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Bias against novelty in science: A cautionary tale for users of bibliometric indicators

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ABSTRACT

Research which explores unchartered waters has a high potential for major impact but also carries a higher uncertainty of having impact. Such explorative research is often described as taking a *novel* approach. This study examines the complex relationship between pursuing a novel approach and impact. Viewing scientific research as a combinatorial process, we measure novelty in science by examining whether a published paper makes first-time-ever combinations of referenced journals, taking into account the difficulty of making such combinations. We apply this newly developed measure of novelty to all Web of Science research articles published in 2001 across all scientific disciplines. We find that highly novel papers, defined to be those that make more (distant) new combinations, deliver high gains to science: they are more likely to be a top 1% highly cited paper in the long run, to inspire follow-on highly cited research, and to be cited in a broader set of disciplines and in disciplines that are more distant from their "home" field. At the same time, novel research is also more risky, reflected by a higher variance in its citation performance. We also find strong evidence of delayed recognition of novel papers as novel papers are less likely to be top cited when using short time-windows. In addition, we find that novel research is significantly more highly cited in "foreign" fields but not in their "home" field. Finally, novel papers are published in journals with a lower Impact Factor, compared with non-novel papers, *ceteris paribus*. These findings suggest that science policy, in particular funding decisions which rely on bibliometric indicators based on short-term citation counts and Journal Impact Factors, may be biased against "high risk/high gain" novel research. The findings also caution against a mono-disciplinary approach in peer review to assess the true value of novel research.

1. Introduction

Scientific breakthroughs advance the knowledge frontier. Research underpinning breakthroughs often is driven by novel approaches. While research that takes a novel approach has a higher potential for major impact, it also faces a higher level of uncertainty of impact. In addition, it may take longer for novel research to have a major impact, displaying a profile of *scientific prematurity* (Stent, 1972), *delayed recognition* (Garfield, 1980), or that of a *sleeping beauty* (Van Raan, 2004), either because of resistance from incumbent scientific paradigms (Kuhn, 1962; Merton, 1973; Planck, 1950) or because of the longer time required to recognize and incorporate the findings of novel research into follow-on research (Garfield, 1980; Wyatt, 1975). The "high risk/high gain" nature of novel research makes it particularly appropriate for public support (Arrow, 1962). Delayed recognition may, however, lead novel research to be undervalued in research evaluations which rely on indicators based on short term citation windows.

Any bias in commonly used bibliometric indicators against novel research, to the extent it exists, is of concern given the increased reliance funding agencies and hiring institutions place on readily available bibliometric information to aid in decision making and performance evaluation (Butler, 2003; Hicks, 2012; Hicks et al., 2015; Martin, 2016; Monastersky, 2005). Such heavy reliance may explain in part the perception that funding agencies and their expert panels are increasingly risk-averse and the charge that competitive selection procedures encourage relatively safe projects, which exploit existing knowledge, at the expense of novel projects that explore untested approaches (Alberts, 2010; Azoulay et al., 2011; Kolata, 2009; NPR, 2013; Petsko, 2012;

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Walsh, 2013).

The goal of this paper is to develop a measure of novel research and compare the citation profile of novel research with that of non-novel research, as well as the Impact Factor of the journals in which novel research is published. We are particularly interested in whether the impact profile of novel research matches the "high risk/high gain" profile associated with breakthrough research and which commonly used bibliometric measures would be biased against novel research. To this end, we define research that draws on new combinations of knowledge components as novel and develop an *ex ante* measure of combinatorial novelty at the paper level, where novelty is operationalized as making new combinations in referenced journals. Utilizing this newly-minted measure of novelty, we explore the complex relationship between novelty and citation impact, using the life-time citation trajectories of research articles across all scientific disciplines published in 2001 and indexed in the Web of Science (WoS), as well as the profile of papers citing them.

We find novel papers to have a larger variance in their citation distribution and be more likely to populate both the tail of high impact and the tail of low impact, reflecting their "high risk" profile. At the same time, novel papers also display a "high gain" characteristic: they have a much higher chance of being a top cited paper in the long run, a higher likelihood of stimulating follow-on top cited research, and a broader impact transcending disciplinary boundaries and reaching more distant scientific fields. We further scrutinize the impact profile of novel research and uncover intriguing characteristics associated with novelty. First, we distinguish between impact in "home" and "foreign" fields and find that, compared with non-novel papers, novel papers are significantly more likely to be highly cited in foreign fields but not in their home field. Second, an examination of time dynamics in the citation accumulation process reveals delayed recognition for novel research. Specifically, although novel papers are highly cited in the long run, they are less likely to be top cited in the short run. We also find that novel papers are less likely to be published in high Impact Factor journals. These findings suggest that over-reliance on Journal Impact Factor and citation counts using short citation time-windows, may bias against novel research.

2. Combinatorial novelty in science

Scientific discovery can be viewed as a form of human problem solving (Klahr and Simon, 1999; Simon, 1966; Simon et al., 1981), the process for which involves a combinatorial aspect, such as integrating different perspectives for defining the problem space and assembling various methods and tools for solving the problem within the problem space. In this respect, the creation of new scientific knowledge builds on combining existing pieces of knowledge. Some of these existing knowledge pieces are embedded in the literature, some in equipment and materials, which themselves are embedded in the literature, and others in the tacit knowledge of individuals engaged in the research. Using knowledge pieces in well-understood ways corresponds to a search process labeled as *exploitation*. Using existing knowledge pieces in new ways corresponds to an *explorative* search process, which is more likely to lead to major breakthroughs but also comes with a substantial risk of no or low impact (March, 1991). From this perspective, novel research is more closely associated with exploration.

Drawing on a combinatorial perspective of the research process, *novelty* can be defined as the recombination of pre-existing knowledge components in an unprecedented fashion. This combinatorial view of novelty has been embraced by scholars in various disciplines (Arthur, 2009; Burt, 2004; Mednick, 1962; Schumpeter, 1939; Simonton, 2004; Weitzman, 1998). For example, Nelson and Winter (1982) state that "the creation of any sort of novelty in art, science or practical life – consists to a substantial extent of a recombination of conceptual and physical materials that were previously in existence." Romer (1994) and Varian (2009) also argue that new combinations of existing components provide a potentially huge source of important new discoveries. The ability to make new combinations of existing knowledge pieces is one reason that "outsiders" from other disciplines arguably can provide exceptional insights when they move from one field to another, as physicist Leo Szilard did, when he switched from physics to biology in the 1950s (Carroll, 2013).

The combinatorial view of novelty has been studied in the technological invention literature and operationalized using patent information. Fleming (2001) takes the technology subclasses in which patents are classified as representing the components of technological know-how and defines inventors' familiarity of a particular combination of subclasses as its occurrence in history weighted by time. Viewing more familiar combinations as less novel, he finds that novel combinations lead to lower average patent citations but a higher variance of citations. Verhoeven et al. (2016) combine this combinatorial novelty measure with a measure of novelty in technological and scientific knowledge origins, based on whether the focal patent cites other technological inventions or scientific literature from areas that were never cited before in its patent class. They find that the combination of the combinatorial novelty and the novelty in knowledge origins is a powerful identifier of breakthrough inventions.

Uzzi et al. (2013) apply a conceptually similar approach to scientific publications. They propose to trace the combinatorial process underlying the research from the references of the published paper. Operationally, they view journals as bodies of knowledge pieces and calculate the relative commonness for each pair of journals referenced by a paper. For this individual paper, they then use the lowest 10th percentile commonness score of its series of commonness scores as an indication of its "novelty" and the median commonness score as an indication of its "conventionality." They find that papers with both high novelty and conventionality are more likely to become top cited. Lee et al. (2015) adapt the Uzzi et al. (2013) measure for their study of creativity in scientific teams and find that the effect of team characteristics on novelty is different from its effect on impact of the publication produced by the team.

Other approaches to assess combinatorial novelty in science also exist in the literature. In a field experiment conducted at a top American medical school, Boudreau et al. (2016) identify whether a research proposal departs from the existing literature, by examining all possible pairs of MeSH (Medical Subject Headings) terms in the proposal and then calculating the fraction of the pairs which have not appeared in all the previous literature in PubMed. They find that evaluators systematically give lower scores to highly novel research proposals. Azoulay et al. (2012) measure the recombinative character of a publication in a similar manner, examining the extent to which pairs of its MeSH descriptors are unusual. They find a negative association between the degree of recombinativeness of a paper and the citation volume.

Taking a network perspective on science, novelty can be understood as making new connections or bridging structural holes in the network of science (Chen et al., 2009; Rzhetsky et al., 2015; Shi et al., 2015). Building on this network view of science, Klavans and Boyack (2013) cluster publications using co-citation analysis and then classify publications into four categories: *uniform*, *conform*, *innovate*, and *deviate*, based on the average distance between the clusters of referenced publications, as well as the focal publication. They observe that more innovative publications receive more citations. Foster et al. (2015) categorize five research strategies for biochemistry research: *jump* (introducing new chemicals), *new consolidation* (introducing new connections between chemicals in the same cluster), *new bridge* (introducing new chemical connections across clusters), *repeat consolidation* (repeating existing chemical connections within the same cluster), and *repeat bridge* (repeating existing chemical connections across clusters). Classifying the first three strategies as innovative ones, they find that, compared with conservative publications, innovative ones on average receive more citations, have a higher standard deviation in citations,