World Patent Information 53 (2018) 39–44

Contents lists available at ScienceDirect

World Patent Information

journal homepage: www.elsevier.com/locate/worpatin

Citations as a measure of technological impact: A review of forward citation-based measures

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ARTICLE INFO

Keywords:
Patent analytics
Intellectual property analytics
Forward citation-based measures
Patent indicators
Technological impact

ABSTRACT

The number of forward citations a patent receives accumulates over time and appears to be correlated to the patent's (i.e. invention's) technological impact. A dominant theory suggests that highly cited patents contain an important technological advance. However, a variety of citation based measures have been proposed by different authors. This study, via a narrative literature review, identified nine forward citation-based measures that appear of particular relevance. We describe each measure and present them in a comparative format.

The measures are divided into two broad categories: firstly the ones that are particularly relevant to the patent level (citation index, forward citation frequency, generality, influence), and secondly the ones that are relevant to the patent portfolio level (current impact index, herfindal-hirschman index, hindrance index, relative patent position, technology strength).

We hope research scholars and industrial users find this review helpful for citation analysis and intellectual property analytics, especially when wanting to employ forward citation-based measures to assess technological impact.

1. Introduction

Patents are an essential source of technical and commercial knowledge [1,2]. In fact, technical information contained in the wordwide patent database represent the largest repository of technological knowledge. Considering the fact that inventions are a source of new technological knowledge, patent data can be considered an important source for understanding technological knowledge, innovation and progress [3]. Through statistical examination of patent documents, it is possible to gain insights into different facets of an invention, the actors involved in the invention and the impact of an invention. For instance, through the analysis of longitudinal patent data it is possible to track the diffusion of inventions [4–6] and the influence particular inventions have had on others [7,8]. The use of citations in legal documents dates back to the second half of the 19th century. Eugene Garfield is one of the pioneers having used citations to analyse academic literature, but also patents. He started the science citation index in 1955 and patent citation index in 1964 [9–12]. Examiners at the United States Patent and Trademark Office (USPTO) are reported to have used citation cards since 1947 during the examination process [13–16].

In recent years citation data has become a centre of interest in big data and patent analytics [17–22]. Citation analysis is based on the examination of links between patents [23]. In addition one may note that one of the largest 21st century corporations is based on citations. The patent US6285999, which lists Lawrence Page as the inventor of a "method for node ranking in a linked database", sets out the basis for Google's search algorithm Dominant theory suggests that the number of citations a patent receives is correlated to the technological and commercial importance of that patent, and the invention described therein [24–26]. As the process of innovation becomes more complex [27], the strategic importance of patent citations analysis has become more relevant, since the number of citations has been used as a measure of technological valuation and diffusion [2,28,29]. Batagelj et al. [30] also argues that the analysis of patent citations helps to assess the originality and relevance of innovation.

This study follows a narrative review approach [31,32] to identify and summarise citation-based measures in the literature. We identify and focus on 9 forward citation-based measures, indicating technological impact. These are divided into two broad categories: firstly the ones that are particularly relevant to the patent level, and secondly the ones that are relevant to the portfolio level. We hope research scholars and industrial users, may find this review helpful for citation analysis and intellectual property analytics [20], especially when searching for forward citation-based measures that measure technological impact.

The paper is structured as follows: section 2 outlines existing

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https://doi.org/10.1016/j.wpi.2018.05.001
Received 18 April 2017; Received in revised form 2 May 2018; Accepted 3 May 2018

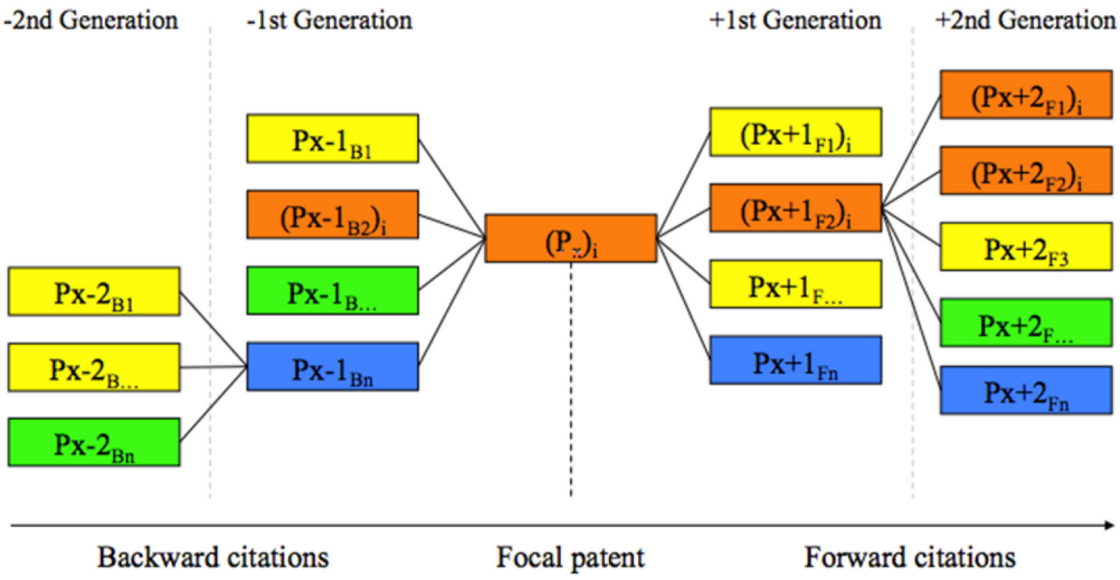

Fig. 1. Patent Citation Framework (Key: colour matching = patents belonging to the same patent family). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

citation theory; section 3 briefly describes our methodology for exploring the citation-based measures; section 4 provides a summary of the 9 identified forward citation-based measures; finally section 5 concludes the study.

2. Citation theory

Citations are mainly divided in two main classes, backward citations and forward citations (Fig. 1). Backward citations are those earlier patents cited by a focal patent [13,33,34]. A patent should be proven novel, wherefore prior art is collected during the examination process and listed on the patent document [35,36]. In different types of studies backward citations are often used as measures of knowledge transfer [13]. Prior art citations are not only added by examiners, but also by applicants, and by third parties e.g. during opposition proceedings; however, examiner citations are relatively associated with technological impact [14,36,37].

While backward citations are determined during the examination process by the examiner or listed by the applicant [14], forward citations are those linked to a focal patent by patent filed afterwards listing the focal patent as a backward citation. The main difficulty in computing forward citations is that they emerge over time, and sometimes a long while after the cited patent was filed, granted or even reached full term [25]. Hence, only with the widespread digitization of patent documents [38] has it become possible to calculate forward citation data in an automatized way on a continuously updated basis.

Forward citations indicate the existence of downstream research efforts, suggesting that money is being invested in the development of the technology [33,34]. Also, the fact that a given patent has been cited by subsequent patent applications suggests that it has been used by patent examiners to limit the scope of protection claimed by a subsequent patentee, to the benefit of society. In this sense, forward citations indicate both the private and the social value of inventions. Forward citations are commonly used to measure the technological impact of innovation [24,25,33,34,39].

In recent years citations have been used widely in different disciplines [19,40]. For instance, Breitzman et al. [41] describe how the analysis of patent portfolios could aid the evaluation of mergers and acquisitions, measuring the quantity and quality of a company's patents using citations. Petruzzelli et al. [8] investigate the drivers leading certain patents to have a stronger influence on subsequent technological developments. Moreover, Yoshikane et al. [42] use a multiple regression analysis on citation frequency, the response variable, and consequently citation index to examine the influence of diversity on backward citations. Lee et al. [2] use a stochastic patent citation analysis approach to assess future technological impact. Wang and Duan [43] use citation data in the form of co-citations to identify the core technologies of the Electric Vehicle industry. Von Wartburg et al. [44] argue that a multi-stage patent citation analysis is necessary to reveal the inventive progress, making use of direct and indirect citations, to explain aspects of technological change. Hu and Jaffe [45] investigate the international knowledge flows of patent citations, where as Karki [46] investigate the use of citation index as a policy analysis index. Patent citation analysis and its limitations have been discussed widely. A particular limitation is the fact that they are a noisy measure of knowledge flows, since the final decision on which patent to cite lies with the patent examiner, although the inventors can suggest it [5,35,36,47].

It is important to understand the concept of a “patent family” when analysing patent data. A patent family is a collection of patent applications covering the same or similar technical content, which are related to each other through priority claims or by one common priority filng(s). However, there are different patent family definitions, and the number of citation counts depends on the chosen one [48]. On Fig. 1, the patent family concept is shown by the colour coding; patents in the same patent family have the same colour. When analysing patent data it makes a difference if the analysis is carried out for individual patents or on a patent family level, and one needs to avoid double counting patents that belong to the same patent family, due to different patent family definitions [49].

3. Methodology

This paper aims to identify and summarise specifically forward citation-based measures relevant for assessing technological impact from the set of measures previously proposed by authors in the literature. While there are numerous citation based measures, we identified nine forward citation based measures via a narrative literature review [31,32], which have been suggested as proxy for assessing technological impact. Using Google Scholar, we searched published articles (March 2015) with the following key words: ‘patent indicators’, ‘patent citation analysis’, ‘citation analysis indicators’, ‘forward citations’, ‘patent importance’, ‘patent impact’, ‘patent influence’, ‘value of innovation’ and ‘value of invention’. The review revealed 9 forward citation-