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

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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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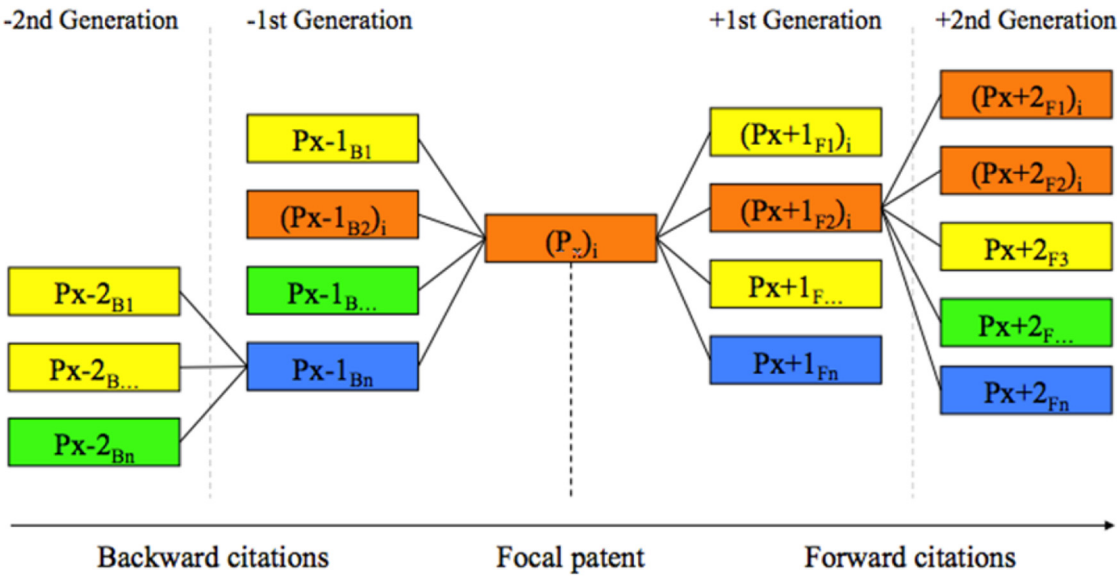

Fig. 1. Patent Citation Framework (Key: colour matching = patents belonging to the same patent family). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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-

Table 1
Citation-based measures - patent level.

Measure	Description	Source	Used by	Equation
Citation Index (CI)	CI is the count of the citations received by a company's patents from subsequent patents. It is used to evaluate the technological impact of patents. The number of forward citations mirrors the technological importance of the patent for the development of subsequent technologies, and also reflects the economic value of inventions [24,34]. Patents with high values of CI are often important inventions or fundamental to future inventions, making these inventions valuable [24] due to the cumulative nature of the process.	[10,11,15,23,25,34,54,56,57]	[24,37,41,43,50,53,58]	$CI = \sum_t \sum_1^n Citations\ citing\ patent_{tn}$ where t is the year of patent publication and tn is the publication year of subsequent patents citing the original patent.
Forward Citation Frequency (FCF)	FCF is defined as the number of forward citations received by a patent per year. This is an indication of the impact of a company's patents. FCF can only be compared within a technological area for a particular year, since the number of citations changes per year.	[24,33,34,39,59,60]	[27,54,61]	$FCF = \frac{CI}{Patent\ Age}$
Generality	The generality of a target patent indicates the diversity of citing patents, i.e. the patents that cite the target patent. The index is defined between zero and one, and the measure is high if subsequent patents belonging to a wide range of fields cite a patent. If most citations are concentrated in a few fields the generality index is low [62]. state the numerical range of the index with 0–0.44 (low), 0.45–0.65 (mid) and 0.66–1 (high).	[25,63]	[13,24,30,39,64]	$Generality = 1 - \sum_{J \in Sf} \left(\frac{Number\ of\ Citing\ patents\ belonging}{Number\ of\ Citing\ Patents} \right)^2$ where Sf is the set of classes of citing patents
Influence	The Influence is defined as the number of forward citations a patent received from subsequent patents in the first years since its publication. The higher influence index suggests that a patent has influenced and impacted the technology scope of subsequent patents on publication.	[8]	[8,65]	$Influence_{i,t} = 1 + (\sum_t^{t+5} Cit_{i,t})$ Cit(i,t) is the number of forward citations the i patent received from following patents up to five years after the publication date, where t is the year.

Table 2
Citation-based measures - portfolio level.

Measure	Description	Source	Used by	Equation
Current Impact Index (CII)	CII is the number of times a company's previous 5 years of patents are cited in the current year, relative to all patents in the U.S. patent system. It can measure the influence of a company in the last 5 years, and indicates patent portfolio quality. CII is a synchronous indicator, which looks back from the current year to the previous five years. In general, patents with higher CII values often represent stronger technological ability. It has the advantage to foresee the development of a technology.	[66]	[41,51,52,54,67]	$CII = \frac{100C_i/\sum_i C_i}{100K_i/\sum_i K_i}$ Ci represents the number of times a patent of company I has been cited in a certain year, from previous 5 years. Ki is the number of patents, company i produced the past 5 years.
Herfindal-Hirschman Index of Patents	HHI describes the concentration of patents across patent classes, and is used to measure the concentration level of a firm's technological capability. HHI is described as a patent quality indicator and is used to explore the relationship between patent quality and market value. According to [68], a HHI index constructed from a small number of counts will generally be biased downwards. To avoid the bias, we also use the HHI index adjusted for Bias measure [68].	[24,25,47,68]	[24,34,39,47,60]	For a set of N patents falling into n classes, with Ni patents in each class (Ni ≥ 0, i = 1 … i), the HHI is calculated $HHI\ of\ patents = \sum_{i=1}^{n}\left(\frac{N_i}{N}\right)^2,\ 0 \le HHI\ of\ patents \le 1 Adjusted\ bias\ measure = \eta = \frac{N.HHI-1}{N-1}$
Hindrance Index (HI)	The measure of hindrance, of the assignee of the target patent is defined as the ratio of 'X' and 'Y' citations received from competitors to all 'X' and 'Y' citations received. If the firms received 'X' or 'Y' references from future patents they can be seen to hinder or block subsequent patents.	[13]	[13]	$HI = \frac{\sum 'X'\ and\ 'Y'\ forward\ citations\ from\ competitors'}{\sum All\ 'X'and\ 'Y'\ forward\ citations\ received}$ Forward citations are split into 'citations by competitors (the no. of patents with a different assignee than the focus patent)' and 'total citations by all other non-competitve companies (the no. of patents developed conjointly between competitors)'.
Relative Patent Position (RPP)	RPP of a company in its most important technological field means the patent counts owned by the company in its technological field where it has more patents than in others divided by the patent counts of the leader in the technological field. RPP is used to measure the degree of leading of the company in the technological field; the higher the value, the more leading position the assignee of that patent has in the field.	[69]	[26,52,70]	$RPP = \frac{\sum N_{p(same\ assignee)}}{\sum N_{p(leader\ in\ the\ field)}}$ The leader in a technological field is defined as the company with the largest amount of patents granted in the field.
Technology Strength (TS)	TS indicator is used to measure the scale of a company in a specific technological field, indicating patent portfolio strength.	[54,71]	[51,54,55,67]	$TS = Number\ of\ Patents\ x\ CII$ It makes the assumption that the number of patents of a company in a specific field is of similar quality and impact as the company's recent patents.

based measures, which we have split into two broad categories for presenting them: firstly the ones that are relevant to the patent level, and secondly the ones that are relevant to the portfolio level.

4. Forward citation-based measures

In order to analyse patent data on a large scale and interpret the results, different citation-based measures have been developed. In this study, we focus on forward citation based measures, which indicate technological impact. The literature review reveals two types of citation based measures. The first group contains citation based measures, which are calculated at the patent level, and provide information about the technological impact of that particular patent relative to other patents in the domain or the dataset [34,39,50,51]. The second category contains citation based measures, which are calculated at the patent portfolio level, and provide information about the technological impact of a particular firm's patent portfolio in relation to its competitors [26–28,31,49,50,53].

Table 1 provides an overview of the citation-based measures relevant to the patent level. These include the citation index, forward citation frequency, generality and influence. The citation index is the number of forward citations a patent receives since its publication, where as the forward citation frequency is the number of forward citations over the patent age, and shows the cited frequency of that patent. These two measures are quite frequently used in citation analysis as they are quite easy to compute. The generality of a target patent indicates the diversity of citing patents, i.e. the patents that cite the target patent. It suffers from truncation because fairly new patents would have a low number of citations. It is the most complicated measure to compute from Table 1. The influence measure shows the influence (number of forward citations) a published patent had in the first 5 years of its existence. It is a relatively new index that has not been used extensively. It can take a variety of forms, i.e. influence in the field, out of the field or across boundaries. One major drawback is that it does not take into account the grant lag period or any legal disputes.

Table 2 provides an overview of the citation-based measures relevant to the patent portfolio level. These include the current impact index, Herfindal-Hirschman index, hindrance index, relative patent position and technology strength. The current impact index is the number of times a company's previous 5 years of patents are cited in the current year, relative to all patents in the U.S. patent system, measuring the influence of a company in the last 5 years. It depends on the number of citations received by a patent in the last five years. The Herfindal-Hirschman index describes the concentration of patents across patent classes, and is used to measure the concentration level of a firm's technological capability. A small size dataset produces a biased downwards measures. The hindrance index measure the level a firm's patent block or hinder other patents. The relative patent position measures the degree of leading of the company in the technological field, where as the technology strength measure is used to quantify the scale of a firm within a specific technological field. The most common measure used is the Herfindal-Hirschman index and the least used is the hindrance index, which is relative new. There is on average less sources using the citation-based measures on the patent portfolio level than the patent level.

5. Conclusion

In this study, via a narrative literature review [31,32], we identify and summarise 9 forward citation-based measures, which indicate technological impact. These are divided into two broad categories: firstly there are 4 that are particularly relevant to the patent level (citation index, forward citation frequency, generality, influence), and secondly we found 5 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 [20], especially when searching and selecting forward citation-based measures when designing their research or analysing their data. Practitioners may find this helpful when reviewing their patents, respectively their patent portfolio and when developing an Intellectual Property (IP) Strategy. The paper provides a quick access point to the literature of forward citation based measures, by referencing original sources and studies that used those measures.

Future investigation into this field should aim to address the interdependencies between the citation-based measures. This could lead to potential development into a framework for patent influence within and across sectors, and the impact it has on the diffusion of innovation. Additionally, future investigation should address the development of a combined index approach, which takes into consideration several citation-based measures [39], which could result in the development of alternative proxies such as multi-indicator approaches, to assess technological impact.

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