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A new approach to explore the knowledge transition path in the evolution of science & technology: From the biology of restriction enzymes to their application in biotechnology

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ABSTRACT

In this contribution, we develop a new approach to explore the process of knowledge transition from discovery-oriented science to technological fields, via applications-oriented research, including a mediator set. This trajectory is referred to as the D-A-T trajectory. It is shown how it can be constructed and measures are proposed to characterize the relational strength among different environments (discovery oriented research, applications-oriented research and patents) and the speed of evolution. Our approach is illustrated by a case study of three fundamental restriction enzymes articles. Among other results we found that 387 patents cited 124 of the 988 articles (a share of 12.55%) in the mediator set. Defining the non-patent references (NPR) transition rate as the number of citing patents divided by the number of articles in the mediator set yields a value 0.392. Our results suggest that the D-A-T path acts as a backbone and reveals important "invisible contributions" of an original scientific work during its evolution from discovery oriented research to outside academia. Our contribution provides a useful tool for bridging the existing gap in detecting the transition of knowledge between science and technology.

1. Introduction

The evolution of science and technology can be seen as a process of knowledge transition between fields, from basic science to applied research or vice versa (Glänzel & Meyer, 2003). Price even stated that "... historically the arrow of causality is largely from the technology to the science" (de Solla Price, 1983). New basic knowledge may lead to a knowledge flow to applied fields and technology, and, in this way, contributes to progress in industry and society (Li, Azoulay, & Sampat, 2017).Of course, sometimes knowledge may also flow from technology to new data, leading to new questions and when these are solved, to new basic knowledge, astronomical instruments, such as the Hubble telescope, being a case in point (http://hubblesite.org/). Knowledge flows manifest themselves sometimes as successions of incremental improvements. Yet, it also happens that progress is temporarily stopped and then revived during periods of revolutionary transitions (Pan, Sinha, Kaski, & Saramäki, 2012). Such knowledge flows can be tracked by roadmaps, showing interactive movements and

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illustrated by evolutional networks between science and technology or vice versa (Boyack, Klavans, & Börner, 2005; Boyack, Klavans, Small, & Ungar, 2014; Li et al., 2017; Pan et al., 2012).

The study of scientific evolution is performed in many ways. Among these we mention:

(1) Determining knowledge diffusion among scientific fields by citations over time (Frandsen, 2004; Frandsen, Rousseau, & Rowlands, 2006; Lewison, Rippon, & Wooding, 2005; Liu & Rousseau, 2010; Rowlands, 2002). Such an approach stays largely within academia and can be performed using databases such as the Web of Science (WoS), Scopus or PubMed.
(2) Measuring knowledge transfer between science and technology through the interaction of scientific articles and patents (Gao, Ding, Teng, & Pang, 2012; Li et al., 2017; Meyer, 2006). This approach goes one step further and moves to the realm of technological applications. These studies are often performed using a patent database, but, to provide a full picture they also need data related to academic research.
(3) When focusing on medicine and the health sciences one often uses the term translational research. The objective of translational research is to harness knowledge from basic research (biomedical) to clinical practice and the development of new drugs and treatments, leading to better patient care (Luwel & van Wijk, 2015).

The former two in this list are studied at least since the 1960s (Sherwin & Isenson, 1967), while the third one dates from somewhat later (the 1990s) (Seiken, 1993). The notions "translational applications" and "translational effect" are hot topics nowadays (leading to specialized journals such as *Science Translational Medicine*, since 2009). Yet, sensible metrics for them are still on their way (Luwel & van Wijk, 2015).

Knowledge transfer is often seen as a largely linear evolution of scientific or technical knowledge through time. In both cases the original piece of knowledge may need to be transformed or adapted to be useful under new circumstances. Knowledge transfer from the basic sciences to technical applications may, e.g., result from contract research between academia and industry, via patenting or via spin off activity. Yet, knowledge transfer may also occur between different fields of science such as from the natural sciences to the social sciences, or from subfields of physics to subfields of chemistry. The term transition is used in the case of a link between different types of fields such as basic and applied fields, as defined by Tijssen (2010). This is explained in more detail further on.

One may observe that among the two major types of research on knowledge diffusion and transfer, the former one maps knowledge transfer within the realm of science according to the records in a science citation database, while the latter type explores the links in particular fields between scientific knowledge and technological inventions via a patent database. Most of them applied a direct citation analysis (Hall, Jaffe, & Trajtenberg, 2005) but this may provide an incomplete picture (Hu, Rousseau & Chen, 2011, 2012). For this reason Kuan, Huang, and Chen, (2018) included bibliographic coupling in their patent analyses. Still there may be many "invisible elements" that stay largely unnoticed as a contribution to science and technology. Tracking the influence of pioneering work during scientific evolution has only recently been investigated seriously, e.g. by the use of Reference Publication Year Spectroscopy (RPYS) (Marx, Bornmann, Barth, & Leydesdorff, 2014; Marx, Bornmann, & Barth, 2013) or by trying to detect so-called under-cited influential articles (Hu & Rousseau, 2016, 2017, 2018).

The article that is the most related to our investigation is Ahmadpoor and Jones' (2017). These authors study the whole articles-patents citation network, starting from patents that directly cite journal articles. They refer to such citations as the "paper-patent boundary". Then they determine for all other papers and patents the minimum citation distance to this boundary. One of their main findings is that a majority of patents (60.5%) is connected (directly or indirectly) to science and engineering papers, while a substantial majority of articles (79.7%) can be linked to patents(also directly or indirectly). They further find that some patent classes such as molecular biology, superconductivity technology and combinatorial chemistry are close to the paper-patent boundary while others, such as locks, buttons, fasteners, chairs are situated at a much larger distance. On the other side of the boundary (papers) they found nanoscience and nanotechnology, materials science and computer science hardware & architecture, while mathematics is situated very far away.

Yet, we think that much more can be done in studying knowledge transfer. Traditionally the evolution of knowledge has mostly been studied either within a scientific context or from a technological point of view. As it is clear that applied sciences provide the (missing?) link between basic science and technology the problem lies in the difficulty in operationalizing the notion of applied science as distinct from basic science.

Detailed knowledge of the backbone of knowledge transfer via a successive process from basic research to technological fields is still lacking. In this article we try to contribute to this aspect of the evolution of science and technology.

We propose a new approach to detect the otherwise "invisible" or at least partially hidden, path of knowledge from an original scientific work during its evolution from science to technology. The term 'invisible' is used here because only studying non-patent-references (NPRs) does not lead to the origin of the used knowledge. This statement implies that we focus on knowledge transfer via documents and this from science to technology, considering other forms of knowledge transfer or of knowledge diffusion out of the scope of this contribution, i.e. we do not consider knowledge transfer via more meandering paths in Fig. 1 or via social media or word of mouth. Particularly, we focus on different environments of knowledge utilization in the process of knowledge transfer via citation networks, hence including indirect citations, focusing on an applications-oriented evolution. Concretely, we will try to find answers to the following questions:

(1) How to construct a new framework to detect transfer of knowledge from basic science to technology?