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Measuring technological novelty with patent-based indicators

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ABSTRACT

This study provides a new, more comprehensive measurement of technological novelty. Integrating insights from the existing economics and management literature, we characterize inventions ex ante along two dimensions of technological novelty: Novelty in Recombination and Novelty in Knowledge Origins. For the latter dimension we distinguish between Novel Technological and Novel Scientific Origins. For each dimension we propose an operationalization using patent classification and citation information. Results indicate that the proposed measures for the different dimensions of technological novelty are correlated, but each conveys different information. We perform a series of analyses to assess the validity of the proposed measures and compare them with other indicators used in the literature. Moreover, an analysis of the technological impact of inventions identified as novel shows that technological novelty increases the variance of technological impact and the likelihood of being among the positive outliers with respect to impact. This holds particularly for those inventions that combine Novelty in Recombination with Novelty in Technological and Scientific Origins. Overall, the results support our indicator as ex ante measure of technological novelty with the potential to drive radical technological change.

1. Introduction

Technology is generally believed to develop along well-defined and predictable trajectories, occasionally interrupted by discontinuities introduced by paradigm shifts (Dosi, 1982). At the heart of such technological discontinuities are inventions that introduce a novel technological approach (Arthur, 2007, 2009) with a potentially game changing impact on industries and markets (Cooper and Schendel, 1976; Henderson and Clark, 1990). As an example, Arthur describes how the turbojet engine introduced the concept of generating thrust by expelling particles to create an opposite force to accelerate an airplane. This was a novel technological approach compared to typical propeller engines that generate a drag in order to drive the plane. In the course of the following decades, a series of follow-on incremental improvements refined this novel approach in terms of its functioning and performance. All this led to an unprecedented performance increase of jet engines, allowing for a tremendous growth in the aviation industry and beyond.

Radical inventions introducing technological novelty, like the turbojet engine, are, more than run-off-the-mill improvements, subject to uncertainty with respect to potential technological and commercial performance (Fleming, 2001; Hall and Lerner, 2010). Beyond their potential for outlier impact, be it with high variance, they have the ability to disrupt existing competences (Tushman and Anderson, 1986), and eliminate existing players from the market (Christensen, 2013). Firms aiming at technologically novel inventions, might require substantially different competences and search strategies (Ahuja and Lampert, 2001). Because of their distinct profile, unpacking the drivers and effects of radical innovations is of major interest to scholars studying the economics and management of innovation.

Technological novelty can be an important driver of radical technological innovation like in the case of the turbojet engine (Arthur, 2007). However, it is clear that not all technologically novel inventions will result in successful innovations with profound technological and economic impact, as they are typically subject to higher uncertainty (Fleming, 2001). And even if eventually successful, the process of development and realization of impact is generally a lengthy one (Rosenberg, 1976), where the invention may pass through several different agents before fruition. Hence, to fully grasp the mechanisms underlying the origins, diffusion and effects of radical innovations, it is important to characterize as early

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as possible these innovations. Yet, in most empirical studies, radical or breakthrough inventions are identified only by their ex post large impact on future technological development (Ahuja and Lampert, 2001; Schoenmakers and Duysters, 2010), product performance (Leifer et al., 2001) or market structure (Mascitelli, 2000). Only considering inventions which have been highly impactful not only requires a long horizon before they can be studied, it typically also introduces a success bias. Many inventions with the potential to have radical impact, may not realize this potential and are therefore missed in the analysis of successful inventions only. Furthermore, an approach which is truly novel often times needs considerable refinements. The impactful invention might not be the one having introduced the novelty, but rather one that builds further on the novel approach. Hence, using an *ex post* definition and operationalization based on direct impact performance, does not take into account unsuccessful novelty and novelty with indirect impact. These limitations motivate us to argue that, to gain more insight in the mechanisms driving radical technological change, it is important to characterize technological novelty *ex ante*. This will help us to better understand the process from creation of novel ideas to possible successful implementation and learn how to improve this process.

In this paper, we address the question of how technological novelty, which characterizes radical inventions, can be measured more comprehensively ex ante. We build on the work of Arthur (2007, 2009) to identify two important dimensions of technological novelty – Novelty in Recombination and Novelty in Knowledge Origins. Novelty in Recombination reflects the extent to which an invention is novel in the way it recombines components and principles to serve its purpose. Novelty in Knowledge Origins reflects the extent to which an invention sources knowledge from fields of knowledge that were previously never used. We use classification and citation information on patent documents to operationalize these dimensions for all patented inventions since 1980.

We perform a number of analyses to assess the validity of the proposed measures. First, we illustrate our measures with the patent for the 'onco-mouse' and a number of other well-known novel technologies. Second, we compare our measures to measures of related constructs commonly used in the literature, more particularly the "originality" measure introduced by Trajtenberg et al. (1997) and the "radicalness" measure employed by Shane (2001). Our technology measures correlate with these existing measures of related constructs, but perform better on characteristics typical for technological novelty. Third, we perform two larger validation exercises using external information about novelty of inventions. First, is a set of inventions that were awarded an R&D prize by 'R&D Magazine' for being among the most technologically novel inventions of the year. Second, we use a sample of patents that were refused by the European Patent Office (EPO) because they lacked novelty or inventive step to assess false positive bias. We find that inventions scoring on our novelty measures are overrepresented in the group of award-winning inventions, and underrepresented in the group of inventions that were refused a patent for lack of novelty.

Finally, we analyze the technological impact generated by inventions and find that inventions identified through our indicators as being technologically novel, have a higher dispersion in terms of forward citations received, and are more likely to end up among the set of highly cited patents, confirming their higher risk profile and their higher probability to be the antecedent of a radical breakthrough. Overall, the results support our indicator as ex ante measure of technological novelty with the potential to drive radical technological change.

The remainder of the paper is structured as follows: In Section 2 we discuss the concepts and measurement introduced in prior literature. In Section 3 we conceptualize technological novelty and propose our new patent-based indicators to measure technological novelty. In Section 4 we perform descriptive analyses of the relatedness between the different dimensions of novelty we identify and compare the indicators to measures of related constructs. In Section 5 we perform a number of validity checks using external information on (lack of) novelty of inventions. Section 6 provides an analysis on the impact of patents characterized by technological novelty. Section 7 discusses the implications of the results, and avenues for future research.

2. Background

Considerable variety exists in the definition and measurement of concepts related to what can be broadly termed 'radical invention'. A range of labels (radical, discontinuous, breakthrough, new, etc.)[1] is given to phenomena touching upon different dimensions of inventive outcomes. A nevertheless common theme across the different angles is the notion of a break from the past and/or a large impact on the future along some technological or economic dimension(s). This section structures the different meanings the literature associates to 'radicalness' of inventions and provides an overview of different practices to operationalize some of these concepts. It will mainly take a technological perspective to identify the characteristics of "radical inventions".

2.1. Concepts

2.1.1. Ex post technological impact of invention

Scholars within the perspective of technology trajectories (Dosi, 1982) define radical invention in terms of their impact on future technological development. Their search is for those inventions that introduce new paradigms. These new paradigms open up avenues for further technological developments, starting new trajectories. An invention on which many future inventions build is argued to be a breakthrough (Fleming, 2001; Ahuja and Lampert, 2001) or deemed radical (Schoenmakers and Duysters, 2010).

Radical inventions have been defined in terms of the profound impact they have on firms, industries and markets. Anderson and Tushman (1990) distinguish between competence-enhancing and competence-destroying technological discontinuities. Utterback (1996) defined radical invention or discontinuous change as "change that sweeps away much of a firm's existing investment in technical skills and knowledge, designs, production technique, plant and equipment," and Henderson (1993) describes an invention as being radical in the organizational sense when it renders a firm's information filters and organizational procedures (partially) obsolete.

2.1.2. Ex ante characteristics of invention

Rather than looking ex post at impact, a number of scholars define radical invention in terms of the characteristics of their underlying technology. In this ex ante perspective, radical inventions are often characterized as incorporating technologies that move away from existing practices (Ettlie et al., 1984; Mascitelli, 2000; Shane, 2001; Dahlin and Behrens, 2005), embedding novel knowledge (Dewar and Dutton, 1986; Lettl et al., 2006; Carlo et al., 2012) and being based on different scientific and engineering principles compared to existing technology (Henderson and Clark,

[1] Because of the lack of consensus in terminology for different constructs related to technological change, we choose to loosely adopt the term 'radical invention' in its broad meaning for the sake of readability. It is to be noted that this term covers a wide range of different constructs, including novelty and impact, as well as technological and economic characteristics of technologies which are reviewed in this section.