Discussion Paper No. 15-051

Measuring Patent Quality in International Comparison – Index Development and Application to China

Philipp Boeing and Elisabeth Mueller

ZEW

Zentrum für Europäische Wirtschaftsforschung GmbH

Centre for European Economic Research

Discussion Paper No. 15-051

Measuring Patent Quality in International Comparison – Index Development and Application to China

Philipp Boeing and Elisabeth Mueller

Measuring patent quality in international comparison – Index development and application to China

Philipp Boeing* and Elisabeth Mueller**

July 2015

Abstract: We develop an index that compares the quality of Patent Cooperation Treaty (PCT) applications by considering citations generated by International Search Reports (ISRs). In its most restrictive variation, i.e. excluding citations from the home country and self-citations, the ISR index is not biased by selectivity in filing strategies, differences in citations due to varying national examination procedures, or domestic economic policies. Against the background of strong increases in Chinese patenting between 2001 and 2009, we compare the quality of Chinese PCT applications with those from high-income countries. Chinese PCT applications achieve only 34% of the quality level of international PCT applications. In addition, their quality is decreasing over time. We find that the patent quality of firms increases in R&D stocks but decreases with the introduction of PCT subsidies. Our results confirm that China's expansion of international filings was achieved to the detriment of quality.

JEL Classification: O34, O32
Keywords: patent quality, PCT system, China

* Centre of European Economic Research (ZEW), L7, 1, 68161 Mannheim, Germany, e-mail: boeing@zew.de

** Frankfurt School of Finance & Management, Sonnemannstr. 9-11, 60314 Frankfurt am Main, Germany; Swinburne University of Technology, Melbourne, Australia; ZEW, Mannheim, Germany; e-mail: e.mueller@fs.de

Acknowledgements: We acknowledge valuable feedback from Can Huang, Xibao Li, Georg Licht, Russell Thomson, and Beth Webster. We thank conference and seminar participants at the ZEW Conference on Economics of Innovation and Patenting 2015, Swinburne University of Technology, Chinese Academy of Social Science, Chinese State Information Center, and Zhejiang University for helpful discussion. We thank patent examiners from the European Patent Office, IP Australia, and the German Patent and Trademark Office as well as Carlo Pandolfi, Director International Co-operation at European Patent Office, for sharing their insights with us. Marian Hafenstein, Evi Kröker, and Wu Taixing provided excellent research assistance.

1 Introduction

The current globalization of R&D activities is reflected in international patenting. Between 1995 and 2013, the number of global patent applications at national offices increased from below one million to 2.4 million, whereas the share filed within the triadic region – the United States Patent and Trademark Office (USPTO), Japanese Patent Office (JPO), and European Patent Office (EPO) – declined from 69% to 49% in the same time period (OECD 2015). These trends reflect both a strong demand for patent protection and a decentralization of inventive activities away from the triadic region, which traditionally hosted most global R&D. Although the international protection of intellectual property is rising, this protection is no longer focused on the triadic region. The 414% increase in the number of Patent Cooperation Treaty (PCT) applications between 1995 and 2013 is disproportionately large in comparison to that of triadic patent families, which increased by a mere 43% over the same time period (OECD 2015).

Due to R&D globalization and the rapidly increasing quantity of patent applications from emerging countries like China, international comparisons of patent quality is growing in relevance. However, as we argue in this paper, there currently exists no satisfactory measure to provide concluding evidence. Addressing this gap, we develop a novel measure and apply it to investigate the quality of China's rapidly rising PCT applications in comparison to an international benchmark.

Prior literature has proposed that the count of triadic patent families at the country or firm level can function as a quality measure to be used in international comparisons (Grupp and Schmoch 1999). Patents filed at the USPTO, the JPO, and the EPO are considered to be the most valuable patents as the granting process is demanding and expensive. However, this measure is crude – significant quality variation exists among different triadic patents and is

not captured by a mere count. The declining relative importance of the triadic region only further diminishes the relevance of this measure.

Alternative quality measures are most commonly based on citations. An advantage of these measures is their ability to allow for different quality levels within a set of patents. However, these measures are problematic if they are based on citations from just one patent office, because patent examiners are typically biased in favor of citing applications from their own countries in search reports (Michel and Bettels 2001). Consequently, single patent office citations measures are not useful for international comparisons. Even if citations from all major patent offices are accounted for, clear cross country comparisons are impossible if analysis is restricted to applications from a single patent office. This is because applications from different countries are not fully comparable: they constitute domestic applications for local applicants but international applications for foreign applicants. There is a positive selection bias for international applications because firms select only their more valuable inventions for protection abroad. Further quality measures proposed in the literature are the grant rate and the renewal rate. However, these indicators can potentially be influenced by domestic economic policy, e.g. as observable in China, which restricts their applicability for international comparisons.

Addressing these limitations, we develop a novel index based on citations generated by the International Search Reports (ISRs) of PCT applications. The index compares the number of ISR citations received by a set of applications from one country to the number of ISR citations received by applications of the same priority year and technology class from other countries. An ISR index of 100% signifies a quality level just equal to the average international application quality.

PCT applications are filed with a competent Receiving Office (RO). During the 30 months following the priority date, a PCT application is in the international phase. The

designated International Search Authority (ISA) publishes the ISR 18 months after priority. References to prior art are contained in the ISR, and the strict PCT guidelines for these references are identical for all ISAs. After 30 months, the application enters the national phase in which national patent offices perform additional search and examination and ultimately make the grant decision.

In its most restrictive form, the ISR index is designed to rely as much on foreign and regulatory oversight as possible. Therefore we exclude citations from the home country of the focal patents as well as self-citations. Focusing on citations originating from the PCT system simplifies international quality comparisons for three reasons. First, selection bias is avoided as, irrespective of the applicant's home country, PCT filings are always international applications. Second, the PCT system subjects applications from different countries to the same procedures. The ISR index is thus not influenced by differing practices at domestic patent offices. Third, distortions by governmental intervention are avoided because the quality measure cannot be influenced by the economic policy of the focal country. In two less restrictive variations of the index we investigate changes depending on the inclusion of citations from the own country as well as self-citations.

Motivated by the tremendous increase in Chinese PCT applications after 2001 (Figure 1), we apply our index to study the quality of these applications. As firms typically face a tradeoff between the quality and quantity of their applications (de Rassenfosse 2013), China's dramatic patent expansion has elicited questions regarding patent quality. China's patent expansion follows quantitative targets set by governmental economic policies.[1] In consideration of these targets, numerous provincial and sub-provincial subsidy programs incentivize patenting, and they commonly support domestic as well as international

[1] Recent cornerstones of China's innovation policy are the "Medium- to Long-term Plan for Science and Technology Development (2006-2020)" (MLP), the "National Patent Development Strategy (2011-2020)," and complementary "Five-Year Plans for Science and Technology Development."

applications. In addition, the central government introduced subsidies for granted PCT patents in 2009 (Ministry of Finance 2009).

Investigating the effect of patent subsidies on China's patent expansion, Li (2012) documents a positive relationship. Lei et al. (2012) confirm this finding but show that the number of claims per applicant remains constant whereas the resulting number of claims per patent decreases in response to increases in subsidies. Because this suggests that increases in patents do not reflect increases in inventions (as measured by claims), it is surprising that resulting decreases in average patent quality are not reflected in decreasing grant rates. Instead, both studies report constant or even increasing grant rates. Consequently, it seems that China's economic policy not only increases the number of patent applications but also lowers examination standards – making grant rates an unreliable measure for patent quality.[2]

Against this background, China's State Intellectual Property Office (SIPO) has recently published two documents that criticize the abundance of provincial and city-level subsidies for patent applications and low examination standards at provincial and city-level patent offices (SIPO 2014, 2013). SIPO suggests that increases in applications are detrimental to average patent quality, and it demands stricter monitoring practices of examination standards. Further, SIPO proposes to change application-based subsidy schemes to grant based ones and thereby to reduce excessive applications while incentivizing patent quality over quantity. Hence, a reliable analysis of the quality of Chinese patents is of great interest to practitioners and academics.

In the application of the ISR index, we start with an analysis of PCT application data based on the April 2013 version of the international patent database PATSTAT and consider

[2] The effect of China's economic policy on examination standards may be direct, if provincial policy makers encourage constant grant rates, or indirect, if examiners are confronted with increasing applications – leading to considerably shortened examination periods that are negatively correlated with the probability of discovering prior art.

applications where the first applicant is from China for the country-wide analysis. In a separate step, the full patent data is matched to data on the population of listed firms in order to extend the analysis from the country to the firm level. For our most restrictive index (non-self citations from outside own-country) we find that for the priority years 2001-2009, the full set of PCT applications with Chinese origin achieves a quality level of only 34% of the quality level of international PCT applications. Furthermore, patent quality is strongly decreasing over time. In contrast, the most inclusive index (citations from own-country and self-citations) shows an increase in quality, with quality surpassing the international benchmark in the later years. These divergent results can be explained by the increasing size of the Chinese patent system (through which earlier patents become more likely to be cited) and the growth of self-citations prompted through Chinese firm growth. At the firm level, we only observe a significant relationship between R&D stock and the most restrictive index whereas firm size plays a role for the least restrictive form. These results highlight the need for utmost precision when selecting the set of citations to be considered for quality evaluations.

The ISR index has a broad applicability beyond the scope of applications in this paper. In its most restricted form, the index provides a clear quality assessment regardless of economic and political influences from the focal country. As such, it is highly suitable for policy analysis. Depending on the researcher's analytical focus, it is possible to include a wider set of citations, e.g. from the focal country or self-citations. The index is equally applicable to countrywide analysis, analysis of a sub-group of applicants (e.g. universities), analysis of a single applicant (e.g. a large multi-national firm), and even to the analysis of single applications.

The remainder is structured as follows. Section 2 develops our quality index, Section 3 describes the prior literature on the quality of Chinese patents and explains the application of

the index to the Chinese setting, Section 4 introduces data sources, Section 5 presents the analysis, and Section 6 concludes.

2 Index development

2.1 Definition of the ISR index

In this section we introduce an index that allows for cross-country comparisons of patent quality. We define this index in three variations, all of which together deepen our understanding of the considered inventions. In order to achieve a high comparability between countries, we only consider citations generated by PCT applications during the stage of international search, i.e. the citations mentioned in the ISR. PCT applications are characterized as filing strategies with identical legal backgrounds independent of the applicant's country of origin and are comparable because they represent international applications for all firms (Grupp and Schmoch 1999). Due to high filing costs, organizations typically file only a selection of their inventions for international protection. Thus, the index is based on an evaluation of the most valuable inventions of each country.

Below we provide the formula for the most restrictive form of the index. The indicator *non-self citation*$_{i,j}$ is equal to one if application *i* is cited by application *j* within the defined time window and zero otherwise. *i, j, k* are a specific PCT application with *I* the total number of applications. *c* is the country of the first applicant, *t* is priority year, and *m* is technology. *c'*, *t'* and *m'* denote a specific country, year, and technology, respectively. $N_{t', m', c'}$ is the number of PCT applications with priority year *t'*, technology *m'*, and country *c'*.

For the comparison of the quality of a set of patents from year *t'*, technology *m'*, and country *c'* with an international quality benchmark, we define the following formula:

$$ISR\ index_{t',m',c'} = \frac{\left(\frac{\sum_{i=1,i\in t=t',m=m',c=c'}^{I} \sum_{j=1,c_i\neq c_j}^{I} \text{non-self ISR citation}_{i,j}}{N_{t',m',c'}}\right)}{\left(\frac{\sum_{k=1,k\in t=t',m=m',c\neq c'}^{I} \sum_{j=1,c_k\neq c_j}^{I} \text{non-self ISR citation}_{k,j}}{N_{t',m',c\neq c'}}\right)}$$

Thus, our index compares the average number of non-self citations from ISRs received by PCT applications of country *c'* to the average number of such citations received by PCT applications of the other countries.

The most restrictive of the three variations of the index uses only non-self citations emanating from ISRs of applicants from outside of the focal country. To avoid any national biases, we exclude citations if the applicants of citing and cited patent are from the same country. Due to technological specialization of countries, applicants may receive a disproportionate share of citations from their home country. This exclusion procedure also ensures that the citation count is independent of the size of the home economy; likewise, citation count is independent of trends in application numbers of the home patent system. Furthermore, we exclude self-citations from our citation count to only measure the use of an invention by a third party. To avoid double counting, only citations from distinct family pairs of citing and cited patents are considered. Fractional counting is used to apportion patents that belong to more than one technology class. A value of the *ISR index* of larger (smaller) than 100% signifies quality above (below) the international benchmark.

The first extension of the index includes citations from PCT filings of the home country, and it thereby reflects the degree to which the economy builds on its own research as compared with benchmark countries. The second extension additionally accounts for self-citations. Larger values of this latter extension are expected for economies dominated by large individual applicants.

2.2 Advantages of using PCT citations to measure quality

We follow prior literature by choosing citations as a proxy for the economic value and thus the quality of patents. Citations have been shown to be a good proxy for both the economic value (Harhoff et al. 1999) and the technological value (Trajtenberg 1990) of patents. However, they are not an indicator of the legal quality of the draft of the application. Considering survey responses for the actual economic value of patents, Gambardella et al. (2008) show that citations have a closer relationship to value than references, claims, or family size – other proxies typically available in large-scale analyses. In addition, citations are available from many patent offices. The length of the renewal period is an alternative quality measure, but its international comparability is limited due to differences in renewal fees. Finally, legal procedures called oppositions, while good quality measures, are not available in all jurisdictions.

Even though citations are generally a credible quality measure, citation counts can be difficult to compare across countries. In applications with an international context one has to consider different practices in national patent offices. For a set of triadic patent families, Michel and Bettels (2001) show that the USPTO cites three-times more patent references than the EPO when examining these families according to the national standard. In contrast, the authors demonstrate very similar citation rates for USPTO, EPO, and the JPO when the offices prepare ISRs as ISAs, and they therefore conclude that comparative studies have an advantage if they draw their citation data from only one legal system. We follow their advice and base our quality measure only on citations from the ISRs of PCT applications.

Further differences among patent offices are due to differing rules for applicant citations. Whereas in the US the applicants need to provide references to all relevant prior art they are aware of, the EPO requires only the examiner – not the applicant – to perform this task (Michel and Bettels 2001). With respect to applicant citations, the rules of the PCT system are in between the extremes of USPTO and EPO. The description of the application

should “indicate the background art which, as far as known to the applicant, can be regarded as useful for the understanding, searching and examination of the invention, and, preferably, cite the documents reflecting such art” (Rule 5 of WIPO 2014c).[3] Ultimately, the examiner controls which references are included in the search report. The selected references measure the technical and legal relationship among patents and are the appropriate measures of patent value for our analysis.

Restricting the analysis to citations from the ISR has several advantages. The PCT system applies common standards for the search of prior art, which makes the citations internationally comparable regardless of the nationality of the ISA conducting the search. The search guidelines explain in detail how citations should be selected by the examiners (WIPO 2014b, §15.63-15.67). For example, examiners are encouraged to cite only the most relevant documents and to cite documents in the language of the application, if several members of one patent family are available (WIPO 2014b, §15.64). As we aggregate citations at the family level, our quality index is not influenced by which family member is actually cited. International comparability is further enhanced because the search for prior art is highly concentrated among few ISAs. According to WIPO (2014a, p. 69), the top five ISAs were responsible for more than 90% of ISRs in 2013 (EPO 37.7%, JPO 20.7%, SIPO 11.6%, Korean Patent Office (KPO) 14.8%, USPTO 8.1%).

PCT applications move from the international to the national phase 30 month after priority. National patent offices conduct additional searches and examine the application before deciding a grant. Citations in the national phase can differ from ISR citations as they

[3] Analyses of knowledge flows should only consider applicant references as there is a higher likelihood that the inventors are aware of them (see Alcácer and Gittelman 2006 for differences between the two types of references). As we are not interested in the measurement of knowledge flows, the difference between applicant and examiner citations are of second order to us and we therefore include both types of citations.

follow national guidelines. In order to restrict the citations to one institutional setting, we do not consider citations generated during the national phase for our quality index.

In international comparisons, one must account for potential language barriers that deter patent examiners from identifying prior art from a specific country. Patent examiners typically start their search for prior art with a keyword search in English, regardless of which searches – i.e. searches for the ISR or searches within national procedures – are conducted. Thorough prior art searches are only possible if documents published in other languages can be found. The PCT system provides an English translation of the main parts of PCT applications, namely title, abstract, international search report, and any text relating to figures for all PCT applications not published in English (WIPO 2014c, Rule 48.3 (c)). Concerning search, the abstract plays a key role. According to Rule 8.3 (WIPO 2014c) "The abstract shall be so drafted that it can efficiently serve as a scanning tool for purposes of searching in the particular art, especially by assisting the scientist, engineer or researcher in formulating an opinion on whether there is a need for consulting the international application itself". PCT applications, even if not originally published in English, are therefore easily identifiable as potentially relevant prior art. It remains to be discussed in our application example (Section 4) whether the availability of the full text of the patent document in English makes difference to actual citation rates. In any case, if the quality of national applications should be compared with our index, one has to consider whether language biases exist. If yes, one should try to quantify those.

According to further guidelines of the PCT system, patent examiners conducting the international search have to have access to the minimum documentation standard, which specifies which prior art needs to be searchable for examiners. PCT applications, no matter of which publication language, are part of this minimum standard. As such, all PCT applications are fully available during the search process. Patent applications belonging to the minimum

documentation standard are typically included in the databases most commonly used for search by examiners (e.g. Derwent World Patents Index (DWPI), Chemical Abstracts Service (CAS), and EPOQUE at the EPO). When applying our index, one must ensure that the set of focal patents to be analyzed is contained in the minimum documentation standard. For example, Chinese domestic applications with SIPO are only included in the minimum documentation standard since 2012.

3 Application to China

3.1 Prior literature on the quality of Chinese patents

Before we use our index to compare the quality of Chinese patents to an international benchmark, in this section we discuss relevant prior literature. Although existing studies have approached the topic of patent quality in China from different angles, these studies suffer from several limitations. One method compares the quality of domestic and foreign filings at SIPO. Using renewal decisions as a quality measure, several papers find that patents of Chinese applicants are less valuable than those of non-Chinese applicants. For the time period 1985-2009, Gupeng and Xiangdong (2012) observe that patents from domestic applicants typically reach only 33%-50% of the value of patents from foreign applicants. The authors rely on the method used by Schankerman and Pakes (1986) to relate renewal decisions to patent value, and they extend this method to patents that are still in force. Taking possible infringement into account, Zhang et al. (2014) find that domestic applicants reach 40%-60% of the value of patents of foreign applicants. According to Huang (2012), the value gap has narrowed in the 2000s. Ultimately, the quantification of the value differences is problematic on two fronts. On one hand, positive selection bias distorts quality results. That is, the measured quality advantage of foreign applicants is in fact overestimated because applicants seek protection abroad only for their more valuable applications (Harhoff et al. 2003). On the other hand, economic policy might encourage applicants to hold a large active patent portfolio

to restrict entry by foreign firms (Herrmann-Pillath 2014, 414-416). Renewal decisions are therefore based not only on economic considerations but also on political incentives, and thus value estimates are inflated. In this example, economic policy may directly influence the chosen quality measure. Prior studies have not used Chinese citations as data on citations is not disclosed by SIPO.

A different approach was chosen by Branstetter et al. (2013) who concentrate on grants at the USPTO from different provenances. The authors first highlight that approximately two thirds of USPTO grants with at least one inventor from China are filed by non-Chinese multi-national companies (MNCs). Using the number of citations as a quality measure, the authors find that purely domestic patents are of lower quality than patents filed by non-Chinese MNCs or with contributions by non-Chinese inventors. Whereas the paper clearly advances our understanding of the patent quality with respect to different economic actors in China, it does not provide a systematic analysis of quality differences between domestic Chinese firms and their international counterparts. Patent quality of MNCs could be systematically higher than patent quality of non-MNCs, and patents with international inventor teams may be of higher value because they can draw on a richer knowledge base.

Kwon et al. (2014) also investigate the comparative quality of filings at the USPTO. Using the number of received citations and the share of patents with at least one citation as a quality measure, the authors observe that grants of Chinese origin were of lesser quality than those originating in the US between 1980 and 1999; however, this quality margin dissipated between 2000 and 2009. In addition, grants from China do not yet reach the technology frontier as they cite on average older US patents than US firms. Because this paper determines the country of origin according to the location of the first inventor, filings from non-Chinese MNCs are included in Chinese filings. Presumably, this measurement technique contributes to the observed equalization of Chinese and US grant quality in the latter time period.

Furthermore, the positive selection bias of foreign filings favors Chinese grants in this analysis.

Finally, Thoma (2013) compares the quality of Chinese and non-Chinese applications at the EPO and finds shorter renewal periods, more supplementary search reports, more oppositions, but no difference in grant probability for indigenous R&D – defined as patents with at least one applicant and one inventor based in China – over the period 2000-2007. As indigenous R&D includes non-Chinese MNCs with locations in China and as there is a positive selection bias for filing at a faraway patent office, shorter renewal periods indicate the lower quality of patents with origin in China. The analysis does not quantify these quality differences, and it is not restricted to purely domestic applicants – i.e. patentees considerably influenced by Chinese economic policy.

3.2 The Chinese setting

Our quality index derived in this paper helps overcome the aforementioned limitations of prior quality measures. It provides an unbiased and most homogeneous comparison of patent quality across countries. By applying this index to the full set of Chinese PCT applications as well as to the set of PCT applications of listed, domestic firms, we are able to establish the quality level based on the comparison of the number of ISR citations received by PCT applications of Chinese origin to the number of ISR citations received by PCT applications from other countries. We evaluate both the full set of PCT filings with Chinese origin and a selection of PCT filings applied for by Chinese listed firms.

Non-Chinese PCT applications are taken to constitute the international technology frontier because they originate mostly from high-income countries. In 2013, 87% of PCT applications came from high-income countries, 12% from upper-middle-income countries (thereof 10% from China) and only 1% from lower-middle-income countries. For the calculation of our benchmark we include applications from all applicant types (firms,

universities, and individuals). We use the same benchmark for the set of all Chinese PCT applications and for the PCT applications of listed firms. Because 85% of all global PCT applications originate from firms, we are confident that the international quality level of firms is reflected in the benchmark.

For Chinese applicants the PCT procedure stipulates that they have to file PCT applications with SIPO as Receiving Office (RO). SIPO is also the only competent office to act as ISA and to write an International Preliminary Examination Report (IPER).

The application of the index requires a choice for the citation window. When choosing the length of the citation window one faces a tradeoff. A long window means more subsequent patents have the possibility to cite and therefore the citation count will be a more precise measure of value. However, a shorter window allows the assessment of more recent patents. We choose a 3-year time period for the citation window because the Chinese economy shows a very dynamic development.[4] For the classification into different technologies we choose the 3-digit level of the IPC classification.

When applying the index to a specific setting, one has to make sure that it is not influenced by aspects outside the realm of quality. In our case this applies to potential language barriers. As Chinese PCT applications can be published in Chinese, a language which is not understood by the majority of patent examiners, we need to investigate whether there is a possible bias against citing Chinese PCT applications as prior art, and if yes, to try to quantify the corresponding language bias.

For the ultimate decision of whether to include a document as prior art, patent examiners want to consult the full text of the application. Examiners at ISAs have multiple

[4] The correlations between the 3-year and the 5-year citation counts for the variations of our index are with 0.81-0.90 relatively high. We are therefore confident that the shorter time period already gives a quite precise measure of quality. Furthermore, citations counts restricted to ISR citations are highly correlated with citation counts additionally including citations from the national phase: the correlation coefficients are around 0.8 and citation counts almost double. The ISR indices achieve a high information content even though citations are taken from just one institution.

sources of help available when encountering prior art in Chinese. At the EPO, for example, as a first line of immediate support, examiners can call on colleagues that are native speakers of Chinese for identifying whether a document is relevant. If the document is relevant, examiners can request a human translation of the full text. Machine translation of Chinese documents has become an intermediate step prior to requesting a human translation since 2008. For example, since April 2008, SIPO provides free machine translation of the full text of its patents to the public through its website (Kaemmer 2010). Only since 2012, after our sample period, could examiners at the EPO machine translate documents from Chinese into English through their search system EPOQUE.

By conducting interviews with patent examiners of several patent offices, we tried to identify possible biases against citing prior art in Chinese. When encountering Chinese prior art, examiners first try to find an equivalent document in English. In their decision whether this prior art is relevant, examiners are not influenced by their familiarity with the country or applicant. Importantly, it was acknowledged by a subgroup of examiners that under time pressure prior art in Chinese could have a lower probability to be included in the search report. The same could be true if alternative documents in English are readily available and sufficient to negate a claim or to reject an application as a whole.

Thus, we must quantify any downward bias that might affect our quality index. In the following, we derive a back-of-the-envelope calculation of the size of a potential bias. During our sample period of 2001-2009, the majority (91%) of PCT applications of Chinese applicants are published in Chinese with the remainder 9% published in English. However, when considering English equivalents published before or at the same time as the PCT application, only 44% of PCT applications of Chinese origin are not available with an equivalent full text in English. These applications are the candidates for a language bias. On

average, these PCT applications receive an English equivalent after 664 days after publication.

In order to quantify the actual citation bias, we calculate the share of non-self citations from outside China to all non-self citations before and after an English equivalent is available.[5] As this share increases from 31% to 69%, we need to adjust our citation count by 38% for the PCTs without English equivalents during the full citation window. We do not apply the adjustment for PCTs with English equivalents at publication, and we weigh the adjustment factor by 664/1095 for PCTs that obtain an English equivalent during the citation window, as the full 3-year citation window has a length of 1095 days. Thus, we arrive at a weighted correction factor of 11%. Even though the size of the language barrier is substantial for affected applications, the overall effect is smaller as not all applications are affected or are not affected over the full citation window. We will come back to the correction factor of 11% when interpreting our results. As it takes time for knowledge to diffuse geographically (Jaffe et al. 1993, Peri 2005), an increase of foreign citations is expected purely on technological grounds. The calculated correction factor is therefore an upper limit for the language bias.[6]

4 Data and descriptive statistics

For the subsequent analysis we construct two panel datasets, one at the patent level and one at the firm level. Our patent data is accessed via the EPO Worldwide Patent Statistical Database (PATSTAT, version October 2013). For the development of the quality index we consider the global population of PCT applications with a priority date between 2001 and 2009. Country allocation of PCT applications takes place according to the country of the first applicant. We

[5] Self-citations from outside China are possible in general, if an international subsidiary of a Chinese firm cites inventions of its mother company.

[6] More detailed investigation of how publication languages influence the identification of prior art in search reports is a worthwhile topic for future research but is beyond the scope of our analysis.

use the DOCDB standard names available in PATSTAT and the applicant name harmonization from KU Leuven (EEE-PPAT) to identify self-citations among PCT applications of the same applicant.

In the first dataset we observe the population of 34,738 Chinese PCT applications filed between 2001 and 2009. The time period starts in 2001 as Chinese PCT applications before 2001 are a rare event (see Figure 1). The time period ends in 2009 as the 3-year citation window opens 18 months after application and restricts the inclusion of more recent years. Against a continuous annual increase in application numbers from 793 to 9,641 over our time period, we observe a noticeable jump after 2008 – coinciding with the introduction of subsidies for PCT grants in China.

Our firm data covers the population of domestic Chinese firms listed at one of the two stock exchanges in Shanghai and Shenzhen over the time period 2001-2009.[7] Due to governmental stock issuance quotas, listed firms are adequately representative of the industrial composition of China's economy, with a high representation of large manufacturing firms located in China's more developed Coastal region (Pistor and Xu 2005). Note that the China Securities Regulatory Commission only allows listings of 'domestic' Chinese firms, e.g. the percentage of total shares held by foreign parties must not exceed 20%. This implies that patents from non-Chinese MNCs are excluded from our analysis of firm patents. We access firm data from Compustat, Datastream, and the Chinese databases WIND and RESSET. In addition, we derive firms' patent applications with SIPO from PATSTAT to complement PCT applications with domestic applications. Patent and firm data is matched according to the procedure specified in Boeing et al. (2015). Data on provincial GDP per capita is accessed from China's National Bureau of Statistics.

[7] Data on Chinese listed firms has been widely used in high-quality publications (for examples see Fisman and Wang 2010, Kato and Long 2006, and Fernald and Rogers 2002).

We briefly summarize standard firm characteristics for 228 firms with PCT applications for which we have 451 observations (Table 1). Employing the perpetual investment method, we calculate deflated R&D stocks based on an assumed 20% annual growth rate of R&D and the standard rate of 15% annual depreciation. The resulting median R&D stock has a value of 30 million RMB. The PCT and domestic patent stocks include the firms' complete applications, depreciated by 15% annually. To adjust for differences in firm size, we scale patent stocks by employees (in thousands) and find that the ratio is much smaller for PCT than for domestic applications. Firms with PCT applications are relatively large, with a median employment of 3,126. We broadly differentiate between firms with and without any government ownership and find that, according to this definition, 42% of observations are private firms. Figure 2 provides information about the expansion of patent ownership over time. In comparison to a 19% annual growth rate for the number of firms with at least one domestic application, the growth rate for number of firms with PCT applications and – more restrictively – with PCT applications that receive at least one citation from an ISR is larger, with 31% and 35% respectively. This analysis shows that during our observation period Chinese firms were still catching up with respect to ownership of international patents.

5 Analysis of patent quality

5.1 PCT applications of Chinese origin

Firstly, we discuss our most restrictive index, which considers non-self citations from outside own-country (ISR index 1). Of all Chinese PCT applications, only 6.0% are cited within a 3-year window. The average Chinese PCT application receives 0.08 citations over this time period (see Table A1 in the Appendix for detailed information). In combination with the citation rate of 0.25 for non-Chinese PCT applications, we arrive at a mean value of 0.34 for the quality index (Table 2). Even if we apply the 11% correction factor for potential language bias to the quality index, the corrected index of 0.37 suggests a quality level well below the

international benchmark (parity with the benchmark would imply an index value of one). Furthermore, our results show a strong decline in quality from 0.48 to 0.34. This decline is caused by a significant decrease in citations received by Chinese PCT applications – from 0.13 to 0.06 – and not by an increase in the international benchmark, which remains very stable over time.[8] Our results are highly relevant for a better understanding of the technological progress of China. The country experienced an impressive increase in the number of PCT applications, but restricting attention to a simple count measure is not enough. When comparing the technological progress of countries, the quality of applications must be considered as well. If Chinese PCT applications were weighted with their quality, a smaller growth rate of technological progress would obtain.

Secondly, we focus on the quality index that excludes self-citations but considers citations from the own-country (ISR index 2). Given this indicator, 15.5% of Chinese PCT applications are cited. Average citations of a Chinese PCT application increase to 0.22 and non-Chinese PCT applications receive 0.37 citations. Consequently, the mean quality index is calculated as 0.63. This sizable increase with respect to the former measurement may be attributed to the rapid expansion of Chinese PCT applications and the related increase in citations received from the own country.

Finally, we focus on the most inclusive index, which considers citations from the applicant's own country and self-citations (ISR index 3). In this specification, an even higher share of Chinese PCT applications – 28.8% – is cited. The average Chinese PCT application receives 0.44 citations. In combination with 0.50 citations for a non-Chinese PCT application, we arrive at a mean value of 0.91 for the quality index – close to average international quality.

[8] 95% of non-Chinese PCT applications originate from only 18 countries. If one would use these countries separately as a benchmark, the benchmark would increase in six cases, be constant in 11 cases, and decrease in one case. Because the citation count of the benchmark is weighted to mirror the technological composition of the target country, it is not identical to the quality of the average application of the country. The analysis of the quality development of patents from other countries is left for future research.

Turning attention to the development over time, in 2008 the index exceeds the quality level of the international benchmark for the first time. This finding suggests that in recent years Chinese applicants have increased self-citations more than non-Chinese applicants.

In effect, our least restrictive index combines two developments: one is the expansion of the Chinese patent system, and the other is a potentially increasing technological specialization of the Chinese economy and of Chinese firms. As a quality measure for international comparisons, we prefer the most restrictive ISR index 1 because it is only based on foreign citations. As such it is not influenced by the expansion of the Chinese patent system. In a rapidly expanding system it is possible that the economic value of a single citation is declining. In general, it would be possible to include second-order citations in our index. Second-order citations attribute higher value to a citation if the citing application itself is more highly cited. Citations from within China could be weighted by how many foreign citations the citing application has received. However, second-order citations have the disadvantage of requiring two adjacent citations windows, which restricts analysis to older applications. An alternative procedure for quality analysis is to collect outside information about the economic value of a citation, which would provide an anchor to the real economy. However, such outside information can only be obtained through expensive surveys. It is an advantage of the ISR indices that they are only derived from publicly available patent information and are therefore readily available for large-scale analysis.

It is evident that the three quality indices show different pictures of the evolution of quality. Which indicator is the right one? A priori, there are no good or bad citations and there is not a single best way of counting citations. Our quality indices provide a full picture of patent quality when taken together. The divergent results call for caution when interpreting citation-based indices. One must be very careful about which sets of citations to include and

which ones to exclude. Furthermore, the indices should not be interpreted in isolation but in conjunction with knowledge about the respective economy.

5.2 PCT applications of Chinese listed firms

In this section, we narrow our analysis to PCT applications filed by Chinese listed firms (Table 3). We observe 5,184 patent filings between 2001 and 2009. As firms are more responsive to patent subsidies than individuals, universities, or public research institutes, the jump between 2008 and 2009 is especially pronounced. In comparison to Table 2, average index values are higher, indicating that PCT applications of listed firms are of higher quality than the Chinese average.[9] In the most inclusive specification (ISR index 3), the index reaches increasingly high values in recent years – summing to an average of 1.44. If we add the multiplicative correction factor of 11% for potential language bias the index reaches 160% of the global average.

Because 59% of PCT applications by listed firms originate from ZTE, we recalculate the Table 2 without ZTE. Interestingly, the averages of the most restrictive index, considering non-self citations from outside own country, increases to 0.54 while the index that includes self-citations increases to 0.91. Thus, both indices suggest that PCT applications filed by ZTE are of lower average quality. However, the least restrictive index decreases to 1.1 when ZTE is excluded – suggesting that, on average, PCT applications by ZTE self-cite more frequently than the average PCT application of listed firms. This is not necessarily detrimental to quality; prior work has found self-cites to be closely related with firm value (Hall et al. 2005). It seems that from 2004 onward ZTE consistently filed PCT applications, and it again intensified PCT filings in 2009 in response to PCT subsidies.

[9] Again, Table A2 in the Appendix provides detailed information on average citation rates for Chinese patents and for the international benchmark.

5.3 Large applicants and technology leaders

Based on our observation that certain firms are influential in determining the quality index – and thereby relevant to the transition towards a knowledge-based economy – we investigate firms leading in size or technology in Table 4.[10] Each applicant is assigned to the main technology area in which it has the highest share of PCT applications. Reflective of its size, ZTE dominates electrical engineering with an exceptionally large PCT stock of 3,084 applications. Tsinghua Tongfang is the largest firm in instruments, Sinopec in chemistry, Sany in process engineering, Gree in mechanical engineering, and Haier in consumer goods and construction. Even though Tsinghua Tongfang is the largest applicant in its main technology, the firm still exhibits a quality index of approximately 100% while the remaining firms rank lower.

Regarding China's technology leaders, we consider those firms with a minimum PCT stock greater than five applications. Irtouch leads in electrical engineering, Tsinghua Tongfang in instruments, OTIC in chemistry, Sany in process engineering, Longyuan Technology in mechanical engineering, and Hisense in consumer goods and construction. In contrast to the largest applicants, technology leaders own smaller but more valuable patent stocks – 5 out of 6 firms exhibit a quality index above 100%. Also, differentiation of filing strategies according to firm size becomes apparent. Whereas OTIC is a relatively small, specialized supplier of the electronics industry and has small domestic and PCT stocks, Hisense – as established firm in consumer goods – has a large domestic stock but files PCT applications selectively.

[10] In the years after 2009, more firms increased the number of PCT filings. Because we need a 3-year time-period for the quality measure, we cannot take these developments into account.

5.4 Influence of firm characteristics on patent quality

In this section we investigate the influence of firm characteristics on patent quality (Table 5). In our panel of firm-year observations, we measure quality as the firms' mean ISR index in a respective priority year. The main regressors at the firm level correspond to the variables presented in Table 1. In addition, we control for annual macro-economic shocks, provincial GDP per capita to capture regional differences in China's economic development, and industry-specific effects. A Tobit model with standard errors clustered at the firm level is estimated and the average marginal effects are reported to the right side of coefficients.

In Model (1) our dependent variable is our most restrictive ISR index, which considers non-self citations from outside own country. The variable has a mean of 0.45 which differs from the total mean of 0.36 in Table 3 because the change in the level of observations from patent to firm-year level implies a different weighting. Patents of firms with a high number of annual filings obtain a smaller weight. We confirm a positive effect ($p<0.01$) for the R&D stock and a positive effect ($p<0.01$) for the PCT stock but a negative effect ($p<0.05$) for the domestic patent stock. Precisely, a 1% increase in the stock of R&D expenditures corresponds to an increase in the quality index by 0.04 points. Adding one unit to the PCT stock (scaled by thousand employees) increases the index by 0.05 points, whereas adding one unit to the domestic patent stock (scaled by thousand employees) decreases the index by 0.001 points.

Thus, our results suggests a positive and economically important relation between R&D input as well as PCT intensity and patent quality, whereas the negative marginal effect of domestic patenting intensity is rather small. Nonetheless, opposite signs of the PCT stock and the domestic patent stock point to key differences in firms' patenting strategies. While firms with higher PCT intensities file PCT patents of higher quality, firms with higher

domestic patent intensities may consider patenting rather as a source of subsidy income with detrimental consequences for the quality of PCT applications.[11]

Except for the year dummy 2009, the coefficients of the remaining firm level regressors and control variables are not significant. The negative effect ($p<0.1$) for 2009 coincides with the introduction of PCT subsidies by the central government and corresponds to a relatively large 1.0-point reduction in the index. In line with the sizable expansion in PCT applications between 2008 and 2009, it seems plausible that the increase in quantity causes a decrease in quality.

In Model (2) we change the dependent variable to allow for citations from the applicant's home country. The relationship between the R&D stock and PCT quality turns insignificant – suggesting that a sizable R&D input is necessary to produce inventions that are built upon by foreign firms but it is not necessary to achieve follow-on inventions by Chinese firms. The PCT stock remains positive but declines in significance ($p<0.05$): an increase by one unit only results in an increase by 0.02 points. Further, the domestic patent stock turns insignificant. In combination with the significant negative sign of the domestic patent stock in Model (1), this result suggests that own-country ISR citations are a less strict quality measure compared to ISR citation from abroad. All remaining regressors are insignificant.

Finally, in Model (3) we allow the quality index to consider all citations, including self-citations of the firm. Again, the PCT stock remains positive but declines further in significance ($p<0.1$): an increase by one unit only results in an increase of the quality index by 0.02 points. It is not surprising that larger firms have a significantly higher index. Firms of larger size have a higher probability of citing own PCT patents because they typically have a larger existing patent stock. Interestingly, the year dummy for 2009 turns positive as subsidies

[11] In 2014, listed firms received more than 15 billion USD in subsidies, with patent-related payments reported as the most frequent source of subsidy income (21st Century Business Herald, April 30, 2015).

for PCT patents motivate firms to file more PCT patents that often cite PCT patents within the firm's patent stock.

We conduct two robustness tests. Firstly, due to a high correlation of 0.7 between both patent stocks, we re-estimate all models excluding the domestic patent stock. In the modified specifications, pairwise correlation between all regressors is around 0.4 or lower and the regression results remain very similar. Secondly, we exclude ZTE as it is by far the largest applicant. Again, we obtain robust results but in Model (3) the year dummy for 2009 turns insignificant. This change suggests that the positive and significant effect was driven by ZTE's response to PCT subsidies introduced in 2009 – ZTE filed more patents that generated more self-citations.[12] Overall, the estimations presented in Table 5 shed light on the question of how firm characteristics and the changing economic environment of firms influence patent quality.

6 Conclusions

Our novel index compares the quality of PCT applications by considering the number of ISR citations received by a set of applications from one country to the number of ISR citations received by applications of the same priority year and technology class from other countries. In its most restrictive variation, e.g. excluding citations form the home country and self-citations, the ISR index is not biased by selectivity in filing strategies, differences in citations due to varying national examination procedures, and domestic economic policy. Thereby, our index substantially improves upon earlier measures of patent quality.

Observing strong increases in Chinese patenting between 2001 and 2009, we compare the quality of Chinese PCT applications with those from high-income countries. The quality

[12] Note that subsidies for PCT grants are only applicable for small and medium sized firms since 2012 (Ministry of Finance 2012) , which can be interpreted as an effort to balance the dominance of large applicants in Chinese PCT applications.

level of Chinese PCT applications achieves only 34% of the quality level of international PCT applications and decrease over time. Our results confirm that China's rise in international patenting was achieved to the detriment of quality. Against this background, we find that the patent quality of firms, as measured by the strictest ISR index, increases with R&D stocks but decreases with the introduction of PCT subsidies.

Whereas our index has a wide applicability, its main advantage lies in quality comparisons among countries or firms with respect to an international benchmark, which can be adjusted according to the question of interest. For example, the index allows for quality comparisons between the USA and China or between leading MNCs, such as Apple and Samsung. In addition, specific technology fields can be analyzed. For example, countries or firms can be compared with respect to patent quality in green technology. Further, the index is particularly useful for ex-post policy evaluation if it cannot be ruled out that the policy influences the behavior of the national patent office, a situation which applies to China. Our index improves upon quality measures of patent applications that are currently in use, e.g. counting of triadic patent families and standard citation measures.

References

Alcácer, J., Gittelman, M. (2006) Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations. *Review of Economics and Statistics* 88: 774-779.

Boeing, P., Mueller, E., Sandner, P. (2015) China's R&D Explosion – Analyzing Productivity Effects Across Ownership Types and Over Time, ZEW Discussion Paper No. 15-006.

Branstetter, L., Li, G., Veloso, F. (2013) The Globalization of R&D: China, India, and the Rise of International Co-invention. mimeo.

de Rassenfosse, G. (2013) Do Firms Face a Trade-off Between Quantity and the Quality of Their Inventions?. *Research Policy* 42: 1072-1079.

Economist (2010) Innovation in China – Patents, yes; ideas, maybe. Oct 14th 2010, print edition.

Fernald, J., Rogers, J. H. (2002) Puzzles in the Chinese Stock Market. *Review of Economics and Statistics* 84: 416-432.

Fisman, R., Wang, Y. (2010) Trading Favors within Chinese Business Groups. *American Economic Review* 100: 429-433.

Gambardella, A., Harhoff, D., Verspagen, B. (2008) The Value of European Patents. *European Management Review* 5: 69-84.

Grupp, H., Schmoch, U. (1999) Patent Statistics in the Age of Globalisation: New Legal Procedures, New Analytical Methods, New Economic Interpretation. *Research Policy* 28: 377-396.

Gupeng, Z., Xiangdong, C. (2012) The Value of Invention Patents in China: Country Origin and Technology Field Differences. *China Economic Review* 23: 357-370.

Hall, B., Jaffe, A., Trajtenberg, M. (2005) Market Value and Patent Citations. *RAND Journal of Economics* 36: 16-38.

Harhoff, D., Scherer, F. M., Vopel, K. (2003) Citations, Family Size, Opposition and the Value of Patent Rights. *Research Policy* 32: 1343-1363.

Harhoff, D., Narin, F., Scherer, F. M., Vopel, K. (1999) Citation Frequency and the Value of Patented Inventions. *Review of Economics and Statistics* 81: 511-515.

Herrmann-Pillath, C., Growth, Power, and Order. An Economic-philosophical Analysis of China (Marburg: Metropolis, 2014), (in German).

Huang, C. (2012) Estimates of the Value of Patent Rights in China. UNU-MERIT Working Paper Series, 2012-004.

Jaffe, A.B., Trajtenberg, M., Henderson, R. (1993) Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *Quarterly Journal of Economics* 63: 577-598.

Kaemmer, C. (2010) Searching Chinese Patent Information on Free Online Sources. *Business Information Review* 27: 39-42.

Kato, T., Long, C. (2006) Executive Turnover and Firm Performance in China. *American Economic Review* 96: 363-367.

Kovac, W. (2010) Documentation and Quality – Quo Vadis Patent System? A Patent Attorney's View. *World Patent Information* 32: 229-232.

Kwon, S., Lee, J., Lee, S. (2014) International Trends in Technological Progress: Stylized Facts from Patent Citations, 1980-2011. cemmap working paper CWP 16/14.

Lei, Z., Sun, Z., Wright, B. (2012) Patent Subsidy and Patent Filing in China, University of California, Berkeley, mimeo.

Li, X. (2012) Behind the Recent Surge of Chinese Patenting: An Institutional View. *Research Policy* 41: 236–249.

Michel, J., Bettels, B. (2001) Patent Citation Analysis – A Closer Look at the Basic Input Data from Patent Search Reports. *Scientometrics* 51: 185-201.

Ministry of Finance (2009), "Interim Measures for the Administration of Special Funds for Subsidizing Foreign Patent Applications," (in Chinese).

Ministry of Finance, "Measures for the Administration of Special Funds for Subsidizing Foreign Patent Applications," (2012), (in Chinese).

OECD (2015), Main Science and Technology Indicators, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB.

Schankerman, M., Pakes, M. (1986) Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period. *Economic Journal* 96: 1052-1076

Peri, G. (2005) Determinants of Knowledge Flows and Their Effect on Innovation. *Review of Economics and Statistics* 87: 308-322.

Pistor, K., Xu, C. (2005) Governing Stock Markets in Transition Economies: Lessons from China. *American Law and Economics Review* 7: 184-210.

Thoma, G. (2013) Quality and Value of Chinese Patenting: An International Perspective. *Seoul Journal of Economics* 26: 33-72.

Trajtenberg, M. (1990) A Penny for Your Quotes. Patent Citations and the Value of Innovation. *Rand Journal of Economics* 21: 172–187.

SIPO (2014), “Interpretation of Opinions of the State Intellectual Property Office to Further Enhance the Quality of Patent Applications,” (in Chinese).

SIPO (2013), “Opinions of the State Intellectual Property Office to Further Enhance the Quality of Patent Applications,” (in Chinese).

WIPO (2014a) Patent Cooperation Treaty Yearly Review – The International Patent System. Economics & Statistics Series. World Intellectual Property Organization, Geneva.

WIPO (2014b) PCT International Search and Preliminary Examination Guidelines. World Intellectual Property Organization, PCT/GL/ISPE/3, July 11, 2014, Geneva.

WIPO (2014c) Regulations under the Patent Cooperation Treaty (as in force from July 1, 2014). World Intellectual Property Organization, Geneva.

Zhang, G., Lv, X., Zhou, J. (2014) Private Value of Patent Right and Patent Infringement: An Empirical Study based on Patent Renewal Data of China. *China Economic Review* 28: 37-54.

Tables and Figures

Table 1: Firm characteristics

Variable	Mean	Median	Std. Dev.	Min	Max	Obs.
R&D stock (million RMB)	487.89	30.45	2,184	0	25,001	451
PCT stock/'000 employees	3.443	0.825	8.443	0.005	100	451
Domestic stock/'000 employees	55.26	8.589	217.0	0	2,920	451
Employees	20,237	3,126	68,680	10	539,168	451
Firm age	11.49	11	5.057	1	29	451
Private ownership	0.417	0	0.494	0	1	451

Note: Statistics based on firms with at least one PCT application.

Table 2: PCT applications of Chinese origin

	ISR index 1	ISR index 2	ISR index 3	Obs.
Considered citations				
Applicant country	*excluded*	*included*	*included*	
Self-cites	*excluded*	*excluded*	*included*	
2001	0.478	0.390	0.375	793
2002	0.373	0.338	0.313	1,060
2003	0.403	0.362	0.327	1,368
2004	0.349	0.281	0.323	1,948
2005	0.429	0.403	0.459	3,321
2006	0.315	0.430	0.523	4,649
2007	0.290	0.558	0.732	5,799
2008	0.299	0.768	1.138	6,159
2009	0.335	0.904	1.536	9,641
Total	0.335	0.626	0.913	34,738

Note: Analysis at patent level. Mean values of variables displayed.

Table 3: PCT applications of Chinese listed firms

	ISR index 1	ISR index 2	ISR index 3	Obs.
Considered citations				
Applicant country	*excluded*	*included*	*included*	
Self-cites	*excluded*	*excluded*	*included*	
2001	0.608	0.859	0.949	53
2002	0.576	0.574	0.692	102
2003	0.429	0.538	0.492	159
2004	0.844	0.811	0.704	195
2005	0.580	0.731	0.588	347
2006	0.586	0.650	0.702	429
2007	0.507	0.834	1.164	710
2008	0.252	0.705	1.668	871
2009	0.220	0.727	1.877	2,318
Total	0.360	0.727	1.441	5,184

Note: Analysis at patent level. Mean values of variables displayed.

Table 4: Comparison of largest firms and technology leaders

	Largest applicant				Technology leader			
Main technology area	Firm	PCT stock	CN stock	ISR index	Firm	PCT stock	CN stock	ISR index
Electrical engineering	ZTE	3,084	13,942	0.237	Irtouch	13	32	1.912
Instruments	Tsinghua Tongfang	64	781	1.073	Tsinghua Tongfang	64	781	1.073
Chemistry	Sinopec	117	3,770	0.471	OTIC	7	6	3.32
Process engineering	Sany	75	542	0.849	Sany	75	542	0.849
Mechanical engineering	Gree	69	1,013	0	Longyuan Power	8	42	1.713
Consumer goods and construction	Haier	35	2,497	0.700	Hisense	7	1,682	2.014

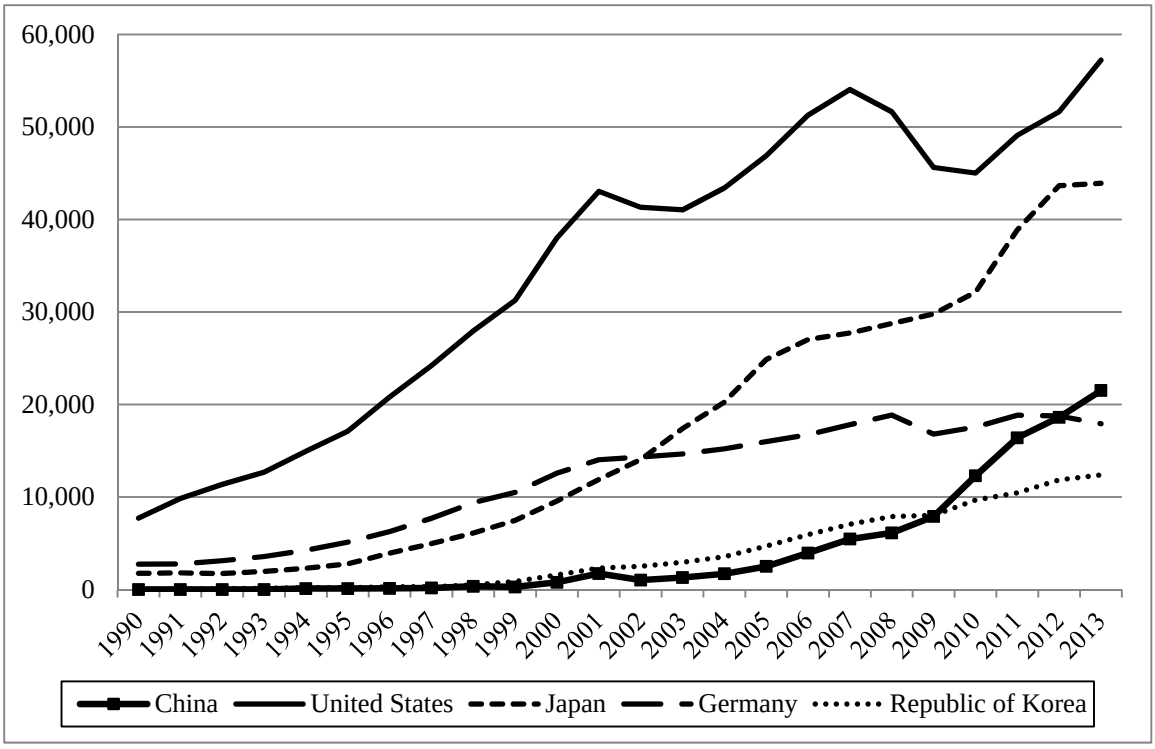
Note: Mean values of ISR index 1 shown. Analysis at patent level. To ensure a minimum size of the PCT stock, technology leaders are required to have a PCT stock > 5. Full names of firms are as follows: ZTE Zhongxing Telecommunication Equipment Corporation, Tsinghua Tongfang Company, SINOPEC China Petroleum & Chemical Corporation, Sany Heavy Industry Corporation, Gree Electric Appliances Incorporated, Haier Group,, Irtouch Systems, OTIC Ningxia Orient Tantalum Industry Corporation, Longyuan Power Group Corporation, and Hisense Corporation.

Table 5: Tobit estimations on ISR index

	(1)		(2)		(3)	
	ISR index 1		ISR index 2		ISR index 3	
Considered citations						
Applicant country	*excluded*		*included*		*included*	
Self-cites	*excluded*		*excluded*		*included*	
ln(R&D stock)	0.180***	[0.037]	0.039	[0.011]	-0.004	[-0.001]
	(0.064)		(0.035)		(0.026)	
PCT patent stock /'000 employees	0.239***	[0.049]	0.085**	[0.024]	0.055*	[0.019]
	(0.050)		(0.043)		(0.028)	
Domestic patent stock/'000 employees	-0.006**	[-0.001]	-0.001	[-0.0003]	-0.001	[-0.0003]
	(0.003)		(0.002)		(0.001)	
ln(employees)	0.252	[0.051]	0.206	[0.058]	0.221**	[0.077]
	(0.237)		(0.151)		(0.098)	
ln(age)	-0.827	[-0.169]	-0.144	[-0.040]	-0.022	[-0.008]
	(0.688)		(0.450)		(0.300)	
Private ownership	0.825	[0.169]	-0.113	[-0.032]	-0.052	[-0.018]
	(0.687)		(0.459)		(0.304)	
2002	-1.587	[-0.426]	-1.211	[-0.359]	-0.809	[-0.238]
	(2.355)		(1.629)		(1.079)	
2003	-2.611	[-0.656]	-2.128	[-0.585]	-1.376	[-0.379]
	(2.439)		(1.536)		(1.032)	
2004	-0.559	[-0.16]	-1.410	[-0.411]	-0.354	[-0.110]
	(2.258)		(1.560)		(0.977)	
2005	-2.147	[-0.556]	-2.163	[-0.593]	-1.261	[-0.352]
	(2.159)		(1.444)		(0.959)	
2006	-2.273	[-0.584]	-1.367	[-0.400]	-0.346	[-0.108]
	(2.294)		(1.509)		(0.992)	
2007	-3.300	[-0.795]	-1.658	[-0.474]	-0.518	[-0.158]
	(2.501)		(1.572)		(1.043)	
2008	-3.340	[-0.803]	0.168	[0.056]	0.827	[0.298]
	(2.445)		(1.508)		(0.995)	
2009	-4.198*	[-0.958]	-0.392	[-0.124]	1.706*	[0.687]
	(2.321)		(1.508)		(0.994)	
ln(provincial GDP/capita)	-0.733	[-0.150]	-0.265	[-0.074]	-0.458	[-0.159]
	(0.654)		(0.458)		(0.349)	
Industry controls	Yes		Yes		Yes	
Observations (firms)	451 (228)		451 (228)		451 (228)	
Log pseudo likelihood	-348.87		-550.58		-615.78	

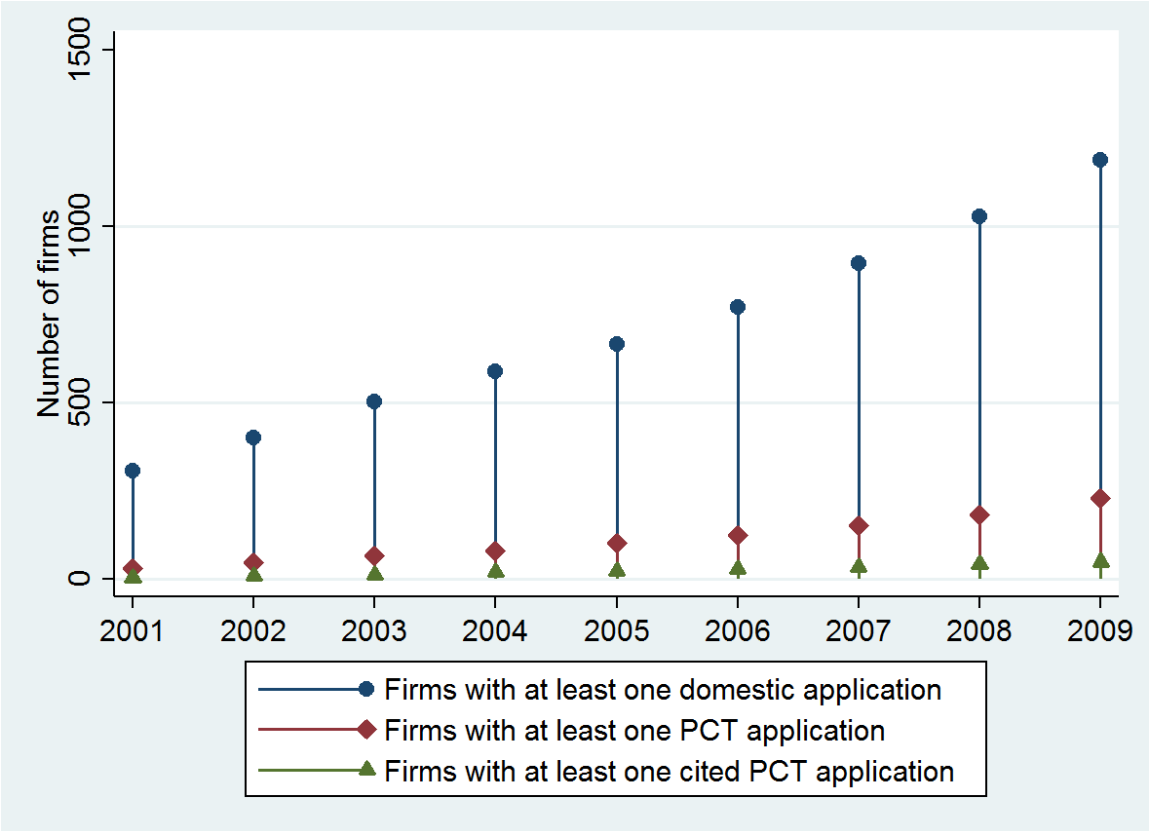
Note: Analysis at firm level. The dependent variable is the average ISR index of the annual patent applications. Tobit analysis with standard errors clustered at the firm level. Average marginal effects are reported in square brackets. Reference category for year is 2001, for industry it is remaining, and for region it is Coast. *** sig. level < 1%, ** sig. level < 5%, * sig. level < 10%.

Figure 1: PCT applications by country of origin



Sources: WIPO 2014a

Figure 2: Expansion of patent ownership in Chinese firms



Appendix

Table A1: PCT applications of Chinese origin

	Chinese patents 1	Chinese patents 2	Chinese patents 3	Bench-mark 1	Bench-mark 2	Bench-mark 3	Obs.
Considered citations							
Applicant country	*excluded*	*included*	*included*	*excluded*	*included*	*included*	
Self-cites	*excluded*	*excluded*	*included*	*excluded*	*excluded*	*included*	
2001	0.131	0.165	0.217	0.269	0.414	0.576	793
2002	0.079	0.108	0.144	0.243	0.362	0.517	1,060
2003	0.085	0.112	0.147	0.236	0.342	0.493	1,368
2004	0.074	0.088	0.143	0.219	0.313	0.443	1,948
2005	0.091	0.125	0.199	0.225	0.318	0.437	3,321
2006	0.073	0.154	0.262	0.253	0.36	0.491	4,649
2007	0.075	0.235	0.407	0.285	0.41	0.541	5,799
2008	0.077	0.311	0.627	0.292	0.423	0.573	6,159
2009	0.076	0.324	0.781	0.281	0.416	0.569	9,641
Total	0.079	0.233	0.473	0.268	0.389	0.531	34,738

Note: Analysis at patent level. Mean values of variables displayed.

Table A2: PCT applications of Chinese listed firms

	Chinese patents 1	Chinese patents 2	Chinese patents 3	Bench-mark 1	Bench-mark 2	Bench-mark 3	Obs.
Considered citations							
Applicant country	*excluded*	*included*	*included*	*excluded*	*included*	*included*	
Self-cites	*excluded*	*excluded*	*included*	*excluded*	*excluded*	*included*	
2001	0.132	0.283	0.453	0.273	0.419	0.604	53
2002	0.118	0.196	0.343	0.269	0.406	0.58	102
2003	0.094	0.195	0.264	0.257	0.37	0.524	159
2004	0.185	0.246	0.282	0.232	0.327	0.468	195
2005	0.107	0.196	0.23	0.225	0.317	0.44	347
2006	0.14	0.228	0.352	0.251	0.355	0.488	429
2007	0.131	0.339	0.614	0.281	0.395	0.519	710
2008	0.065	0.288	0.91	0.287	0.406	0.537	871
2009	0.050	0.226	0.866	0.258	0.371	0.487	2,318
Total	0.097	0.253	0.620	0.262	0.374	0.503	5,184

Note: Analysis at patent level. Mean values of variables displayed.