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The relation between knowledge accumulation and technical value in interdisciplinary technologies

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ABSTRACT

A challenging task in technology management is the early identification of potentially valuable inventions. The depth, breadth, and age of the body of knowledge underlying an invention are theorized to indicate the technical experience of the sectors relevant to the invention. Prior research assessing this body of knowledge have focused on the content of knowledge through bibliometric and semantic indicators but neglected the structural role of knowledge underlying a patent. Focusing on technical value, we propose a new metric that accounts for the structural maturity of knowledge preceding an invention. Using a composite patent value and multiple generation citation networks, we compare knowledge accumulation in 60 originating patents for inventions in the energy-harvesting sector over a 100-year observation period, resulting in an analysis of 1900 patents. The results indicate that our metric for knowledge accumulation reveals a statistically significant correlation between the structural maturity of the knowledge that contributes to the specific invention and technical value of a patent. The structural view on knowledge accumulation explains at least as much variance in the composite value of patents as current knowledge content-based indicators, and, unlike those indicators, is useful as a leading rather than lagging indicator. This metric can therefore find application in technology forecasting as a forward indicator of the technical value of inventions.

1. Introduction

The need to identify superior inventions has fuelled studies in patent valuation techniques. These techniques value a patent based upon the importance the patent holds for other inventions (Albert et al., 1991; Carpenter et al., 1981; Hall et al., 2005; Harhoff et al., 1999) or the commercial strategy of the company that applies the patent (Baron and Delcamp, 2012; Harhoff et al., 2003; Lerner, 1994). Even though the limitations of using patent indicators for assessing patent value have been raised (Reitzig, 2004; Van Zeebroeck, 2011; van Zeebroeck and van Pottelsberghe de la Potterie, 2011), the increasing number of studies in this domain point to the fact that patents can be valuable sources of information on the *potential* value of inventions.

Patent valuation techniques may broadly be divided into single-level relationship and multiple-level relationship based methods. Single-level relationship methods use surface-level metadata about the patent (such as citations, claims, classifications etc.) while multiple-level relationship methods consider indirect factors that affect patent value (such as knowledge background and technological complexity). While single-level relationship techniques are useful in understanding a broad picture of the sector, they can fail to differentiate the technical feasibility of inventions that perform similar functions. For example, citation counts will reveal that thin-film photovoltaics based on Cd-Te technology have been referenced more often than Ga-As technology; however, within Cd-Te technologies, citation counts alone cannot indicate if physical-vapour deposition based inventions are more feasible than chemical-vapour deposition based inventions. Valuation techniques that utilise single-level metadata about the patent do not account for the differences in the knowledge content between inventions. It is also important to note that a majority of these techniques are post hoc in their predictive ability as they use indicators that are time dependent. For example, citations received by the patent and its family size may increase with time. Patent renewal decisions come into force only after a certain number of years after the grant of the patent. For a valuation technique to be practical and useful, one should be able to apply it at the early stage of the invention. However, the information used by patent-based indicators becomes available about 18 months after the filing date of the patent (Reitzig, 2004). This time frame may vary based on the patent office. Hence, these techniques cannot be used to evaluate an invention when the patent in question is new.

The use of references may be seen as an exception to this approach. References, also known as backward citations, describe the knowledge

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upon which the invention is based. The idea is that the more references a patent has and the more mature those references are, the likelihood of the technical viability of the patent increases. The patent will have a higher probability of being implemented into products (Beierlein et al., 2015; McNamee and Ledley, 2012; McNamee and Ledley, 2013). Nerkar (2003) showed that it is important that both old and new knowledge are applied toward the target patent, though. The author argues that recombining knowledge from broad time periods enables uncovering of valuable knowledge that is forgotten or whose time has not come yet. The age of the knowledge indicates that it has had the time to be tested and perfected. Nonetheless, it is generally true that the age of the knowledge preceding an invention is an essential factor that may have an effect on the technical value of inventions (Karlsson and Åhlström, 1999).

There are at least two significant problems with a reference-based approach to evaluating the technical value of a patent. First, the amount of knowledge in any domain will always increase with time. If the age of knowledge preceding the target patent is referenced to the registration date of the target patent, then newer inventions by definition, will always refer to more mature knowledge. Yet, it may not be true that the newer patent is more technically viable at its date of registration than the older patent at its date of registration. Second, scholars have argued that one needs to consider the relationship with patents that have an indirect effect on the target patent. As such, they have tried to define these indirect relationships and their effect on patent value. Such thinking has given rise to a structural view of inventions.

The knowledge structure of an invention is comprised of interconnected and interdependent knowledge elements. Scholars have argued that the technological background, which makes up the knowledge structure of an invention, is an important indicator of its value (Harhoff et al., 2003; Hu et al., 2012; Lin et al., 2007). In prior studies, authors used patents' immediate references as its knowledge base. Hu et al. (2012) included two generations of references to include the influence of technological complexity on the value of the invention. Bosworth (2004), on the other hand, included many more generations of references in his study to demonstrate that such structures can be used to explore the ancestral roots of a patent. Ellis et al. (1978) drew out a similar patent citation network to study the important milestones in a technological field. It is unclear how many generations of citations were included in their study. A partial structure cannot give a complete view of the influencing factors of patent value. This research considers the complete knowledge structure of an invention by including all the generations of references in evaluating the patent value. In order to account for the maturity of the complete knowledge structure, we propose a new indicator to measure knowledge accumulation (KA) in a patent citation network. We use this new indicator to distinguish between high value and low value patents. We compare our method with some of the other known patent evaluation techniques given in literature.

This article is organized as follows. Section 2.1 describes the literature on existing patent valuation techniques. Section 2.2 explains knowledge accumulation and leads to our hypothesis. Section 3 outlines the methodology employed, with Section 3.1 describing the process of constructing the patent citation network and Section 3.2 describing the derivation of KA based on that knowledge network. Section 3.3 describes the calculation of composite patent value. Section 4 describes our data followed by a discussion of results in Section 5. Finally, Section 6 presents the conclusions and recommendations for future study.

2. Patent valuation

2.1. Existing patent valuation methods

Patent analysis, which probably started in legal firms as a prior-art search, has now found application as a management tool. As a management tool, patent analysis informs managers about the competitive landscape of the technology (Choe et al., 2013), technological trends of a sector (Wu and Leu, 2014), potential collaborators (Lee, 2010), infringement possibilities (Reitzig, 2004), and future product development pathways (Su et al., 2009). The literature contains different techniques to assess patents to meet these purposes. These techniques may be broadly divided into bibliometric approaches and content-based approaches. Content-based analysis uses text-mining techniques such as text segmentation, summary extraction, and co-word analysis to detect technological trends (e.g. see Gerken and Moehrle, 2012; Tseng et al., 2007; Yoon et al., 2011). Bibliometric approaches, on the other hand, analyse patent value indicators such as citation counts (Carpenter et al., 1981; Verspagen, 2007), claims (Baron and Delcamp, 2012; Lerner, 1994), patent life (Bessen, 2008), family size (Harhoff et al., 2003; Sternitzke, 2009), processing time (Lin et al., 2007) and other metrics using statistical and mathematical techniques.

Many companies hold a patent portfolio rather than a single patent. To understand the value of a patent portfolio, the evaluation methods assess the portfolio from bibliometric-technological and economic-strategic perspectives (Grimaldi et al., 2015) in order to manage the portfolio strategically and optimize its full potential. Whether the analyst is considering the value of a particular patent or a patent portfolio, the analyst is typically concerned with two forms of value. They consider the commercial value of market transactions (Hall et al., 2005) with respect to internal business strategies (Harhoff et al., 2003). Commercial value is the perceived value of the invention in the market and depends on various factors such as the ability of the company to market it, market conditions, and the socio-economic environment. The technical value on the other hand is associated with the practical realization of the technology described by the patent at a commercial scale. The technical value is generally revealed through the importance of the patent to the implementation of successive technologies (Carpenter et al., 1981; Harhoff et al., 1999). The technical value results from the maturity of the technology.

This research focuses on assessing the technical value of an invention. We focus on technical value because inventions employing highly mature technologies generally result in successful products (Beierlein et al., 2015; McNamee and Ledley, 2012; McNamee and Ledley, 2013) and find application in future technologies, thus likely demanding a higher net present commercial value. Different techniques have been demonstrated to evaluate the technical value of an invention. These measures have attempted to consider the underlying technical base of a patent rather than its surface-level metadata alone. Hu et al. (2012) used indicators based on a patent citation network, also termed an “ego patent citation network”. Hu et al. (2012) defines the *Technical Interest Index* (TII) of a patent as an indicator of the innovative density of the technological knowledge flow. It is measured as the squared root of the total number of citations of its references.

$$\mathrm{TII} = \sqrt{\mathrm{CIT}} \tag{1}$$

where CIT denotes the total number of citations received by the references of patent A. Hu argues that a patent's technical value reflects its technological knowledge base, knowledge flow, and technological complexity.

The technical value of an invention has also been defined through its “basicness” or its closeness to science. Trajtenberg (1997) suggests that “basicness” can be measured through the following equation:

$$\mathrm{IMPORTB} = \mathrm{NCITED} + \lambda \sum_{j=1}^{\mathrm{ncited}} \mathrm{NCITING}_{\mathrm{A}-1,\mathrm{j}} \tag{2}$$

where NCITED is the number of patents cited (references) by the target patent A, λ is a discount factor ($0 < \lambda < 1$) meant to down weight the second-generation patents, A − 1 indicates the cited patents, and NCITING is the number of patents citing the originating patent. In other words, NCITING is the citations received by the references of the target