number of publications citing Griliches; ii) what were the most relevant keywords (topics), iii) highly cited articles, and iv) journals of choice.

Determining the accuracy of a taxonomy of scientific knowledge using bibliometric methods is a challenge (Klavans and Boyack, 2017). In Table 2 we tried to triangulate the different methods we applied (Figures 7, 8, 9, 10 and A.3) in order to achieve a coherent result. This exercise allows us to produce a set of key observations. First, from the keyword analysis we can observe that the topics covered by this literature are vast and evolved in directions that Zvi Griliches surely did not have in mind (e.g. "open innovation", "eco-innovations"). Second, research streams vary in size with "Innovation management/performance" being the major one with 20% of publications, and "Green Innovation" the smaller with 8% of publications. Third, a journal specialisation (i.e. the context for publication) for the different streams is also observable.

contributions about the knowledge-based economy (Archibugi and Pianta, 1996; Arundel and Kabla, 1998; Hagedoorn and Cloodt, 2003).

Table 2. Taxonomy of literature on patent statistics

Stream	Period	Pubs per period	Frequent keywords	Theme/Research question of highly cited articles	Journal of article
Economic Growth	90s	+	Productivity growth	Productivity, research-and-development, and the data constraint. (Griliches, 1994)	*American Economic Review*
Median year: 2011	00s	+++	Technology diffusion	What determines the effectiveness of technology diffusion in the World? (Lerner, 2004)	*J. of Economic Literature*
	10s	++++++	Total factor productivity	New measure of the economic importance of each innovation that exploits the stock market response to news about patents. (Kogan et al., 2017)	*The Quarterly J. of Economics*
Geography of Innovation	90s	+	Tacit knowledge	Is the specialization/diversity of economic activities more conducive to knowledge spillovers and innovation? (Feldman and Audretsch, 1999)	*European Economic Review*
Median year: 2012	00s	++++	Agglomeration	Patents and innovation count as measures of regional production of new knowledge (Acs et al., 2002)	*Research Policy*
	10s	++++++++	Knowledge spillovers	Was technological relatedness at the city level a driving force behind technological change in 366 US cities from 1981 to 2010? (Boschma al., 2015)	*Industrial and Corporate Change*
Innovation Management / Performance	90s	.	Strategic alliances	To what extent there are interfirm knowledge transfers within strategic alliances? (Mowery et al., 1996)	*Strateg. Manag. Journal*
Median year: 2012	00s	+++++	Dynamic capabilities	What are the effects of a firm's network of relations on innovation? (Ahuja, 2000)	*Admin. Science Quarterly*
	10s	++++++++++++	Open Innovation	Reviews research on open innovation that considers how and why firms commercialize external sources of innovations (West and Bogers, 2014)	*J. of Product Innovation Manag*
Pat-methods	90s	.	Indicators	Do highly cited patents have more economic value? (Harhoff et al., 1999)	*Review of Economics and Statistics*
Median year: 2014	00s	++	Network analysis	Are the number of references to the patent literature as well as the citations a patent receives positively related to its value? (Harhoff et al., 2003)	*Research Policy*
	10s	+++++++++	Citation analysis	Discusses the uses of patent citation data in social science research. (Jaffe and Rassenfosse, 2017)	*J. of the Assoc. for Inf. S.Science and Tech.*
Green Innovation	90s	.	Environmental regulation	What are the effects of environmental regulations on the competitiveness of firms? (Jaffe et al., 1995)	*J. of Economic Literature*
Median year: 2014	00s	+	Induced innovation	What are the right environmental and technology policies for climate mitigation? (Fischer and Newell, 2008)	*J. of Environmental Economics and Management*
	10s	+++++	Eco-innovation	Can directed technical change be used to combat climate change? (Aghion et al., 2016)	*J. of Political Economy*

Note 1: The amount of publications per decade in 3rd column is calculated based on the cluster analysis in section 4.4 (bibliographic coupling); Each "+" corresponds roughly to 20 publications; **Note 2**: There are 629 publications citing Griliches (1990) that were not assigned to any stream. **Note 3:** The top3 keywords were obtained by: 1) analysing Fig. 9; 2) ranking all keywords appearing in the publications in each WoS category; dropping the less frequent ones (less than 2% of publications); calculating the Bella Ballassa index for each keyword by having as a denominator the total number of occurrences of that keyword in the sample; 3) comparing top keywords in 1) and 2). The top3 keywords in each theme should not be seen as the most frequent ones (those are in all categories "innovation" and "research-and-development"), but the keywords that are specific to the category (relative specialization). **Note 4:** The articles in the 5th column were selected based on the analysis of the most highly cited articles in each period (Fig. 10)

4.7. Emerging trends

While our approach allows us to capture the main streams of research that cite Griliches (1990), and some of their key characteristics (topics, highly-cited papers, journals), over three decades, it only brings us so far in terms of understanding what are the new trends of usage of patent data. Therefore, we carried out a sensitivity analysis looking into recent studies. In order to guide our search, we analyse the latest research articles (2019 and 2020) citing Griliches (1990) and we match them to the five research streams that were previously identified in section 4.4. We complement this analysis by also including highly-cited articles from 2019 and 2020 found using the query that generated the results presented in Fig. 3, which fit our five streams.[26]

As far as the *Economic growth* is concerned, we witness the continuation of the trajectories related to the use of endogenous growth models to understand long-run research problems and, increasingly, the relations between finance and innovation. Recent studies include Anzoategui et al. (2019) who implement an endogenous growth model to examine the hypothesis of secular productivity slowdown, and Diebolt and Hippe (2019) who rely on patents to analyse the historical impact of human capital on innovation. At the same time, some studies have capitalised on novel combinations of creative data sources like innovation announcements, analyst forecasts, newspaper items, and stock market valuation (Billings et al., 2020; Hussinger and Pacher, 2019). Thus, historical work and new indicator combinations appear to be extending this trajectory.

Some recent explorations regarding local and global innovation patterns can also be seen as stretching forward the *Geography of innovation* stream. Ever richer patent datasets have been used to identify major innovation clusters as well as to map and measure co-inventor networks (Balland et al., 2020; Graf and Broekel, 2020; Grashof et al., 2019; van der Wouden and Rigby, 2019). Other developments have been a trans-territorial focus on inventor mobility, migration and diasporas (Bell et al., 2019) and the place-based dynamics of university-industry interactions through student spin-offs and academic inventors (Breznitz and Zhang, 2019; Quatraro and Scandura, 2019). In other words, this research strand is being stretched by the usage of more detailed data and mobility-sensitive approaches.

In relation to the *Innovation management/performance* stream, patents have been used recently to profile and evaluate the rise and influence of a number of characteristics/settings, namely business models and innovation practices. Examples include the influence of automation (Furman and Teodoridis, 2020), digital technologies (Forman and Goldfarb, 2020), openness to external

[26] We read the titles and abstracts of all publications citing Griliches in 2019 and 2020, plus the titles and abstracts of the top10% highly cited publications (as of April 29, 2021) in 2019 and 2020 using our Fig. 3 query.

knowledge (Subtil Lacerda and van den Bergh, 2020; Wang et al., 2020), corporate governance forms (Chemmanur et al., 2019; Custódio et al., 2019; Flammer et al., 2019; López and Vives, 2019), and team size (Wu et al., 2019) and a diversity of public policies such as R&D subsidies, direct governmental alliances and public procurement (Atanassov and Liu, 2020; Bellucci et al., 2019; Buchmann and Kaiser, 2019; Clò et al., 2020; Crespi and Guarascio, 2019; Doblinger et al., 2019). That is to say, this stream is being propelled forward by incorporating more holistic frameworks, namely from the business and cross-organisational/trans-sectoral perspectives.

There are also novel developments in the creation of patent data sources and methods, which can be seen as enhancing the *Pat-methods* trajectory. For instance, the application of text-mining techniques (e.g. natural language processing, semantic-based analysis) is opening possibilities to analyse the entire technical content available in patent documents so as to provide information regarding novelty, impact and research-innovation interaction (Arts et al., 2020). There also has been a re-vamping of patents to build new indicators that transform qualitative into quantitative data and to studying hard-to-measure disruptive innovations like artificial intelligence and FinTech (Fujii and Managi, 2018; Lerner et. al., 2020; Rizzo et al., 2020;). Likewise, the distinctiveness of the patent contents has been further explored, looking for example into standard-setting patents (Bekkers et al., 2020) or the citation distributions of patents and its methodological implications (Kuhn et al., 2020). Other work has emphasised new uses of patent meta-data, namely regarding the activity of examiners themselves or judges' allocation in court disputes (Righi and Simcoe, 2019). Hence, this research stream is being fuelled by new big data techniques, while niche-type institutional aspects of patents are entering to the fore more systematically.

Finally, the *Green innovation* stream is becoming ever more vibrant and diverse. Recent studies look at the nature and impact of green innovation (Barbieri et al., 2020; Perruchas et al., 2020), factors influencing innovation in renewable energy technologies (Lin and Chen, 2019; Sun et al., 2019), the interplay between firm characteristics and the advance of cleaner solutions (Leoncini et al., 2019), and the effects of environmental innovation on climate change (Du et al., 2019; Töbelmann and Wendler, 2020).

Overall, three decades on, it would seem that lots of mileage is yet to be obtained from patent statistics (either in terms of methods or applications) and also that Zvi Griliches' classic paper is still a leading light. Patent usage is contingent on the appearance of both new research problems and research methods, which have moved well beyond the econometrics of R&D. The five research streams we identified seem to point to main pathways through which the analytical value of patents has been, and continues to be, appropriated.

A final word by Griliches himself can perhaps be gleaned from a "time capsule". In the end of a "warm-up" session at the Brookings Institution to his 1990 contribution, we have the minutes of the debate than ensued. In noting that the diffusion process that takes place after a major breakthrough, Griliches (1989, p. 330) said: "it takes a long time for these ideas to be put into effect in enough places to have a significant impact on productivity in the alleged time frame" Indeed, so much could be said his path-breaking work on using patents to relax the data constraint in the study of innovation. In the end of the day, his insights were appropriated (absorbed but also adapted) by a variety of players and through a number of streams of research pursuing different analytical routes and aiming at different goals.

5. Conclusions

In an interview, Zvi Griliches said that "It's interesting to model how the knowledge spreads" (Krueger and Taylor, 2000). In our paper, we tried to understand how learning induced by Griliches (1990) impacted the practices and agendas of the academic community. Our review of the literature on the empirics of patent analysis differs significantly from previous ones, as we carefully examined three decades of research through a comprehensive analysis of the citation tree of a crucial contribution. Moreover, we offer an up-to-date taxonomy of the research trajectories: a prism on innovation studies through the perspective afforded by patent data.

Appearing at the turn of a new decade in which market-driven globalisation and technology-based competitiveness would be key, Griliches (1990) became a springboard for the development of the empirical study of economic and societal change. This paper, produced by an already famous American expert on technical change and delivered in a top mainstream economics journal, hit a nerve: the computer revolution was well under way, facilitating the availability and processing of the data, and the world economic environment was at a turning point, providing the motivation to understand new trends of competition and cooperation from a knowledge-based perspective. The empirical value of patents, which he decisively helped to unleash, can be partially but firmly grasped by the sheer volume, prominence, variety, and profile of the subsequent research. Overall, we found that Griliches (1990) was cited by nearly 2,000 papers in almost 400 different journals in WoS from 1990 until 2019, suggesting a very deep imprint and broad spectrum of influence.

From a bibliometric perspective, the analysis along two main dimensions yielded the first results. On the one hand, the geographical dimension reveals a prolific US-based cluster of contributions and a couple of European-based clusters (conspicuously an Italian-French cluster and a Belgium-Dutch-German cluster), while Chinese researchers are a recent but productive entrant in this kind of literature, seemingly collaborating mostly among themselves. On the other hand, a disciplinary dimension reveals that economics and management studies remain hegemonic throughout the period, but with environmental and regional studies increasing their importance over time. That is, we learn that the research referring to patent data achieves wide reception and high notoriety in a variety of areas (in the Western hemisphere, and increasingly in the Far East), but also that it recently attracted interest from emerging fields (especially those concerned with geography and the environment).

From a content perspective, keyword trends and bibliographic coupling patterns yielded further insight. We detect five distinguishable research streams that use and/or discuss patents as indicators. The vast majority of the research seems to be on issues related to *Innovation management/performance* (around topics such as "dynamic capabilities" and "strategic alliances"), *Geography of innovation* (e.g. "knowledge spillovers", "agglomeration"), and *Economic growth* (e.g. "productivity growth", "competitiveness"). However, a *Pat-methods* stream is also discernible, which dabbles on several methodological issues and techniques (including citation networks or text mining) which have been contributing to get new insights from patent analysis. Finally, new research rising in importance in recent years is related to *Green innovation* (e.g. "renewable energy", "eco-innovation"), a distinct stream that has gained prominence and addresses what will be a defining global challenge in the 21st century.

The examination of the scientometric life of Griliches' survey adds, updates and brings a systematic overview to what is being practiced in terms of patent-based empirical research. Our contribution provides evidence that patents as an indicator are quite elastic and adaptable as time goes by. The tracking of the citation tree of Griliches (1990) over time shows that patents, which in the original terminology of Griliches were seen as "economic statistics", have become better understood as "innovation indicators" serving a variety of research agendas. Patent statistics were introduced to economic analysis within a given context, specifically those already developed countries from the Northern hemisphere specialised in high-tech industries. Nonetheless, the research programme was able to incorporate the needs of new global actors, like communities of researchers in catching-up countries, and the growing concerns stemming from sustainability pressures. In sum, the agenda initially articulated by Griliches (1990) has been expanding continuously, and although there are at least five discernible streams constituting the dominant research trajectories, it is also clear that patent data can be continuously repurposed.

Several caveats must be borne in mind with regard to our study. First, in sections 4.1-4.6 our dataset includes only publications that cite Griliches (1990) on WoS database between 1990 and

2019. We do not include publications from authors that use or discuss patents in their work and did not cite this paper. Additionally, although we rely on clustering techniques together with reasoned interpretation to identify research trajectories, the research streams could be examined at a more detailed/fine-grained level which might reveal some other sub-streams. Also, in section 4.7 we choose publications partially based on the number of citations they received until April 30, 2021 meaning that, since the time citation window is very limited, we might certainly be miss out other relevant "emerging" themes in our analysis. These shortcomings, in turn, point to possibilities for further research. First, the bibliographic material can be expanded. Second, other clustering algorithms may be trialled. Third, less restricted methods for identifying new trends in patent analysis will allow further contributions regarding the widening uses (and abuses) of patent data.

Griliches saw himself as an empirical scientist concerned with the analysis of real data. In his 1994 Presidential address to the American Economic Association, he referred to what was perhaps his major legacy. Despite acknowledging that "our understanding of what is happening in our economy (and in the world economy) is constrained by the extent and quality of the available data" (Griliches, 1994, p. 2), he clearly set an agenda for doing something about it. According to him, progress was attainable by paying adequate attention to how data is produced, the institutional underpinning of the sources of chance and, importantly, to the productivity promise of technical progress to both the economy and its study, namely through the application of the increasing computational capabilities. In what concerns patent data, he was well aware of methodological problems. But like the proverbial image with which he ends his Presidential address, he thought to be misleading to see the glass half full; then as now, "the glass keeps growing" (Griliches, 1994, p. 18). The same can be said about the reservoir of possibilities yielded by patents after his call to arms. There was much to learn regarding patent statistics back then; but more is there to learn as the knowledge frontiers keep expanding. Indeed, in the introduction of the book collecting a number of his foremost papers, Griliches (1998, p. 10) remarked about his 1990 survey: "I was under the illusion that we had mined out this topic and was closing the subject." Fortunately, as our contribution shows, and thanks to the lessons that can be traced back to his own work, the subject is far from being closed.

References

Acharya, V., Xu, Z., 2017. Financial dependence and innovation: The case of public versus private firms. J. financ. econ. 124, 223–243. doi:10.1016/j.jfineco.2016.02.010

Acs, Z.J., Anselin, L., Varga, A., 2002. Patents and innovation counts as measures of regional production of new knowledge. Res. Policy 31, 1069–1085. doi:10.1016/S0048-7333(01)00184-6

Acs, Z.J., Audretsch, D.B., 1990. Innovation and small firms. MIT Press.

Acs, Z.J., Audretsch, D.B., 1989. Patents as a Measure of Innovative Activity. Kyklos 42, 171–180. doi:10.1111/j.1467-6435.1989.tb00186.x

Aghion, P., Howitt, P., 1992. A Model of Growth Through Creative Destruction. Econometrica 60, 323. doi:10.2307/2951599

Ahuja, G., 2000a. Collaboration Networks, Structural Holes, and Innovation: A Longitudinal Study. Adm. Sci. Q. 45, 425–455. doi:10.2307/2667105

Ahuja, G., 2000b. The duality of collaboration: Inducements and opportunities in the formation of interfirm linkages. Strateg. Manag. J. 21, 317–343.

Ahuja, G., Katila, R., 2001. Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study. Strateg. Manag. J. 22, 197–220. doi:10.1002/smj.157

Ahuja, G., Lampert, C.M., 2001. Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions. Strateg. Manag. J. 22, 521–543. doi:10.1002/smj.176

Almeida, P., Kogut, B., 1999. Localization of knowledge and the mobility of engineers in regional networks. Manage. Sci. 45, 905–917. doi:10.1287/mnsc.45.7.905

Andreoni, J., 1990. Impure Altruism and Donations to Public Goods : A Theory of Warm-Glow Giving Author (s): James Andreoni Published by : Wiley on behalf of the Royal Economic Society Stable URL : http://www.jstor.org/stable/2234133 Accessed : 02-03-2016 06 : 35 UTC Your. Econ. J. 100, 464–477.

Angrist, J., Azoulay, P., Ellison, G., Hill, R., Lu, S.F., 2020. Inside Job or Deep Impact? Extramural Citations and the Influence of Economic Scholarship. J. Econ. Lit. 58, 3–52. doi:10.1257/jel.20181508

Anselin, L., Varga, A., Acs, Z., 1997. Local Geographic Spillovers between University Research and High Technology Innovations. J. Urban Econ. 42, 422–448. doi:10.1006/juec.1997.2032

Anzoategui, D., Comin, D., Gertler, M., Martinez, J., 2019. Endogenous technology adoption and R & D as sources of business cycle persistence. Am. Econ. J. Macroecon. 11, 67–110. doi:10.1257/mac.20170269

Archibugi, D., 1992. Patenting as an indicator of technological innovation: A review. Sci. Public Policy 19, 357–368. doi:10.1093/spp/19.6.357

Archibugi, D., Pianta, M., 1996. Measuring technological change through patents and innovation surveys. Technovation 16, 451–468. doi:10.1016/0166-4972(96)00031-4

Arrow, K.J., 2012. The Economics of Inventive Activity over Fifty Years, in: Lerner, J., Stern, S. (Eds.), The Rate and Direction of Inventive Activity Revisited. University of Chicago Press, pp. 43–48. doi:10.7208/CHICAGO/9780226473062.003.0004

Arts, S., Hou, J., Gomez, J.C., 2020. Natural language processing to identify the creation and impact of new technologies in patent text: Code, data, and new measures. Res. Policy 104144. doi:10.1016/j.respol.2020.104144

Arundel, A., Kabla, I., 1998. What percentage of innovations are patented? Empirical estimates for European firms. Res. Policy 27, 127–141. doi:10.1016/S0048-7333(98)00033-X

Atanassov, J., Liu, X., 2020. Can corporate income tax cuts stimulate innovation? J. Financ. Quant. Anal. doi:10.1017/S0022109019000152

Balland, P.-A., Rigby, D., 2017. The Geography of Complex Knowledge. Econ. Geogr. 93, 1–23. doi:10.1080/00130095.2016.1205947

Balland, P.A., Jara-Figueroa, C., Petralia, S.G., Steijn, M.P.A., Rigby, D.L., Hidalgo, C.A., 2020. Complex economic activities concentrate in large cities. Nat. Hum. Behav. 4, 248–254. doi:10.1038/s41562-019-0803-3

Barbieri, N., Marzucchi, A., Rizzo, U., 2020. Knowledge sources and impacts on subsequent inventions: Do green technologies differ from non-green ones? Res. Policy 49, 103901. doi:10.1016/j.respol.2019.103901

Barro, R., 1990. Government Spending in a Simple Model of Endogeneous Growth. J. Polit. Econ. 98.

Basberg, B.L., 1987. Patents and the measurement of technological change: A survey of the literature. Res. Policy 16, 131–141. doi:10.1016/0048-7333(87)90027-8

Baumol, W.J., 1990. Entrepreneurship : Productive, Unproductive, and Destructive. J. Polit. Econ. 98, 893–921.

Bekkers, R., Martinelli, A., Tamagni, F., 2020. The impact of including standards-related documentation in patent prior art: Evidence from an EPO policy change. Res. Policy 49, 104007. doi:10.1016/j.respol.2020.104007

Bell, A., Chetty, R., Jaravel, X., Petkova, N., Van Reenen, J., 2019. Who becomes an inventor in America? The importance of exposure to innovation. Q. J. Econ. 134, 647–713. doi:10.1093/qje/qjy028

Bellucci, A., Pennacchio, L., Zazzaro, A., 2019. Public R&D Subsidies: Collaborative versus Individual Place-Based Programs for SMEs. Small Bus. Econ. 52, 213–240.

Bessen, J., Meurer, M.J., 2008. Patent failure : how judges, bureaucrats, and lawyers put innovators at risk. Princeton University Press.

Billings, B.K., Moon, J.R., Morton, R.M., Wallace, D.M., 2020. Can Employee Stock Options Contribute to Less Risk-Taking? Contemp. Account. Res. 37, 1658–1686. doi:10.1111/1911-3846.12562

Blundell, R., Griffith, R., Van Reenen, J., 1999. Market share, market value and innovation in a panel of British manufacturing firms. Rev. Econ. Stud. 66, 529–554. doi:10.1111/1467-937X.00097

Boschma, R., Balland, P.A., Kogler, D.F., 2015. Relatedness and technological change in cities: The rise and fall of technological knowledge in US metropolitan areas from 1981 to 2010. Ind. Corp. Chang. 24, 223–250. doi:10.1093/icc/dtu012

Bottazzi, L., Peri, G., 2003. Innovation and spillovers in regions: Evidence from European patent data. Eur. Econ. Rev. 47, 687–710. doi:10.1016/S0014-2921(02)00307-0

Breschi, S., Malerba, F., Orsenigo, L., 2000. Technological Regimes and Schumpeterian Patterns of Innovation. Econ. J. 110, 388–410.

Breznitz, S.M., Zhang, Q., 2019. Fostering the growth of student start-ups from university accelerators: an entrepreneurial ecosystem perspective. Ind. Corp. Chang. 28, 855–873. doi:10.1093/icc/dtz033

Brouwer, E., Kleinknecht, A., 1999. Innovative output, and a firm's propensity to patent. An exploration of CIS micro data. Res. Policy 28, 615–624. doi:10.1016/S0048-7333(99)00003-7

Buchmann, T., Kaiser, M., 2019. The effects of R&D subsidies and network embeddedness on R&D output: evidence from the German biotech industry. Ind. Innov. 26, 269–294. doi:10.1080/13662716.2018.1438247

Cabral, L.M.B., 2017. Introduction to industrial organization. The MIT Press, Cambridge, Mass.

Carlino, G.A., Chatterjee, S., Hunt, R.M., 2007. Urban density and the rate of invention. J. Urban Econ. 61, 389–419. doi:10.1016/j.jue.2006.08.003

Carlton, D.W., Perloff, J.M., 2015. Modern industrial organization, Fourth Edi. ed, The Addison-Wesley series in economics. Pearson Education Limited.

Chavarro, D., Tang, P., Rafols, I., 2017. Why researchers publish in non-mainstream journals: Training, knowledge bridging, and gap filling. Res. Policy 46, 1666–1680. doi:10.1016/J.RESPOL.2017.08.002

Chemmanur, T.J., Kong, L., Krishnan, K., Yu, Q., 2019. Top Management Human Capital, Inventor Mobility, and Corporate Innovation. J. Financ. Quant. Anal. 54, 2383–2422. doi:10.1017/S0022109018001497

Choi, C., Park, Y., 2009. Monitoring the organic structure of technology based on the patent development paths. Technol. Forecast. Soc. Change 76, 754–768. doi:10.1016/j.techfore.2008.10.007

Clò, S., Florio, M., Rentocchini, F., 2020. Firm ownership, quality of government and innovation: Evidence from patenting in the telecommunication industry. Res. Policy 49, 103960. doi:10.1016/j.respol.2020.103960

Coad, A., Rao, R., 2008. Innovation and firm growth in high-tech sectors: A quantile regression approach. Res. Policy 37, 633–648. doi:10.1016/j.respol.2008.01.003

Comanor, W.S., Scherer, F.M., 1969. Patent Statistics as a Measure of Technical Change. J. Polit. Econ. 77, 392–398. doi:10.1086/259522

Confraria, H., Ferreira, V.H., Mira, M., 2021. Emerging 21st Century technologies: Is Europe still falling behind? (No. 0188–2021), REM Working Paper Series. Lisbon.

Costantini, V., Crespi, F., Palma, A., 2017. Characterizing the policy mix and its impact on eco-innovation: A patent analysis of energy-efficient technologies. Res. Policy 46, 799–819. doi:10.1016/j.respol.2017.02.004

Crespi, F., Guarascio, D., 2019. The demand-pull effect of public procurement on innovation and industrial renewal. Ind. Corp. Chang. 28, 793–815. doi:10.1093/icc/dty055

Custódio, C., Ferreira, M.A., Matosc, P., 2019. Do general managerial skills spur innovation? Manage. Sci. 65, 459–476. doi:10.1287/mnsc.2017.2828

David, P., 2005. Zvi Griliches on Diffusion, Lags and Productivity Growth …Connecting the Dots. Labor Demogr.

del Río González, P., 2009. The empirical analysis of the determinants for environmental technological change: A research agenda. Ecol. Econ. 68, 861–878. doi:10.1016/j.ecolecon.2008.07.004

Diamond, A.M., 2004. Zvi Griliches's contributions to the economics of technology and growth*. Econ. Innov. New Technol. 13, 365–397. doi:10.1080/10438590410001629043

Diebolt, C., Hippe, R., 2019. The long-run impact of human capital on innovation and economic development in the regions of Europe. Appl. Econ. 51, 542–563. doi:10.1080/00036846.2018.1495820

Du, K., Li, P., Yan, Z., 2019. Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. Technol. Forecast. Soc. Change 146, 297–303. doi:10.1016/j.techfore.2019.06.010

Dziallas, M., Blind, K., 2019. Innovation indicators throughout the innovation process: An extensive literature analysis. Technovation. doi:10.1016/j.technovation.2018.05.005

Fagerberg, J., 2003. Schumpeter and the revival of evolutionary economics: An appraisal of the literature. J. Evol. Econ. 13, 125–159. doi:10.1007/s00191-003-0144-1

Fagerberg, J., Verspagen, B., 2009a. Innovation studies—The emerging structure of a new scientific field. Res. Policy 38, 218–233. doi:10.1016/J.RESPOL.2008.12.006

Fagerberg, J., Verspagen, B., 2009b. Innovation studies-The emerging structure of a new scientific field. Res. Policy 38, 218–233. doi:10.1016/j.respol.2008.12.006

Feldman, M.P., Audretsch, D.B., 1999. Innovation in cities: Science-based diversity, specialization and localized competition. Eur. Econ. Rev. 43, 409–429. doi:10.1016/S0014-2921(98)00047-6

Fischer, C., Newell, R.G., 2008. Environmental and technology policies for climate mitigation. J. Environ. Econ. Manage. 55, 142–162. doi:10.1016/j.jeem.2007.11.001

Flammer, C., Bansal, P., 2017. Does a long-term orientation create value? Evidence from a regression discontinuity. Strateg. Manag. J. 38, 1827–1847. doi:10.1002/smj.2629

Flammer, C., Hong, B., Minor, D., 2019. Corporate governance and the rise of integrating corporate social responsibility criteria in executive compensation: Effectiveness and implications for firm outcomes. Strateg. Manag. J. 40, 1097–1122. doi:10.1002/smj.3018

Flammer, C., Kacperczyk, A., 2016. The impact of stakeholder orientation on innovation: Evidence from a natural experiment. Manage. Sci. 62, 1982–2001. doi:10.1287/mnsc.2015.2229

Forman, C., Goldfarb, A., 2020. Concentration and agglomeration of IT innovation and entrepreneurship: Evidence from patenting. NBER Work. Pap.

Freeman, C., 2008. Systems of Innovation: Selected Essays in Evolutionary Economics. Edward Elgar Publishing.

Freeman, C., 1987. Preface, in: Freeman, C. (Ed.), Output Measurement in Science and Technology. North-Holland. doi:10.1016/C2009-0-07257-2

Freeman, C., 1982. Economics Of Industrial Innovation, Second Edi. ed. Francis Pinter, London.

Furman, J.L., Stern, S., 2011. Climbing atop the shoulders of giants: The impact of institutions on cumulative research. Am. Econ. Rev. 101, 1933–1963. doi:10.1257/aer.101.5.1933

Furman, J.L., Teodoridis, F., 2020. Automation, research technology, and researchers' trajectories: Evidence from computer science and electrical engineering. Organ. Sci. 31, 330–354. doi:10.1287/orsc.2019.1308

Geroski, P., Machin, S., Reenen, J. Van, 1993a. The Profitability of Innovating Firms. RAND J. Econ. 24, 198. doi:10.2307/2555757

Geroski, P., Machin, S., Van Reenen, J., 1993b. The Profitability of Innovating Firms. RAND J. Econ. 24, 198–211.

Gilbert, R., 2011. A world without intellectual property a review of Michele Boldrin and David Levine's Against Intellectual Monopoly. J. Econ. Lit. doi:10.1257/jel.49.2.421

Gilfillan, S.C., 1935. The Sociology of Invention.

Glaeser, E.L., Kerr, W.R., 2009. Local Industrial Conditions and Entrepreneurship: How Much of the Spatial Distribution Can We Explain? J. Econ. Manag. Strateg. 18, 623–663. doi:10.1111/j.1530-9134.2009.00225.x

Godin, B., 2004. Measurement and statistics on science and technology: 1920 to the present, Measurement and Statistics on Science and Technology: 1920 to the Present. Routledge. doi:10.4324/9780203481523

Godinho, M.M., Ferreira, V., 2012. Analyzing the evidence of an IPR take-off in China and India. Res. Policy 41, 499–511. doi:10.1016/j.respol.2011.09.009

Graf, H., Broekel, T., 2020. A shot in the dark? Policy influence on cluster networks. Res. Policy 49, 103920. doi:10.1016/j.respol.2019.103920

Granstrand, O., 1999. The Economics and Management of Intellectual Property: Towards Intellectual Capitalism. Edward Elgar Publishing. doi:10.1080/00213624.2000.11506329

Grashof, N., Hesse, K., Fornahl, D., 2019. Radical or not? The role of clusters in the emergence of radical innovations. Eur. Plan. Stud. 27, 1904–1923. doi:10.1080/09654313.2019.1631260

Graue, E., 1943. Inventions and Production. Rev. Econ. Stat. 25, 221. doi:10.2307/1927338

Griliches, Z., 1998. Introduction to "R&D and Productivity: The Econometric Evidence," in: R&D and Productivity: The Econometric Evidence. pp. 1–14.

Griliches, Z., 1994. Productivity, R&D, and the Data Constraint. Am. Econ. Rev. 84, 1–23.

Griliches, Z., 1992. The Search for R&D Spillovers. Scand. J. Econ. 94, S29. doi:10.2307/3440244

Griliches, Z., 1990. Patent Statistics as Economic Indicators: A Survey. J. Econ. Lit. 28, 1661–1707.

Griliches, Z., 1989. Patents: Recent Trends and Puzzles. Brookings Pap. Econ. Act. Microeconomics 20, 291–330. doi:10.2307/2534723

Griliches, Z., 1967. Distributed Lags: A Survey. Econometrica 35, 16. doi:10.2307/1909382

Griliches, Z., 1958. Research Costs and Social Returns: Hybrid Corn and Related Innovations. J. Polit. Econ. 66, 419–431.

Griliches, Z., 1957. Hybrid Corn: An Exploration in the Economics of Technological Change. Econometrica 25, 501. doi:10.2307/1905380

Griliches, Z., Schmookler, J., 1963. Inventing and Maximizing . Am. Econ. Rev. 53, 725–729.

Guan, J., Chen, K., 2012. Modeling the relative efficiency of national innovation systems. Res. Policy 41, 102–115. doi:10.1016/j.respol.2011.07.001

Guan, J., Chen, K., 2010. Measuring the innovation production process: A cross-region empirical study of China's high-tech innovations. Technovation 30, 348–358. doi:10.1016/j.technovation.2010.02.001

Guan, J.C., Yam, R.C.M., 2015. Effects of government financial incentives on firms' innovation performance in China: Evidences from Beijing in the 1990s. Res. Policy 44, 273–282. doi:10.1016/j.respol.2014.09.001

Hagedoorn, J., Cloodt, M., 2003. Measuring innovative performance: Is there an advantage in using multiple indicators? Res. Policy 32, 1365–1379. doi:10.1016/S0048-7333(02)00137-3

Hagedoorn, J., Schakenraad, J., 1994. The effect of strategic technology alliances on company performance. Strateg. Manag. J. 15, 291–309. doi:10.1002/SMJ.4250150404

Hall, B.H., Jaffe, A., Trajtenberg, M., 2005. Market value and patent citations. RAND J. Econ. 36, 16–38.

Hall, B.H., Jaffe, A.B., 2018. Measuring Science, Technology, and Innovation: A Review. Ann. Sci. Technol. Policy 2, 1–74. doi:10.1561/110.00000005

Harhoff, D., Narin, F., Scherer, F.M., Vopel, K., 1999. Citation frequency and the value of patented inventions. Rev. Econ. Stat. 81, 511–515. doi:10.1162/003465399558265

Harhoff, D., Scherer, F.M., Vopel, K., 2003. Citations, family size, opposition and the value of patent rights. Res. Policy 32, 1343–1363. doi:10.1016/S0048-7333(02)00124-5

Hart, O., Moore, J., 1990. Property Rights and the Nature of the Firm. J. Polit. Econ. 98, 1119–1158. doi:10.1086/261729

Heckman, J., 2005. Contributions of Zvi Griliches. Ann. Econ. Stat. 5. doi:10.2307/20777568

Heckman, J.J., Moktan, S., 2020. Publishing and promotion in economics: The tyranny of the top five. J. Econ. Lit. doi:10.1257/JEL.20191574

Hirshleifer, D., Hsu, P.H., Li, D., 2013. Innovative efficiency and stock returns. J. financ. econ. 107, 632–654. doi:10.1016/j.jfineco.2012.09.011

Hitt, M.A., Hoskisson, R.E., Johnson, R.A., Moesel, D.D., 1996. The market for corporate control and firm innovation. Acad. Manag. J. doi:10.2307/256993

Hunt, J., Gauthier-Loiselle, M., 2010. How much does immigration boost innovation. Am. Econ. J. Macroecon. 2, 31–56. doi:10.1257/mac.2.2.31

Hussinger, K., Pacher, S., 2019. Information ambiguity, patents and the market value of innovative assets. Res. Policy 48, 665–675. doi:10.1016/j.respol.2018.10.022

Jaffe, A.B., 1986. Technological Opportunity and Spillovers of R & D: Evidence from Firms' Patents, Profits, and Market Value. Am. Econ. Rev. 76, 984–1001. doi:10.2307/1816464

Jaffe, A.B., de Rassenfosse, G., 2017. Patent citation data in social science research: Overview and best practices. J. Assoc. Inf. Sci. Technol. 68, 1360–1374. doi:10.1002/asi.23731

Jaffe, A.B., Palmer, K., 1997. Environmental regulation and innovation: A panel data study. Rev. Econ. Stat. 79, 610–619. doi:10.1162/003465397557196

Jaffe, A.B., Peterson, S.R., Portney, P.R., Stavins, R.N., 1995. Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the evidence tell us? J. Econ. Lit. doi:10.2307/2728912

Jaffe, A.B., Trajtenberg, M., Henderson, R., 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. Q. J. Econ. 108, 577–598. doi:10.2307/2118401

Jensen, C.M., Murphy, J.K., 1990. Performance Pay and Top-Management Incentives Author (s): Michael C . Jensen and Kevin J . Murphy Published by : The University of Chicago Press Stable URL : http://www.jstor.org/stable/2937665 REFERENCES Linked references are available on JSTOR for thi. J. Polit. Econ. 98, 225–264.

Johansen, S., Juselius, K., 1990. Maximum Likelihood Estimation and Inference on Cointegration--With Applications to the Demand for Money. Oxf. Bull. Econ. Stat. 52, 169–210. doi:10.1111/j.1468-0084.1990.mp52002003.x

Johnstone, N., Haščič, I., Popp, D., 2010. Renewable energy policies and technological innovation: Evidence based on patent counts. Environ. Resour. Econ. 45, 133–155. doi:10.1007/s10640-009-9309-1

Jorgenson, D.W., Griliches, Z., 1967. The Explanation of Productivity Change. Rev. Econ. Stud. 34, 249–283. doi:10.2307/2296675

Kahneman, D., Knetsch, J.L., Thaler, R.H., 1990. Experimental Tests of the Endowment Effect and the Coase Theorem. J. Polit. Econ. 98, 1325–1348.

Kaplan, S., Vakili, K., 2015. The double-edged sword of recombination in breakthrough innovation. Strateg. Manag. J. 36, 1435–1457. doi:10.1002/smj.2294

Keller, W., 2004. International technology diffusion. J. Econ. Lit. 42, 752–782. doi:10.1257/0022051042177685

Kessler, M., 1963. Bibliographic coupling between scientific papers. Am. Doc. 14, 10–25. doi:10.1002/asi.5090140103

Keuchenius, A., Törnberg, P., Uitermark, J., 2021. Adoption and adaptation: A computational case study of the spread of Granovetter's weak ties hypothesis. Soc. Networks 66, 10–25. doi:10.1016/j.socnet.2021.01.001

Klavans, R., Boyack, K.W., 2017. Which Type of Citation Analysis Generates the Most Accurate Taxonomy of Scientific and Technical Knowledge? J. Assoc. Inf. Sci. Technol. 68, 984–998. doi:10.1002/asi.23734

Kogan, L., Papanikolaou, D., Seru, A., Stoffman, N., 2017. Technological Innovation, Resource Allocation, and Growth. Q. J. Econ. 132, 665–712. doi:10.1093/qje/qjw040

Kovács, A., Van Looy, B., Cassiman, B., 2015. Exploring the scope of open innovation: a bibliometric review of a decade of research. Scientometrics 104, 951–983. doi:10.1007/s11192-015-1628-0

Krueger, A.B., Taylor, T., 2000. An Interview with Zvi Griliches. J. Econ. Perspect. 14, 171–190. doi:10.1257/jep.14.2.171

Kuhn, J., Younge, K., Marco, A., 2020. Patent citations reexamined. RAND J. Econ. 51, 109–132. doi:10.1111/1756-2171.12307

Kuznets, S., 1962. Inventive Activity: Problems of Definition and Measurement, in: The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton University Press, pp. 19–52.

Lanjouw, J.O., Schankerman, M., 2004. Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. Econ. J. 114, 441–465. doi:10.1111/j.1468-0297.2004.00216.x

Larivière, V., Gong, K., Sugimoto, C.R., 2018. Citations strength begins at home. Nature. doi:10.1038/d41586-018-07695-1

Leoncini, R., Marzucchi, A., Montresor, S., Rentocchini, F., Rizzo, U., 2019. 'Better late than never': the interplay between green technology and age for firm growth. Small Bus. Econ. 52, 891–904. doi:10.1007/s11187-017-9939-6

Lerner, J., 1994. The Importance of Patent Scope: An Empirical Analysis. RAND J. Econ. 25, 319. doi:10.2307/2555833

Lhuillery, S., Raffo, J., Hamdan-Livramento, I., 2017. Measurement of innovation, in: Bathelt, H., Cohendet, P., Henn, S., & Simon, L. (Ed.), The Elgar Companion to Innovation and Knowledge Creation. Edward Elgar, Chichester, UK, pp. 99–118. doi:10.4337/9781782548522.00013

Li, X., 2012. Behind the recent surge of Chinese patenting: An institutional view. Res. Policy 41, 236–249. doi:10.1016/j.respol.2011.07.003

Li, X., 2011. Sources of External Technology, Absorptive Capacity, and Innovation Capability in Chinese State-Owned High-Tech Enterprises. World Dev. 39, 1240–1248. doi:10.1016/j.worlddev.2010.05.011

Li, X., 2009. China's regional innovation capacity in transition: An empirical approach. Res. Policy 38, 338–357. doi:10.1016/j.respol.2008.12.002

Lin, B., Chen, Y., 2019. Does electricity price matter for innovation in renewable energy technologies in China ? Energy Econ. 78, 259–266. doi:10.1016/j.eneco.2018.11.014

Long, J.B. De, Shleifer, A., Summers, L.H., Waldmann, R.J., 1990. Noise Trader Risk in Financial Markets. J. Polit. Econ. 98, 703–738.

López, Á.L., Vives, X., 2019. Overlapping Ownership, R&D Spillovers, and Antitrust Policy. J. Polit. Econ. 127, 2394–2437. doi:10.1086/701811

Machlup, F., 1962. The production and distribution of knowledge in the United States. Princeton University Press.

Makri, M., Hitt, M.A., Lane, P.J., 2010. Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions. Strateg. Manag. J. 31, 602–628. doi:10.1002/smj.829

Malerba, F., Orsenigo, L., 1996. Schumpeterian patterns of innovation are technology-specific. Res. Policy 25, 451–478. doi:10.1016/0048-7333(95)00840-3

Malerba, F., Orsenigo, L., 1995. Schumpeterian patterns of innovation. Cambridge J. Econ. 19, 47–65. doi:10.1093/oxfordjournals.cje.a035308

Martín-Martín, A., Orduna-Malea, E., Thelwall, M., Delgado López-Cózar, E., 2018. Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. J. Informetr. 12, 1160–1177. doi:10.1016/j.joi.2018.09.002

Martin, B.R., 2019. The future of science policy and innovation studies: some challenges and the factors underlying them. Handb. Sci. Public Policy 523–542. doi:10.4337/9781784715946.00039

Martin, B.R., Irvine, J., 1983. Assessing basic research: Some partial indicators of scientific progress in radio astronomy. Res. Policy 12, 61–90. doi:10.1016/0048-7333(83)90005-7

Mendonça, S., 2017. On the discontinuity of the future by other means: Reviewing the foresight world of Richard Slaughter. Futures 86, 84–91. doi:10.1016/J.FUTURES.2016.08.005

Mendonça, S., Pereira, T.S., Godinho, M.M., 2004. Trademarks as an indicator of innovation and industrial change. Res. Policy 33, 1385–1404. doi:10.1016/j.respol.2004.09.005

Merton, R.K., 1973. The Sociology of Science: Theoretical and Empirical Investigations. University of Chicago Press.

Metcalfe, J.S., James, A., Mina, A., 2005. Emergent innovation systems and the delivery of clinical services: The case of intra-ocular lenses. Res. Policy 34, 1283–1304. doi:10.1016/j.respol.2005.01.015

Meyer, M., Pereira, T.S., Persson, O., Granstrand, O., 2004. The scientometric world of Keith Pavitt: A tribute to his contributions to research policy and patent analysis. Res. Policy 33, 1405–1417. doi:10.1016/J.RESPOL.2004.07.008

Mina, A., Ramlogan, R., Tampubolon, G., Metcalfe, J.S., 2007. Mapping evolutionary trajectories: Applications to the growth and transformation of medical knowledge. Res. Policy 36, 789–806. doi:10.1016/J.RESPOL.2006.12.007

Moed, H.F., 2005. Citation Analysis in Research Evaluation, Information Science and Knowledge Management. Springer-Verlag, Berlin/Heidelberg.

Mongeon, P., Paul-Hus, A., 2016. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 106, 213–228. doi:10.1007/s11192-015-1765-5

Moser, P., 2005. How Do Patent Laws Influence Innovation ? Evidence from Nineteenth-Century World' s Fairs. Am. Econ. Rev. 95, 1214–1236.

Mowery, D.C., Oxley, J.E., Silverman, B.S., 1996. Strategic alliances and interfirm knowledge transfer. Strateg. Manag. J. 17, 77–91. doi:10.1002/smj.4250171108

Nagaoka, S., Motohashi, K., Goto, A., 2010. Patent statistics as an innovation indicator, in: Handbook of the Economics of Innovation. Elsevier B.V., pp. 1083–1127. doi:10.1016/S0169-7218(10)02009-5

Narin, F., Noma, E., Perry, R., 1987. Patents as indicators of corporate technological strength. Res. Policy 16, 143–155. doi:10.1016/0048-7333(87)90028-X

Narin, F., Stevens, K., Whitlow, E.S., 1991. Scientific co-operation in Europe and the citation of multinationally authored papers. Scientometrics 21, 313–323. doi:10.1007/BF02093973

Nerlove, M., 2001. Zvi Griliches, 1930–1999: A Critical Appreciation. Econ. J. 111, 422–448. doi:10.1111/1468-0297.00638

Newman, M.E.J., 2003. Fast algorithm for detecting community structure in networks. Phys. Rev. E - Stat. Physics, Plasmas, Fluids, Relat. Interdiscip. Top. 69, 5. doi:10.1103/PhysRevE.69.066133

OECD, Eurostat, 2005. Oslo manual. Proposed guidelines for collecting and interpreting technological innovation data, Oslo manual. Guidelines for collecting and interpreting innovation data. OECD Publishing, Paris.

Oldham, G.R., Cummings, A., 1996. Employee Creativity : Personal and Contextual Factors at Work Author (s): Greg R . Oldham and Anne Cummings Source : The Academy of Management Journal , Vol . 39 , No . 3 (Jun ., 1996), pp . 607-634 Published by : Academy of Management Stable URL : ht. Acad. Manag. J. 39, 607–634.

Patel, P., Pavitt, K., 1995. Patterns of Technological Activity: their Measurement and Interpretation, in: Stoneman, P. (Ed.), Handbook of the Economics of Innovation and Technological Change. Blackwell Publishers, Oxford, pp. 14–51.

Pavitt, K., 1985. Patent statistics as indicators of innovative activities: Possibilities and problems. Scientometrics 7, 77–99. doi:10.1007/BF02020142

Pavitt, K., 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory. Res. Policy 13, 343–373. doi:10.1016/0048-7333(84)90018-0

Perianes-Rodriguez, A., Waltman, L., van Eck, N.J., 2016. Constructing bibliometric networks: A comparison between full and fractional counting. J. Informetr. 10, 1178–1195.

Perruchas, F., Consoli, D., Barbieri, N., 2020. Specialisation, diversification and the ladder of green technology development. Res. Policy 49, 103922. doi:10.1016/j.respol.2020.103922

Plant, A., 1934. The Economic Theory Concerning Patents for Inventions. Economica 1, 30. doi:10.2307/2548573

Ponds, R., Oort, F. van, Frenken, K., 2010. Innovation, spillovers and university–industry collaboration: an extended knowledge production function approach. J. Econ. Geogr. 10, 231–255. doi:10.1093/jeg/lbp036

Popp, D., 2002. Induced innovation and energy prices. Am. Econ. Rev. 92, 160–180.

doi:10.1257/000282802760015658

Quatraro, F., Scandura, A., 2019. Academic Inventors and the Antecedents of Green Technologies. A Regional Analysis of Italian Patent Data. Ecol. Econ. 156, 247–263. doi:10.1016/j.ecolecon.2018.10.007

Rakas, M., Hain, D.S., 2019. The state of innovation system research: What happens beneath the surface? Res. Policy 48, 103787. doi:10.1016/j.respol.2019.04.011

Rigby, D.L., 2015. Technological Relatedness and Knowledge Space: Entry and Exit of US Cities from Patent Classes. Reg. Stud. 49, 1922–1937. doi:10.1080/00343404.2013.854878

Righi, C., Simcoe, T., 2019. Patent examiner specialization. Res. Policy 48, 137–148. doi:10.1016/j.respol.2018.08.003

Rizzo, U., Barbieri, N., Ramaciotti, L., Iannantuono, D., 2020. The division of labour between academia and industry for the generation of radical inventions. J. Technol. Transf. 45, 393–413. doi:10.1007/s10961-018-9688-y

Romer, P.M., 1990. Endogenous technological change. J. Polit. Econ. S71–S102.

Rosenkopf, L., Nerkar, A., 2001. Beyond Local Search: Boundary-Spanning, Exploration, and Impact in the Optical Disk Industry. Strateg. Manag. J. 22, 287–306. doi:10.1002/smj

Rossetto, D.E., Bernardes, R.C., Borini, F.M., Gattaz, C.C., 2018. Structure and evolution of innovation research in the last 60 years: review and future trends in the field of business through the citations and co-citations analysis. Scientometrics 115, 1329–1363. doi:10.1007/s11192-018-2709-7

Rothaermel, F.T., Hess, A.M., 2007. Building dynamic capabilities: Innovation driven by individual-, firm-, and network-level effects. Organ. Sci. 18, 898–921. doi:10.1287/orsc.1070.0291

Rubashkina, Y., Galeotti, M., Verdolini, E., 2015. Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors. Energy Policy 83, 288–300. doi:10.1016/j.enpol.2015.02.014

Sampat, B.N., Mowery, D.C., Ziedonis, A.A., 2003. Changes in university patent quality after the Bayh-Dole act: A re-examination. Int. J. Ind. Organ. 21, 1371–1390. doi:10.1016/S0167-7187(03)00087-0

Saviotti, P.P., 1988. Information, variety and entropy in technoeconomic development. Res. Policy 17, 89–103. doi:10.1016/0048-7333(88)90024-8

Scherer, F.M., 1983. The propensity to patent. Int. J. Ind. Organ. 1, 107–128. doi:10.1016/0167-7187(83)90026-7

Scherer, F.M., 1965. Firm Size , Market Structure , Opportunity , and the Output of Patented Inventions. Am. Econ. Rev. 55, 1097–1125.

Schilling, M.A., Phelps, C.C., 2007. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation. Manage. Sci. 53, 1113–1126. doi:10.1287/mnsc.1060.0624

Schmookler, J., 1966. Invention and Economic Growth. Invent. Econ. Growth. doi:10.4159/HARVARD.9780674432833/

Schmookler, J., 1962. Economic Sources of Inventive Activity*. J. Econ. Hist. 22, 1–20. doi:10.1017/S0022050700102311

Schmookler, J., 1950. The Interpretation of Patent Statistics. J. Pat. Off. Soc. 32.

Segerstrom, P.S., 1998. Endogenous Growth Without Scale Effects. Am. Econ. Rev. 88, 1290–

1310. doi:10.2307/116872

Smith, K., 2005. Measuring Innovation, in: Fagerberg, J., Mowery, D.C., Nelson, R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, New York, NY.

Soete, L.G., Wyatt, S.M.E., 1983. The use of foreign patenting as an internationally comparable science and technology output indicator. Scientometrics 5, 31–54. doi:10.1007/BF02097176

Subtil Lacerda, J., van den Bergh, J.C.J.M., 2020. Effectiveness of an 'open innovation' approach in renewable energy: Empirical evidence from a survey on solar and wind power. Renew. Sustain. Energy Rev. 118, 109505. doi:10.1016/j.rser.2019.109505

Sun, H., Edziah, B.K., Sun, C., Kporsu, A.K., 2019. Institutional quality, green innovation and energy efficiency. Energy Policy 135, 111002. doi:10.1016/j.enpol.2019.111002

Teixeira, A.A.C., 2014. Evolution, roots and influence of the literature on national systems of innovation: A bibliometric account. Cambridge J. Econ. 38, 181–214. doi:10.1093/cje/bet022

Tirole, J., 1988. The Theory of Industrial Organization. The MIT Press.

Többelmann, D., Wendler, T., 2020. The impact of environmental innovation on carbon dioxide emissions. J. Clean. Prod. 244, 118787. doi:10.1016/j.jclepro.2019.118787

Torrisi, S., Gambardella, A., Giuri, P., Harhoff, D., Hoisl, K., Mariani, M., 2016. Used, blocking and sleeping patents: Empirical evidence from a large-scale inventor survey. Res. Policy 45, 1374–1385. doi:10.1016/j.respol.2016.03.021

Trajtenberg, M., 1990. A Penny for Your Quotes: Patent Citations and the Value of Innovations. RAND J. Econ. 21, 172. doi:10.2307/2555502

van der Wouden, F., Rigby, D.L., 2019. Co-inventor networks and knowledge production in specialized and diversified cities. Pap. Reg. Sci. 98, 1833–1853. doi:10.1111/pirs.12432

van Eck, N.J., Waltman, L., 2020. VOSviewer manual, CWTS: Univeristeit Leiden. Leiden.

Van Eck, N.J., Waltman, L., 2009. How to normalize cooccurrence data? An analysis of some well-known similarity measures. J. Am. Soc. Inf. Sci. Technol. 60, 1635–1651. doi:10.1002/asi.21075

Verspagen, B., 2007. Mapping technological trajectories as patent citation networks: A study on the history of fuel cell research. Adv. Complex Syst. 10, 93–115. doi:10.1142/S0219525907000945

Waltman, L., 2016. A review of the literature on citation impact indicators. J. Informetr. 10, 365–391. doi:10.1016/j.joi.2016.02.007

Wang, C., Chin, T., Lin, J.H., 2020. Openness and firm innovation performance: the moderating effect of ambidextrous knowledge search strategy. J. Knowl. Manag. 24, 301–323. doi:10.1108/JKM-04-2019-0198

West, J., Bogers, M., 2014. Leveraging external sources of innovation: A review of research on open innovation. J. Prod. Innov. Manag. doi:10.1111/jpim.12125

WIPO, 2019. World Intellectual Property Report 2019 – The Geography of Innovation: Local Hotspots, Global Networks. World Intellectual Property Organization, Geneva.

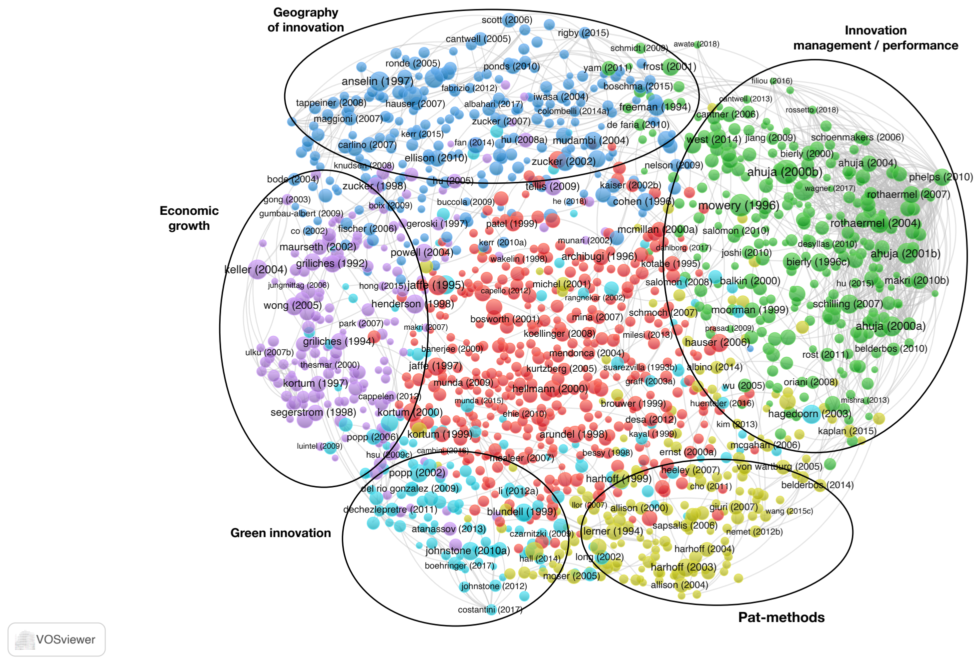
Wong, P.K., Ho, Y.P., Autio, E., 2005. Entrepreneurship, innovation and economic growth: Evidence from GEM data. Small Bus. Econ. 24, 335–350. doi:10.1007/s11187-005-2000-1

Wu, L., Wang, D., Evans, J.A., 2019. Large teams develop and small teams disrupt science and technology. Nature 566, 378–382. doi:10.1038/s41586-019-0941-9

Zucker, L.G., Darby, M.R., Armstrong, J., 1998. Geographically localized knowledge: Spillovers or markets? Econ. Inq. 36, 65–86. doi:10.1111/j.1465-7295.1998.tb01696.x

3. Appendix

Figure A1. Clusters of publications citing Griliches (1990), based on their bibliographic coupling links. 1990-2019



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