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Measuring patent's influence on technological evolution: A study of knowledge spanning and subsequent inventive activity

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ABSTRACT

We introduce technological influence as a variable to measure an invention's direct and indirect impact on the evolution of technology. This provides a novel means to study the short and long run effect of invention antecedents on technological evolution, invention activity, and economic growth. A comparison between models of technological influence and direct technological impact is presented. Model estimations are based on data from semiconductor patents granted over a 5-year period. Results from quantile regression estimations show significant differences in the relationships between antecedents of technological influence and impact. For example, pioneering the spanning of knowledge boundaries has a positive relationship with the patent's influence, while no relationship is found with direct citations. These results have important implications for public policy and the management of technology. They suggest the need for deeper understanding of the micro-foundations of the technological evolution process and raise the question of whether inventors under current IP protection receive adequate economic incentives to promote actions driving economic growth.

"The value of a technology lies not merely in what can be done with it but also in what further possibilities it will lead to."

W. Brian Arthur [Economist, 1945-]

1. Introduction

It is widely accepted that patents spur both technology and the economy – especially when the invention is incorporated into innovation with commercial impact (Cohen et al., 2000; Levin, 1988; Trajtenberg, 1990); for example, it is recognized that inventions such as the internal combustion engine and the incandescent light bulb revolutionized industry and society. Since the seminal piece by Griliches (1990), extant literature has measured the technological significance of a patent based on the number of citations it received (Guerzoni et al., 2012; Nemet and Johnson, 2011; Sampat and Ziedonis, 2004; Singh and Fleming, 2010). While this approach helps to answer important questions, particularly those associated with invention's rent appropriation, it does not capture the overall technological significance of a patent. In other words, the number of citations received cannot capture the ripple effect that a patent may have by means of the indirect citations it receives from ensuing patents. Thus, there is a gap in our understanding of the relationship between inventive search process characteristics and subsequent inventive activity. This is particularly salient in our understanding of which inventive search processes results in breakthrough inventions.

In this paper, we propose a new measurement of patent influence that overcomes this limitation by accounting for indirect citations.[1] The study of direct and indirect effects deserves attention since it is not immediately clear whether both types behave similarly. An example that illustrates this point is the Scanning Tunneling Microscope patent (Binnig and Rohrer, 1982), considered a breakthrough technology and for which the Nobel Prize was won in 1986. This invention was the technological solution that made possible great advances in many fields, among them

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[1] NB. This measure applies to patents, the embodiment of an invention, i.e., a technological solution for a technical problem. We distinguish it from innovation, which included all the different factors needed to create a business solution in order to extract value from a market opportunity (Ahuja and Lampert, 2001; Schumpeter, 1934).

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nanotechnology (Anon, 1986).[2] While it received many citations in the first 10 years, this microscope had a much larger influence on inventive activity than what is suggested just by direct citations. Compared with a similar patent, the Ion beam apparatus (Hongo et al., 1985), the Scanning Tunneling Microscope has roughly twice the direct impact but 15 times the influence in future inventive activity, as measured by the variable we here introduced. Since patents include citations in order to limit the scope of their claim (Hall et al., 2001), only immediate prior art is cited and the full effect the patent has on the evolution of technology is not reflected when indirect citations are not taken into account.

Including indirect effects is important in studying technological trajectories because invention is an evolutionary process whereby technology builds on itself. Furthermore, technology has the potential of being self-producing as novel technology is created through combinations that draw from existing technology (Arthur, 2009; Belenzon, 2011; Fleming, 2001; Podolny and Stuart, 1995). In fact, the origin of every technology can be traced to existing technologies, going back to humankind's earliest technological solutions. If we think of a citation as a patent's child, a citation to a child as a patent's grandchildren, and so on; we can see that larger patent influence on technological evolution is reflected in the larger number of children (direct technological descendants) or the larger number of grandchildren and their descendants (indirect technological descendants). By counting only direct citations, we fail to capture when a patent opens new research paths or belongs to a dead end. As show by Fig. 1, the number of direct technological descendants is a flawed indicator of the number technological descendants.

While the count of citations received tells a patent's number of children, that count gives only an imperfect estimate of size and reach of a patent's "genealogical" tree. The long-term effect of breakthrough inventions should be reflected on the number of future inventions building directly and indirectly on the invention. Our influence measure, as discussed below, captures both effects. Our sample of semiconductor patents presents evidence highlighting the contribution of our variable to the study of breakthrough patents. A look at the distribution of patent with top influence and impact (see Fig. 2) reveals that using top 1% impact to capture breakthrough invention (Ahuja et al., 2005) only captures a small proportion of the top 1% influence patents and includes roughly 75% of patents that are not in the top 1% of influence. This disconnect is also present in not having one patent sharing top one per thousandth influence and impact. These results illustrate the importance of including indirect citations to fully capture the long-range effects of inventions (Jaffe and Trajtenberg, 2002).

This study brings attention to an invention's indirect effect and how to measure its overall influence. By including the count of indirect citations on the measure of influence, this paper shows that patents pioneering the spanning of knowledge boundaries have more influence on technological evolution than what one would expect based on the extant research. Returns on exploration have been explained by the "larger variance" thesis (Fleming, 2001, 2007; March, 1991), an argument contradicted by this result. We also find those patents showing no significant difference in the number of citations received (impact). This suggests that pioneering utilization of novel knowledge significantly affects technological evolution in a manner that is not captured when patent technological significance is measured only by the count of citations received. Even more, the result for exploration is significant and sizeable for the population of patents that deserves most of the attention regarding technological evolution, the patents with the most influence.[3] By showing significant differences with practical implications, this paper contributes to the growing literature on antecedents of an invention's impact (Guerzoni et al., 2012; Hall et al., 2001; Nemet and Johnson, 2011; Phene et al., 2006). Our findings provide a new perspective: indirect citations cannot be ignored when studying technological evolutions; which questions whether assessing the value of inventions based only on direct citations is appropriate.

2. The measurement of patent influence on technology evolution

Further clarification of what we mean by technology and its relationship with science is needed. We follow Arthur's view (2009) and see technology as the means developed to fulfill a human need. Collective technology is the assembly of technologies generated by a combinatory process that (a) builds on natural phenomena and (b) creates new elements from the combination of existing ones. In this view, technology draws upon itself and upon basic research in a process where science organically becomes part of technology. In other words, science provides the basic knowledge to harness natural phenomena in technological solutions to human problems.

Restricting the study of inventions' influence on the evolution of technology does not ignore how basic research may drive this process. We are simply focusing on how technology evolves from the combination of collective technology in a manner that, thanks to patent records, makes the invention more concrete, identifiable, and measurable in terms of usefulness, novelty, and non-obviousness. The studying of basic research informational contribution to technology evolution demands a measure of influence – such as the one introduced in this paper – that captures direct and indirect effects. Particularly, we need to account for concrete and identifiable inventions drawing on specific basic research – i.e., direct contributions to collective technology – and for, what perhaps is more important, the inventions drawing on them –i.e. indirect contributions to collective technology (Pavitt, 1991; Stokes, 1997; United States Office of Scientific Research and Development and Bush, 1945).

Due to the recombinative nature of technology (Arthur, 2009; Fleming, 2001; Podolny and Stuart, 1995), the invention's importance to the evolution of technology can be captured by how many inventions directly build on it (what can be done with it) and how many indirectly build on it (how many possibilities it will lead to). This indirect effect is as relevant if not more than the direct effect, particularly for those technological solutions that are changing the application area of the technological challenges that can be solved – the type of solutions that we think as breakthrough inventions. For example, the transistor is a main component in modern microprocessors; however, one would be hard pressed to find recent semiconductor patents citing those that pioneered the transistor's design: Shockley's bipolar junction transistor (Shockley, 1951) or its predecessor, Lilienfeld's field-effect transistor (Lilienfeld, 1930). This illustrates the real need to measure a patent's importance by also accounting for the indirect effect on inventions linked to the focal invention by a chain of citations.

[2] The inventors of the scanning tunneling microscope received the 1986 Nobel Prize in Physics for this invention (1986). This invention has significantly contributed to the development of the nanotechnology field by being the first technology able to provide and visual representation of the distribution of single atoms on a surface.

[3] Spanning knowledge increases the influence on inventive activity associated with a patent by more than 100% for patents with top 1% influence. Contrast this result with spanning knowledge showing no significant effect on patent's number of citations received by patents in the top 1% impact.