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Development of indices and application to Chinese firm-level data

Philipp Boeing and Elisabeth Mueller

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Philipp Boeing[a,c] and Elisabeth Mueller[b,d]

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1. Introduction

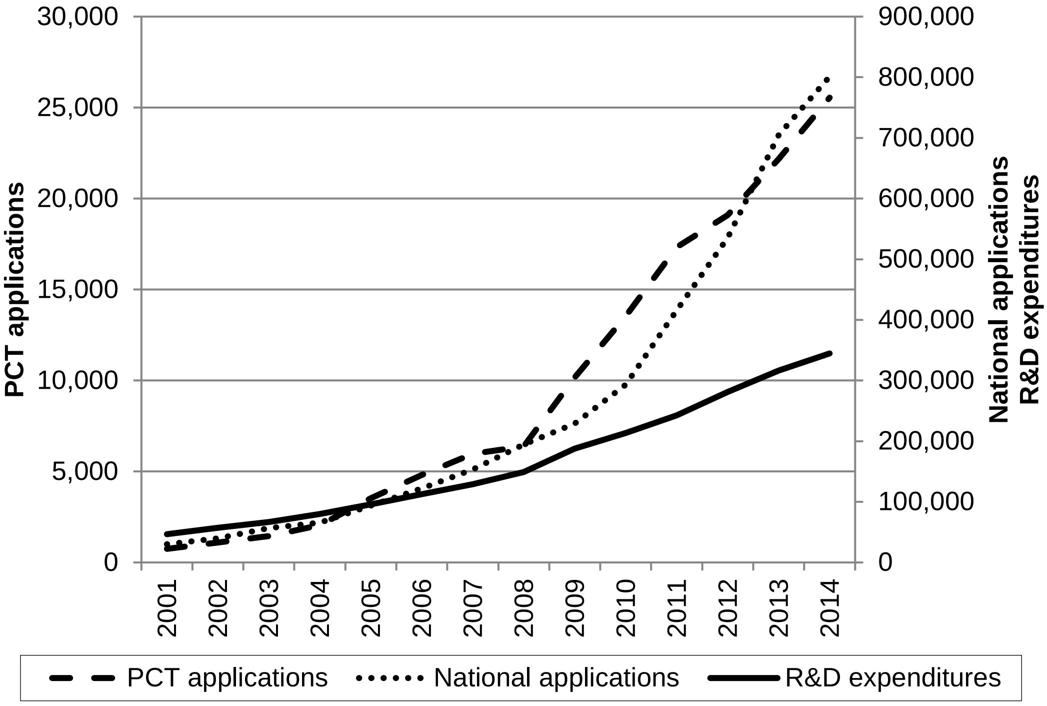
The Chinese government aims to transform China into an innovative country by 2020 and a world leader in science and technology by 2050 (State Council 2006). According to China's economic development plans, patents represent a leading indicator of the country's emerging technological prowess (State Council 2014).[1] Supported by governmental policy, China not only overtook the USA as the world leader in patent applications in 2011 (OECD 2014) but ranks third since 2013 in applications made under the Patent Cooperation Treaty (PCT), which typically precede the international commercialization of valuable inventions (WIPO 2015a, Grupp and Schmoch 1999). Having achieved the initial target for PCT applications (22 thousand in 2013), achievement of the following targets (33 thousand in 2015 and 75 thousand in 2020) would imply world leadership in PCT applications.

Whereas prior successes are documented by patent statistics, it remains uncertain whether patent counts as such provides a reliable measure for China's emerging innovation. This concern is nurtured by the seminal critiques of Goodhart (1975) and Lucas (1976), who postulate that indicators may fail as reliable measures if they become the target of policy. In recent years China's patent applications have risen faster than R&D expenditures (Figure 1), resulting in decreasing R&D inputs per patent (Figure 2). This observation not only corresponds to a comparatively low elasticity between patents and R&D investments for Chinese firms (Hu et al. 2017), but also to a decreasing correlation between patent applications and total factor productivity (Boeing et al. 2016).

We aim to empirically assess the quality of Chinese patents. Forward citations provide the best approximation of patent quality (Gambardella et al. 2008, Reitzig 2004), given that

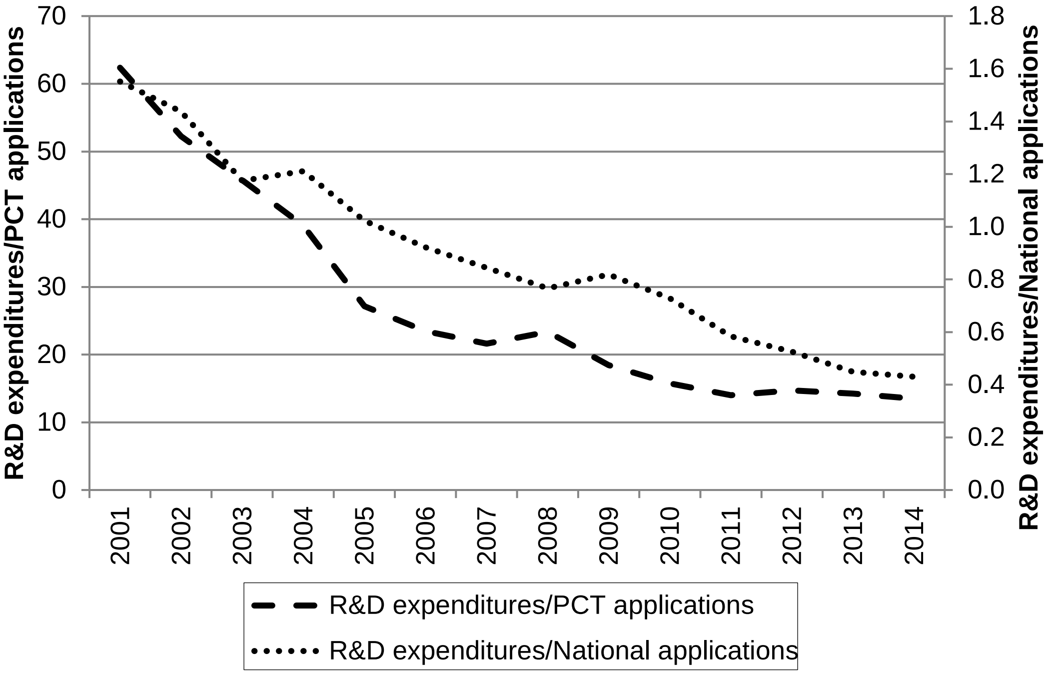
[1] Important aspects of China's innovation policy are specified in the "Medium- to Long-term Plan for Science and Technology Development (2006-2020)" and the "National Patent Development Strategy (2011-2020)".

Figure 1: China's PCT applications, national applications, and R&D expenditures



Note: R&D expenditures is Gross domestic Expenditure on Research and Development (GERD) as defined by OECD (2015), measured in million USD in constant prices of 2010. National applications are national patent applications filed by residents. *Source*: OECD (2016), WIPO (2015a), World Bank (2016).

Figure 2: China's R&D expenditures per PCT application and per national application



Note: R&D expenditures is Gross domestic Expenditure on Research and Development (GERD) as defined by OECD (2015), measured in million USD in constant prices of 2010. National applications are national patent applications filed by residents. *Source*: OECD (2016), WIPO (2015a), World Bank (2016).

differences affecting citation propensity, e.g. technology, are controlled for (Jaffe and Rassenfosse 2016, Harhoff et al. 1999, Trajtenberg 1990). However, as China's policy, especially patent subsidies (Dang and Motohashi 2015, Li 2012), provided incentives for nearly exponential patent growth in recent years, the annual increase in citing applications may lead to an inflation of received citations (Marco 2007). More generally, potential endogeneity of quality measures with respect to policy-induced increases in application numbers complicates the assessment. Taking into account that patents have become increasingly decoupled from R&D inputs, we aim to validate Chinese forward citations – in comparison to foreign ones, which are invariant to China's policy – as an economic indicator.

Having formulated our research agenda, we acknowledge that a citation-based comparison of patent quality across countries is difficult. First, as firms select only their more valuable inventions for international protection, a direct comparison between domestic and foreign applications is invalid (Harhoff et al. 2003). Second, national patent offices follow different examination guidelines, which leads to variation in citation counts (Michel and Bettels 2001). Third, a preference of patent examiners to cite prior art from their home countries leads to discrimination against foreign prior art (Bacchiocchi and Montobbio 2010). Prior citation-based investigations of Chinese patent quality in international comparison are affected by these difficulties. For example, Kwon's et al. (2014) analysis of patents granted to Chinese and US firms at the United States Patent and Trademark Office (USPTO) avoids differences in national examination by focusing on citations from the USPTO but suffers from self-selection of more valuable inventions for protection abroad by Chinese firms and a potential home country bias of US examiners.

To address these difficulties, we build on a novel quality measure developed by Boeing and Mueller (2016), which is based on citations from international search reports (ISRs). ISR citations are generated during the international phase of PCT applications and allow for cross-country comparison because they originate from a homogenous institutional setting determined by the World Intellectual Property Organization (WIPO). In this study, we extend the original ISR index by considering not only foreign citations ($index_F$) but also domestic ($index_{FD}$) and self citations ($index_{FDS}$).

A general limitation of patent data is that only a fraction of inventions is patented (Griliches 1990). Similarly, only a fraction of patent applications is filed via the PCT system. For a profit maximizing applicant a PCT filing is rational as long as the discounted return exceeds the cost of patenting. Consequently, we take the resulting selection of PCT applications as given and emphasize that this sample is not representative for all inventions or all patents. Nonetheless, the PCT system is widely used in general and typically receives the most valuable inventions (Grupp and Schmoch 1999). As China has experienced double-digit growth in annual PCT applications since 2002 (WIPO 2017) and is projected to overtake the USA as the leading applicant country before 2020, the number of applications is sufficient to warrant dedicated analysis.

Covering the start of China's patent expansion, we apply the ISR indices to the population of Chinese PCT applications filed between 2001 and 2009. According to $index_F$, China's average patent quality reaches only 32.1% of the comparison group of non-Chinese applications and declines from 44.9% to 30.4% between 2001 and 2009. In contrast, $index_{FD}$ (61.6%) and $index_{FDS}$ (90.0%) indicate a Chinese quality level closer to that of the global comparison group. In recent years, $index_{FD}$ converges towards the comparison group while $index_{FDS}$ surpasses it. Interestingly, the increasing discrepancy among indices reveals that in global comparison Chinese applicants disproportionally cite domestic and own inventions. However, if these discrepancies are not only the result of greater technological self-reliance but are also caused by a policy-driven inflation of domestic citations, economic indicators based on Chinese citations will lead to an overestimation of China's patent quality.

To validate citations as an economic indicator, we estimate their relation with R&D stocks for all domestic firms listed in mainland China. Our regression results confirm a robust relation between firms' R&D stocks and patent quality approximated by foreign citations. However, failure to confirm this relation for Chinese domestic and self citations negates the validity of Chinese citations as quality indicators. These findings also suggest an incidence of government failure as China's policy has incentivized a rapid patent expansion but this expansion is increasingly decoupled from economic inputs, such as R&D. Analyzing the different setting of German firms, we show that all three citations types may be used as an economic indicator if policy distortion is not a concern. In conclusion, Chinese patent data should be employed with caution if it is interpreted as an economic indicator.

The contributions of this paper are twofold. First, we extend the ISR index by Boeing and Mueller (2016) to domestic and self citations and provide the first application of the ISR indices to firm-level data. Employing all three indices in combination provides a more nuanced assessment of innovation performance. Depending on the policy environment in which the analysis is situated, it has to be determined whether only $index_F$ provides an unbiased analysis, as $index_F$ is exogenous with respect to national policy, or whether policy distortion is not a concern and $index_{FD}$ and $index_{FDS}$ can be employed to develop a more detailed understanding. Second, we provide novel evidence on the quality of China's patents. Our results reveal that the number of Chinese patent applications and citations thereof are questionable indicators of innovation levels and quality, respectively, and empirically confirm that economic indicators fail as reliable measures if they become the target of policy.

The remainder of the paper is organized as follows. In section 2 we explain relevant details of the PCT system. In section 3 we extend the ISR indices. In section 4 we describe our data. In section 5 we show the results for patent quality and the external validation of our indices. In section 6 we discuss policy implications and the wider applicability of the indices. Finally, section 7 concludes.

2. The PCT system

Basing the quality indices on information from the PCT system enables us to address the aforementioned difficulties of cross-country comparisons of patent quality: self-selection of more valuable inventions for protection abroad, heterogeneity in examination standards at national patent offices, and citation-bias of patent examiners against foreign prior art. In this section, we outline the relevant details of the patenting process via the PCT system and discuss how these specificities help us to overcome the difficulties addressed above.

The PCT system offers applicants international protection of inventions in up to 148 countries (WIPO 2015a). It is increasingly used by applicants worldwide, amounting to a total of about 214,500 PCT filings in 2014 (WIPO 2015a). As applicants choose only more valuable inventions for protection in numerous foreign countries, the resulting PCT applications are more homogeneous than a mixture of national and international applications.

Applications are filed with a competent Receiving Office (RO), which is determined according to the home country of the applicant. For example, Chinese applicants must file PCT applications with the Chinese Patent Office (SIPO) as the RO. SIPO is also the only competent office to act as an International Search Authority (ISA). The designated ISAs publish the ISR 18 months after the priority date. Globally, the search for prior art is highly concentrated – the top five ISAs were responsible for more than 95% of ISRs in 2014 (European Patent Office (EPO) 38.8%, Japanese Patent Office (JPO) 20.0%, Korean Patent Office (KPO) 14.9%, SIPO 13.5%, USPTO 10.6% (WIPO 2015a, p. 74f.)).[2]

[2] Note that applicants from the USA can file applications with numerous other offices than USPTO, e.g. EPO, JPO, and KPO. Thus, the number of searches for prior art at the respective ISAs is not directly indicative of the respective country's level of PCT applications.

ISRs contain the references to prior art. In the PCT system, applicants are encouraged to provide references to prior art. 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 2016b).[3] However, in the PCT system it is ultimately the examiner who determines which references are included in the ISR. Such selected references are an appropriate measure of patent quality as they constitute an evaluation by a third party – namely by the examiner – of the technical and legal relationships between patents. Further, examiner citations show a much stronger correlation with patent value than applicant citations (Hegde and Sampat 2009).

It is important to note that event though national patent offices act as ISAs, the examiners of the different offices follow the same strict examination rules from WIPO when drafting an ISR (WIPO 2016a). As we exclusively consider ISR citations we rule out heterogeneity in national examination procedures and assure the comparability of citations.[4] The search guidelines explain in detail how citations are to be selected by the examiners (WIPO 2016a, §15.67-15.72). Examiners are encouraged to cite only the most relevant documents and, in the case that several members of one patent family are available, to cite documents in the language of the application (WIPO 2016a, §15.69). Due to the strict search rules defined by WIPO, the citation-bias of patent examiners against foreign prior art is adequately addressed.

[3] The PCT rules strike a balance between the regulations of the US Patent and Trademark Office (USPTO) and the European Patent Office (EPO). Whereas the USPTO requires applicants to provide references to all relevant prior art that they are aware of, the EPO requires only that examiners, and not applicants, carry out this task (Michel and Bettels 2001).

[4] The international phase ends 30 months after the priority date and applications enter the national phase in which national patent offices perform additional search and examination before making the grant decision. Citations in the national phase may differ from ISR citations as the former 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 indices.

Against this regulatory background, Michel and Bettels (2001) report insights from actual examination practices and discuss the comparability of ISR citations for statistical analysis. They point out that the USPTO's mean number of citations generated per domestic application is three times larger than the corresponding mean at the EPO. However, when these offices function as ISAs the difference largely disappears and the authors recommend ISR citations generated within the PCT system for comparative purposes. While one cannot rule out idiosyncratic deviations from WIPO's regulations by individual examiners, there seems to be no indication for systematic deviation by individual ISAs. Having provided regulatory and empirical arguments why ISR citations generated via the PCT system are appropriate for cross-country comparison, in the next section we define how these citations are employed in ISR indices.

3. Index development

In this section we extend the ISR index as introduced by Boeing and Mueller (2016). A potential limitation of the original index is the exclusive reliance on foreign citations, i.e. citations where applicants of citing and cited patents are from different countries. Whereas this definition ensures invariance with respect to national policy – because only citations generated outside of national boundaries are considered – the analysis of domestic and self citations may contribute additional insights. In the following, we briefly discuss the characteristics by which foreign, domestic, and self citations differ and define the extended ISR indices.

Generally, foreign citations are understood as a measure of high quality because they indicate the international competitiveness of domestic inventions. Firms build on prior art from third countries given that the cited inventions are closer to the global technology frontier than inventions from their own country. In addition, a high share of foreign citations on domestic science shows that foreign firms seek to appropriate the results of domestic R&D (Tijssen 2001).

In contrast to international competitiveness approximated by foreign citations, domestic citations are rather a measure of an economy's technological self-reliance. Stronger reliance on prior art from the own country may be related to a higher level of development as there is less dependence on research conducted abroad. For example, Kang et al. (2014) study the Chinese and Korean telecommunication industry and find that, over time, firms increasingly cite prior art from their own country for standard-essential patents. As the diffusion of knowledge correlates negatively with geographical distance, it is useful to distinguish foreign and domestic citations because domestic citations are received earlier (Narin 1994, Jaffe et al. 1993, Jaffe and Trajtenberg 1999).

While foreign and domestic citations differentiate between the international and national provenance of follow-up inventions, self citations examine follow-up inventions within organizations. Empirical studies tend to find that self citations are more valuable to firms than non-self citations (e.g., Hall et al. 2005, Deng 2008). Firms with more self citations are able to appropriate returns from earlier investment in R&D and signal the presence of "cumulative innovations" (Lanjouw and Schankerman 2004). Self citations may also be an indicator of "fencing" – which is prevalent when firms build a wall around themselves (Belderbos and Somers 2015). Because foreign, domestic, and self citations characterize different origins of follow-up inventions, a more nuanced understanding of patent quality can be achieved by considering information from all three citation types.

In the reminder of this section we define the extended ISR indices based on foreign, domestic, and self citations. In empirical applications one has to define two sets of patents – the analysis group and the comparison group. In our study, we aim to measure the quality of Chinese PCT patents in comparison to non-Chinese PCT patents. Our comparison group is naturally determined by all foreign competitors operating in the same field of technology in a given year. Therefore, the index allows for relative positioning of one country against the rest of the world.

The indices are first calculated at the year-technology level to control for changes in citation practices and for technology-specific differences in citation patterns, which is best-practice in citation analysis (e.g., Jaffe and Rassenfosse 2016). Therefore one has to allocate patents into subgroups according to priority year and apply fractional counting if a patent is allocated to more than one technology class. In a second step the indices are aggregated to the desired analysis level.

We define three distinct indices for patent quality. ISR $index_F$ is the original index as established by Boeing and Mueller (2016). It only considers non-self citations received by foreign countries, i.e. from countries other than the applicant country (F citations), and is invariant with respect to national policy as it relies only on citations generated outside of national boundaries. The index is defined at the level of year *t* and technology *k*:

(1) $$ISR\ index_{F\ (t,k)} = \frac{avg.\ number\ of\ F\ citations\ received\ by\ analysis\ group\ (t,k)}{avg.\ number\ of F\ citations\ received\ by\ comparison\ group\ (t,k)}$$

In addition to non-self citations from foreign countries considered in $index_F$, the extended $index_{FD}$ also accounts for non-self citations of domestic origin (D citations):

(2) $ISR\ index_{FD\ (t,k)} =$

$$\frac{avg.number\ of\ F\ and\ D\ citations\ received\ by\ analysis\ group\ (t,k)}{avg.number\ of F\ and\ D\ citations\ received\ by\ comparison\ group\ (t,k)}$$

$Index_{FDS}$ is the most comprehensive index as it also takes self citations (S citations) into account:

(3) $ISR\ index_{FDS\ (t,k)} =$

$$\frac{avg.number\ of\ F, D, and\ S\ citations\ received\ by\ analysis\ group\ (t,k)}{avg.number\ of F, D, and\ S\ citations\ received\ by\ comparison\ group\ (t,k)}$$

In order to obtain the quality indices at the desired level of aggregation (e.g. country-, industry-, or firm-level), one has to multiply the year and technology specific indices with the number of applications per year and technology ($N_{t,k}$), sum over the products, and then divide by the number of patents in the aggregate (N). Index values of above (below) 100% correspond to average patent quality above (below) the quality level of the comparison group. The formula below shows the exemplary calculation for ISR $index_F$:

(4) $$ISR\ index_F = \frac{1}{N}\sum_{t=1}^{T}\sum_{k=1}^{K} N_{t,k} * ISR\ index_{F\ (t,k)}$$

4. Data

Beginning with China's patent expansion in 2001, we observe the population of PCT applications with priority years between 2001 and 2009 using the April 2013 version of the EPO Worldwide Patent Statistical Database (PATSTAT). During the priority year the applicant can file applications for the same invention at additional patent offices. Applications are allocated to countries according to the address of the first applicant. We only consider citations from distinct pairs of citing and cited patent families and identify self citations based on

DOCDB standard names from PATSTAT and the EEE-PPAT applicant name harmonization (Magerman et al. 2006). To categorize patents according to technology, we use the 3-digit technology class level of the IPC classification and apply fractional counting to apportion patents that belong to more than one technology class. Given the typical trade-off between precision and timeliness that work with patent citations implies, we restrict the citation window to a still informative three years to capture more recent dynamics in China's patent expansion.

In order to externally validate the ISR indices we calculate the indices for the PCT applications of Chinese firms and relate them to firm characteristics documented in financial statements. We observe the population of domestic Chinese firms listed at the two stock exchanges in Shanghai and Shenzhen between 2001 and 2009. Due to governmental stock issuance quotas, the listed firms are adequately representative of the Chinese economy's industrial composition, with large manufacturing firms strongly represented in more developed Coastal regions (Pistor and Xu 2005).[5] Data on Chinese listed firms has been widely used in high-quality publications, e.g. Fisman and Wang (2010), Kato and Long (2006), and Fernald and Rogers (2002).

Our firm-level panel data is drawn from the following sources. R&D expenditures are obtained from the Chinese database WIND and complementary information is hand-collected from the universe of annual reports accessible via the Chinese CNINFO database. The number of employees is obtained from Datastream and the date of firm establishment and industry affiliation from WIND. Information on state ownership is obtained from the Chinese database RESSET. Provincial GDP per capita is obtained from the Chinese National Bureau of Statistics. Patent data from PATSTAT is matched to firm data according to the matching protocol described in Boeing et al. (2016).

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[5] The China Securities Regulatory Commission only allows listings of "domestic" Chinese firms, i.e. the percentage of total shares held by foreign parties cannot exceed 20%. This implies that foreign subsidiaries operating in China are excluded from the firm-level analysis.

Table 1: Firm characteristics

Variable	Mean	Median	Std. dev.	Min	Max	Obs.
$Index_F$	43.3	0	135.201	0	1350.4	451
$Index_{FD}$	76.4	0	154.2	0	923.7	451
$Index_{FDS}$	87.5	0	139.4	0	890.4	451
R&D stock (million RMB)	487.892	30.449	2183.637	0	25001	451
PCT intensity	3.443	0.825	8.443	0.005	100	451
Employees	20237	3126	68680	10	539168	451
Firm age	11.486	11	5.057	1	29	451
Private ownership	0.417	0		0	1	451
Provincial GDP/capita (RMB)	30996	29447	15786	5905	66006	451

Note: Statistics based on firms with at least one PCT application. ISR indices are calculated as averages of annual patent applications and are expressed as percentages. Observations are at the firm-year level.

We briefly discuss the descriptive statistics of the firm characteristics for the 228 firms with PCT applications for which we have 451 observations (Table 1). We calculate the average ISR index values over all PCT applications filed by a given firm in a given year. $Index_F$ has an average value of 43.3%, $index_{FD}$ of 76.4%, and $index_{FDS}$ of 87.5%. Employing the perpetual investment method, we calculate deflated R&D stocks based on an assumed annual growth rate of R&D of 5% and a standard annual depreciation rate of 15% (Hall et al. 2010). The resulting median R&D stock has a value of 30.45 million RMB. The PCT intensity is calculated as the application stocks of the firm depreciated by an annual rate of 15% and scaled by '000 employees. This variable proxies the accumulated experience in international patent filings and informs us about the relevance of international markets for the firm. Firms with PCT applications are relatively large; the median number of employees is 3,126 and the firms themselves tend to be rather young, with a median age of 11 years. To reflect China's ongoing market reforms, we broadly differentiate between firms with and without any government ownership and find, that according to this differentiation, 41.7% of observations are from private firms. To allow for differences in China's economic development, we control for deflated GDP per capita at the provincial level. In Table 2 we provide pairwise correlations of the variables.

Table 2: Pairwise correlations of firm characteristics

	1.	2.	3.	4.	5.	6.	7.	8.
1. $Index_F$								
2. $Index_{FD}$	0.552							
3. $Index_{FDS}$	0.425	0.753						
4. R&D stock	-0.042	-0.046	-0.038					
5. PCT intensity	0.049	0.022	0.043	0.017				
6. Employees	-0.030	0.003	-0.019	0.651	-0.088			
7. Firm age	-0.075	0.018	0.074	-0.070	0.024	-0.148		
8. Private ownership	-0.007	-0.008	0.050	-0.053	-0.046	-0.116	0.241	
9. Provincial GDP/capita	-0.072	0.020	0.024	0.168	0.100	0.194	0.088	0.025

Note: Statistics based on firms with at least one PCT application. ISR indices are calculated as averages of annual patent applications. Observations are at the firm-year level.

5. Analysis of Chinese patent quality

In section 5.1 we employ the three ISR indices to compare the quality of Chinese PCT applications with non-Chinese PCT applications. In addition, we investigate in how far variation in technology areas and variation in citation counts for Chinese and non-Chinese applications explain the variation of indices. Whereas we first interpret all indices at face value, i.e. we ignore endogeneity of Chinese citations to policy, in section 5.2 we analyze the validity of Chinese citations as economic indicators and report regression results as well as robustness tests.

5.1 Descriptive analysis of patent quality

Table 3 displays the quality of Chinese PCT applications according to our three indices. $Index_F$, with a mean value of 32.1%, shows that China's patent quality is significantly below that of the comparison group, which includes all countries except China and consists mainly of high-income countries.[6] Between 2001 and 2009, $index_F$ declines from 44.9% to 30.4%. Given that the probability of obtaining a foreign ISR citation is lower if a country has a larger share in

[6] 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 (WIPO 2015b).

worldwide PCT applications, the size of a country's PCT stock negatively affects $index_F$.[7] However, as China's share of global PCT applications (2% in 2001, 5% in 2009) remained far below the share of other leading PCT countries, e.g. the US had a share of 40% in 2001 and 29% in 2009, the exclusion of domestic citations penalizes China less than other leading PCT countries.[8] In contrast to $index_F$, $index_{FD}$ (61.6%) and $index_{FDS}$ (90.0%) indicate a Chinese quality level closer to that of the comparison group. In recent years, $index_{FD}$ converges towards the comparison group while $index_{FDS}$ surpasses it.

Table 3. Quality of Chinese PCT applications

	$Index_F$	$Index_{FD}$	$Index_{FDS}$	PCT
2001	44.9	37.3	36.3	793
2002	34.2	32.0	30.1	1,060
2003	38.8	35.3	31.8	1,368
2004	34.4	27.7	32.0	1,948
2005	41.0	38.8	44.5	3,321
2006	30.7	42.4	51.5	4,649
2007	29.0	55.3	72.6	5,799
2008	29.8	76.3	112.0	6,159
2009	30.4	89.1	151.8	9,641
Total	32.1	61.6	90.0	34,738

Note: Mean values for $index_F$, $index_{FD}$, and $index_{FDS}$ displayed as percentages. The first column is a replication from Boeing and Mueller (2016). Observations are at the patent level.

The increasing discrepancy among indices over time implies that, in global comparison, Chinese firms rely disproportionally on domestically- and internally-developed technologies. The rising focus on domestic prior art corresponds to an increasing decoupling from the

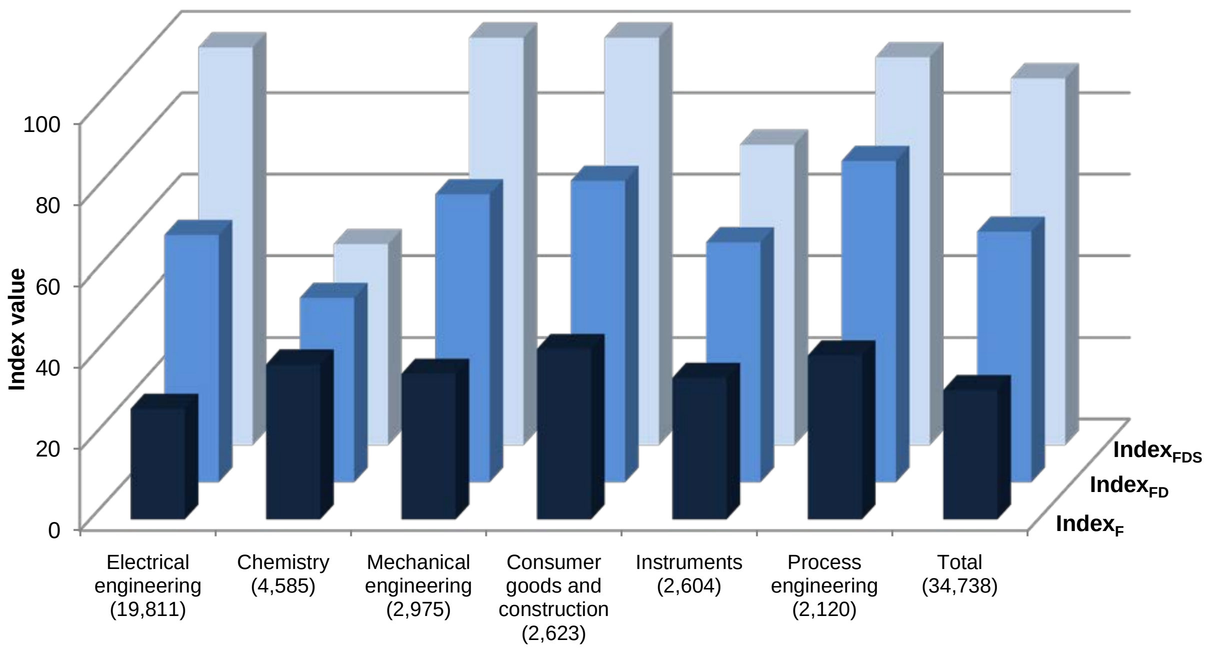
[7] To account for the inverse effect of a China's rising share of global PCT applications on China's citation probability, we divide $index_F$ by China's share of global PCT applications in a given year. The values of $index_F$ change only marginally, e.g. to 45.8 in 2001 and 32.0 in 2009. Note that a country's increasing share of global PCT applications does not necessarily simultaneously induces a downward trend of $index_F$ for that country. For example, the Republic of Korea's global share of PCT applications has increased from 2% in 2001 to 6% in 2009 and Boeing and Mueller (2016) report that its $index_F$ increased from 74.4 to 80.4.

[8] Quantifying the effect of language bias, Boeing and Mueller (2016) report that China's average ISR index increases only modestly from 32.1% to 35.6% after taking the bias into account. As core elements of PCT applications are published in English – i.e. abstract, title, search report, and text of drawings – negative bias that results from Chinese-only language elements is negligible.

international innovation system, which is not without precedence in China,[9] while the rise in self citations may be a reflection of firms working in silos.

The variation in technology areas offers further insights for the interpretation of indices. In Figure 3 we present results for patent quality according to six technology areas:

Figure 3: Quality of Chinese PCT applications according to technology area



Note: Mean values for index$_F$, index$_{FD}$, and index$_{FDS}$ displayed as percentages for the six main technology areas (patent counts in parentheses). Observations are at the patent level.

electrical engineering, chemistry, mechanical engineering, consumer goods and construction, instruments, and process engineering. Patents in the field of electrical engineering, which constitute with 57% the majority of China's PCT applications, exhibit the largest difference between index$_F$ (27.5%) and index$_{FDS}$ (97.6%). The dominance of electrical engineering is

[9] Whereas pre-modern China was able to create seminal inventions (e.g. paper, printing, the compass and gunpowder), beginning in the 15th century, China's isolation from the rest of the world may explain the subsequent technological and economic backwardness compared to the West. In the 1950s, the People's Republic of China relied on substantial support from the Soviet Union to develop its heavy industry base. Hereafter, for several decades China was technologically isolated from the rest of the world – with detrimental consequences for the economy's innovation performance.

related to the activities of ZTE and Huawei, two globally operating ICT firms that together file one third of Chinese PCT applications. Additional firm-level analysis shows that both firms receive fewer foreign citations than the average Chinese applicant but, consistent with their large size, exhibit considerably more self citations. Applications in chemistry, the second largest category with 13%, display the smallest difference between $index_F$ (38.4%) and $index_{FDS}$ (49.3%). In contrast to the complex technology electrical engineering, chemistry is a discrete technology and is not dominated by a few firms in China. Furthermore, patent examiners have less leeway in the selection of prior art in this industry and firms in chemistry have a lower probability of strategically withholding citations (Lampe 2012). The differences in the remaining technology areas are in between those reported for electrical engineering and chemistry.

As variation in indices is not only determined by Chinese patents but also by the comparison group, we investigate average citation counts for both groups separately. In Table 4 we report citation counts for Chinese and non-Chinese PCT applications. Between 2001 and 2009, the decline of $index_F$ is a result of the decrease in the average number of citations obtained by Chinese PCT applications in comparison to the relatively stable number obtained by the comparison group. Similarly, the increases of $index_{FD}$ and $index_{FDS}$ are due to increases in the average number of citations obtained by Chinese PCT applications, whereas the citations obtained by the non-Chinese comparison group are stable over time.

Table 4: Citation counts for Chinese and non-Chinese PCT applications

	Average citation counts					
	$Index_F$		$Index_{FD}$		$Index_{FDS}$	
	Chinese patents	non-Chinese patents	Chinese patents	non-Chinese patents	Chinese patents	non-Chinese patents
2001	0.131	0.276	0.165	0.424	0.217	0.587
2002	0.079	0.249	0.108	0.371	0.144	0.528
2003	0.085	0.241	0.112	0.348	0.148	0.499
2004	0.074	0.224	0.088	0.317	0.143	0.448
2005	0.091	0.230	0.126	0.323	0.199	0.442
2006	0.074	0.258	0.154	0.364	0.262	0.495
2007	0.075	0.292	0.235	0.414	0.407	0.545
2008	0.077	0.302	0.311	0.431	0.627	0.580
2009	0.076	0.292	0.325	0.426	0.781	0.576
Total	0.079	0.276	0.234	0.396	0.473	0.536

Note: Non-Chinese patents weighted according to the technology distribution of China. The values of "Chinese patents" and "non-Chinese patents" are the numerator and denominator values of the indices respectively. Observations are at the patent level.

These results emphasize that the rapid expansion of Chinese PCT applications may have contributed to higher levels and annual increases of $index_{FD}$ and $index_{FDS}$. This could be the case regardless of actual patent quality, as it simply means that over time there are more citing applications in relation to fewer cited applications. This "citation inflation" is discussed by Marco (2007) at a more general level. As the increase in Chinese patent applications and citations thereof is policy-driven, we are concerned that increases of $index_{FD}$ and $index_{FDS}$ are endogenous and biased upwards.

This concern extends to the use of most patent quality measures in the Chinese context, e.g. the grant rate and patent renewals. In response to application- and grant-contingent subsidies, applicants split up inventions to increase the quantity of patents to the detriment of average quality (Lei et al. n.d.).[10] As the growth in applications is not accompanied by a similar

[10] Song et al. (2016) calculate that in ten provinces patent subsidies exceed actual patent fees after common rebates are taken into account – simply filing applications is profitable in these provinces. Prud'homme (2016) reports further shortcomings in the design of patent subsidy schemes: subsidies can be received twice from different government agencies due to a lack of coordination; repeated applications of identical patents and for already commercialized products are possible; filing fees are not paid at all after receiving application subsidies or the patent is withdrawn before substantial examination.

increase in examiners, a shortened examination time per patent negatively affects the probability of discovering prior art.[11] Accordingly, a larger fraction of applications were granted in the years after the introduction of subsidies (Li 2012).

Not only patent subsidies but also other innovation-related government programs may distort the reliability of patent quality measures. Given that eligibility criteria include patents in force, applicants may decide to extend patent protection if renewal fees are overcompensated by the expected government support.[12] In conclusion, endogeneity to policy cannot be ruled out for most measures of patent quality.

A notable exception is the use of independent patent claims, which are a more direct and a rather exogenous measure of actual invention. However, because full claim information is not available from SIPO, the analysis by Dang and Motohashi (2015) is restricted to the number of nouns in the claims as a proxy and such word-based proxies provide comparatively less precise measures of patent quality (Reitzig 2004).

5.2 Regression analysis for index validation

In this section we investigate the validity of different citation types as quality indicators. In a firm's knowledge production function R&D expenditures determine additions to economically valuable knowledge, while patents are a quantitative indicator of the number of inventions (Pakes and Griliches 1984). Early work has often estimated the correlation between patent output and R&D inputs (e.g. Hall et al. 1986, Pakes and Griliches 1984, Scherer 1983), where patent counts provided a proxy for unobservable knowledge. Because the economic value of patents is heterogeneous, there has been continued interest in the average quality of firm patents as a measure of the economic value of knowledge (Griliches 1990). More recently, the literature

[11] Liang (2012) calculates that the average Chinese patent agent only spends two and a half days on each application, in comparison with eighteen days in the US.

[12] An example is the High New Technology Enterprise (HNTE) Program (Garcia et al. 2016).

has empirically confirmed a positive correlation between patent quality and R&D. Based on renewals, Bessen (2008) finds that patent quality increases with the firms' R&D stock, however, there are diminishing returns to patenting as patent quality decreases when more patents are filed. Shane (1993) shows that citations-weighted patents are more highly correlated with R&D than simple patent counts. Finally, Hall and MacGarvie (2010) report that the market valuation of patents increases with the firms' patent stock.

Following this literature, we regress the ISR indices on firms' R&D stock to validate Chinese forward citations – in comparison to foreign ones – as an economic indicator. We expect a positive relation between patent quality and R&D. Failing to confirm this relation for an index would question the validity of the related citations as economic indicator. First, we calculate the ISR indices based on the PCT applications filed by domestic firms listed in mainland China (Table 5). While the total averages for $index_{F}$ and $index_{FD}$ are very similar to the values obtained for all Chinese PCTs (compare to Table 3), we see a larger value for

Table 5: Quality of PCT applications of Chinese listed firms

	$Index_{F}$	$Index_{FD}$	$Index_{FDS}$	Obs.
2001	60.3	85.3	94.2	53
2002	56.6	56.5	68.3	102
2003	42.3	52.7	48.2	159
2004	81.7	78.1	68.0	195
2005	56.0	69.9	56.0	347
2006	55.7	61.0	65.2	429
2007	46.7	74.1	102.4	710
2008	23.1	62.4	144.7	871
2009	18.7	61.2	152.4	2,318
Total	33.1	64.3	121.9	5,184

Note: Mean values for $index_{F}$, $index_{FD}$, and $index_{FDS}$ displayed as percentages. Observations are at the patent level.

$index_{FDS}$. This is to be expected as listed firms are considerably larger than China's average firms and therefore have a greater potential for self citations.[13]

[13] The averages in Table 5 differ from those in Table 1 due to weighting. At the patent level (Table 5), each patent has the same weighting, whereas at firm-year level (Table 1) each firm observation has the same weighting regardless of the size of the patent stock.

For the main analysis in Table 6 we use a Tobit model because the dependent variable is truncated at zero, with standard errors clustered at the firm-level. Assuming a strong impact of R&D on patent quality, in Model (1) we regress $index_F$ on the R&D stock of firms and our control variables, i.e. the PCT intensity, ln(employees), ln(age), private ownership, provincial GDP per capita, year and industry dummies. We find a positive and highly significant effect ($p<0.01$) for the R&D stock. We transform the coefficient of 0.166 into a marginal effect of 0.034 to derive an intuitive interpretation of the size of the effect. The Tobit model has the structure of a linear-log model, i.e. the dependent variable is in linear form and the regressor of interest, R&D stock, is in logarithms. Because an increase of the R&D stock by 1% corresponds to an increase in ln(R&D stock) by 0.01, we need to multiply the marginal effect of 0.034 by 0.01 to arrive at the unit change in the index that is caused by a 1% increase in the R&D stock. Thus, we find that a 1% increase in the R&D stock corresponds to an increase in the quality index by 0.00034, or by 0.034 percentage points. When interpreted relative to the mean of $index_F$ (0.433 or 43.3%), a 1% increase in R&D stock leads to an increase in patent quality of about 0.1%. This result confirms a positive and economically important relationship between the R&D stock and patent quality.

Considering previously filed patents, we find a positive and highly significant impact for PCT intensity ($p<0.01$, with a marginal effect of 0.029). Thus, adding one unit to the PCT intensity increases $index_F$ by 2.9 percentage points.[14]

[14] When we include the quadratic PCT intensity and re-estimate Model (1) we find a declining marginal effect of patenting on patent quality as reported by Bessen (2008).

Table 6: Results of Tobit estimations

	(1)	(2)	(3)
	$Index_F$	$Index_{FD}$	$Index_{FDS}$
ln(R&D stock)	0.166***	0.036	-0.005
	(0.061)	(0.034)	(0.026)
PCT intensity	0.141***	0.060*	0.039**
	(0.048)	(0.034)	(0.017)
ln(employees)	0.298	0.215	0.217**
	(0.222)	(0.146)	(0.095)
ln(age)	-0.951	-0.165	-0.038
	(0.671)	(0.439)	(0.292)
Private ownership	0.641	-0.128	-0.061
	(0.674)	(0.441)	(0.292)
ln(provincial GDP/capita)	-0.486	-0.223	-0.407
	(0.629)	(0.456)	(0.340)
2002	-1.519	-1.207	-0.805
	(2.315)	(1.577)	(1.043)
2003	-2.494	-2.103	-1.359
	(2.393)	(1.487)	(0.997)
2004	-0.571	-1.396	-0.368
	(2.202)	(1.506)	(0.940)
2005	-2.030	-2.125	-1.247
	(2.134)	(1.402)	(0.926)
2006	-2.143	-1.346	-0.363
	(2.264)	(1.459)	(0.957)
2007	-3.164	-1.645	-0.543
	(2.444)	(1.519)	(1.003)
2008	-3.316	0.060	0.710
	(2.392)	(1.462)	(0.962)
2009	-4.036*	-0.457	1.541
	(2.257)	(1.452)	(0.954)
Industries	Yes	Yes	Yes
Observations (firms)	451 (228)	451 (228)	451 (228)
Log pseudo likelihood	-350.75	-545.66	-608.07

Note: The dependent variable is the average quality index of a firm's annual patent applications. Tobit estimation with standard errors clustered at the firm-level. Reference category for year is 2001. Analysis is at firm-year level. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels.

Interestingly, the year dummies show a negative time trend, which becomes more pronounced in later years and turns weakly significant ($p<0.1$) in 2009. Note that in 2009 the central government introduced subsidies for PCT patents (Chinese Ministry of Finance 2009).[15]

[15] Applications in up to five countries (regions) are subsidized with up to 100,000 RMB each (ca. 14,600 USD, exchange rate of 31.12.2009). More support is possible for projects involving significant innovation. Subsidies

This followed the introduction of subsidy programs at the provincial and sub-provincial level in earlier years, which often supported domestic as well as international applications (Li 2012).[16]

In Model (2), we change the dependent variable to $index_{FD}$. With the exception of the PCT intensity, which remains positive and weakly significant ($p<0.10$), all remaining regressors become insignificant. In Model (3) we change the dependent variable to $index_{FDS}$. One of the two significant regressors is the PCT intensity, which remains positive and significant ($p<0.05$). The expected positive correlation between firm size and self citations is confirmed ($p<0.05$). Importantly, neither Model (2) nor Model (3) show a significant relation between the R&D stock and the quality indices, $index_{FD}$ and $index_{FDS}$ respectively. To restrict the analysis to Chinese citations, we calculate indices which only consider either domestic ($index_D$) or self citations ($index_S$). As expected, neither index shows a significant relationship with R&D stock (results not reported). Therefore we conclude that in the Chinese setting only $index_F$, but not $index_{FD}$ or $index_{FDS}$, can be used as quality indicator. Domestic as well as self citations are endogenous to economic policy and should therefore not be used as a measure for patent quality.

5.3 Robustness tests for index validation

As a robustness test we employ a Heckman two-step selection model, which allows us to model the selection into filing at least one PCT application for all 1,743 listed firms from mainland China (Table 7). We use the number of employees relative to the industry mean as an exclusion restriction, following the rationale that relatively larger firms are more likely to file PCT applications, whereas relative firm size is no determinant for average patent quality. The correlation of relative firm size with all other variables remains below 0.4. In addition, we omit

should mainly cover examination fees, patent agent service fees, and renewal fees. Applications are only subsidized once.

[16] For the majority of programs below the central level, proof of patent application is sufficient for reimbursement and additional subsidies are awarded for granted patents. Subsidies for international applications are larger than for domestic ones and reach up to 50,000 RMB apiece, e.g. in Shenzhen (Li 2012).

the PCT intensity as a regressor because the PCT intensity is highly correlated with the probability of having at least one PCT application.

The results of the selection equation (Model 1) show that relatively larger firms are indeed more likely to file PCTs – the relative number of employees has a positive effect on selection ($p<0.01$) – although we already control for individual firm size. In addition, we find that the R&D stock has a positive and highly significant effect ($p<0.01$) on the probability of filing at least one PCT application. Selection is also more likely for private firms ($p<0.10$) as well as for firms situated in provinces with higher GDP/capita ($p<0.01$).

Moving to the outcome equation for $index_F$ (Model 2), we see a significant relation ($p<0.05$) between the R&D stock and patent quality as measured by foreign ISR citations. The marginal effect of the R&D stock in Model (2) is smaller than in Model (1) of Table 6 because the selection equation already partly captures the influence of the R&D stock on PCT applications. As expected, Rho confirms a positive correlation of the error terms in the selection and outcome equation. Nonetheless, the coefficient of Lambda, which is the covariance of the error terms of both equations, is not significant. This finding shows that additional unobservables are unlikely to induce significant selection bias. As in the standard Tobit model, we do not find a significant relation between R&D stock and the quality measures $index_{FD}$ (Model 3) and $index_{FDS}$ (Model 4).

We perform additional robustness tests for $index_F$ (results not reported). We repeat the Tobit estimation of Model (1) in Table 6 but exclude the largest PCT applicant, ZTE, from our sample. Reassuringly, the significance levels remain unchanged and marginal effects are

Table 7: Results of Heckman two-step selection model

	(1)	(2)	(3)	(4)
	Selection equation	Outcome equation	Outcome equation	Outcome equation
	PCT application (0/1)	$Index_F$	$Index_{FD}$	$Index_{FDS}$
ln(R&D stock)	0.023***	0.030**	0.018	0.002
	(0.004)	(0.012)	(0.014)	(0.012)
ln(employees)	0.126***	-0.025	0.064	0.087
	(0.020)	(0.080)	(0.091)	(0.080)
ln(age)	0.047	-0.193	-0.124	-0.069
	(0.053)	(0.142)	(0.163)	(0.142)
Private ownership	0.084*	0.117	-0.052	-0.019
	(0.050)	(0.137)	(0.157)	(0.136)
ln(provincial GDP/capita)	0.387***	0.006	0.090	-0.066
	(0.043)	(0.151)	(0.211)	(0.184)
Relative firm size	0.007***			
	(0.001)			
Lambda		0.168	0.447	0.365
		(0.373)	(0.428)	(0.373)
Years	Yes	Yes	Yes	Yes
Industries	Yes	Yes	Yes	Yes
Rho		0.127	0.289	0.271
Sigma		1.327	1.548	1.345
Observations (firms)		12,575 (1,743)	12,575 (1,743)	12,575 (1,743)

Note: Standard errors clustered at the firm-level. Analysis is at firm-year level. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels.

very similar. Next, we conduct a random effects Tobit estimation with the Chamberlain-Mundlak device. This estimator achieves consistent results even if the time-invariant error term is not independent from the time-variant regressors. As additional controls the regression specification includes the average value of time-variant regressors. Again, we confirm a positive and significant relation between the R&D stock and $index_F$.

As another test we calculate citation intensities in analogy to the three variants of the ISR index. The citation intensities are defined as the average number of citations for the patents in the analysis group without control for year and technology-specific citation averages of the comparison group. We regress the intensities on the R&D stock and our other control variables (results not reported). In parallel to the results with the ISR indices, we find a highly significant relation between R&D stock and the intensity based on foreign citations ($p<0.01$). The R&D

stock shows no significant relation with citation intensities when either domestic or domestic and self citations are included.

5.4 Comparison to Germany for index validation

As a final test, we apply our quality indices to German firms, as policy distortion related to patent subsidies is not a concern in Germany. For the test we repeat the Tobit estimation of Model (1) in Table 6. The firm level data comes from the Mannheim Innovation Panel (MIP), which is maintained by the Centre for European Economic Research (ZEW) on the basis of an annual survey commissioned by the German Federal Ministry of Research and is the German contribution to the European Union's Community Innovation Survey (CIS). The data includes about 3,000 representative German firms and has been used in numerous publications, e.g. Hottenrott and Peters (2012) or Peters et al. (2017).

In Table 8 we calculate the ISR indices based on PCT applications filed by the firms in the MIP panel. While the averages between indices increase monotonically from $index_F$ to $index_{FDS}$, the averages within indices remain rather stable over time. Assuming that $index_{FDS}$ can be readily interpreted in the German setting, the results suggest that the patent quality between 2001 and 2009 narrowly oscillates around the non-German comparison group.

Table 8: Quality of PCT applications of German firms

	$Index_F$	$Index_{FD}$	$Index_{FDS}$	Obs.
2001	63.6	72.9	99.4	7,054
2002	69.1	79.0	106.8	6,753
2003	70.9	94.1	120.1	6,194
2004	69.0	90.0	122.3	6,475
2005	62.5	80.7	111.8	6,738
2006	53.3	72.9	106.8	6,952
2007	52.8	64.6	85.7	7,486
2008	53.5	66.1	84.3	6,623
2009	64.3	72.0	86.4	6,601
Total	61.9	76.6	102.2	60,876

Note: Mean values for $index_F$, $index_{FD}$, and $index_{FDS}$ displayed as percentages. Observations are at the patent level.

However, before we can reach this conclusion we need to verify the validity of German domestic and self citations as an economic indicator.

In Table 9 we regress the ISR indices on the R&D stock of firms and similar control variables as those in Table 6. We find a positive and highly significant effect ($p<0.001$) for the R&D stock in all three models. When we interpret the marginal effects relative to the mean of the indices, we find that a 1% increase in the R&D stock corresponds to an increase in patent quality of 0.11% for $index_F$, 0.06% for $index_{FD}$, and 0.05% for $index_{FDS}$. The effect for $index_F$ is very similar to the results reported for the Chinese firms. However, the significance of $index_{FD}$ and $index_{FDS}$ suggests that for the case of Germany, where policy distortion is not a concern, all three citations types can be used as measures for patent quality.

Table 9: Results of Tobit estimations for German firms

	(1)	(2)	(3)
	$Index_F$	$Index_{FD}$	$Index_{FDS}$
ln(R&D stock)	0.334***	0.185***	0.145***
	(0.077)	(0.047)	(0.034)
PCT intensity	0.022***	0.148***	0.012***
	(0.004)	(0.003)	(0.002)
ln(employees)	0.200*	0.157**	0.114**
	(0.104)	(0.069)	(0.049)
ln(age)	-0.152	-0.141	-0.169**
	(0.150)	(0.104)	(0.077)
Eastern Germany	-0.929*	-0.923**	-0.682**
	(0.502)	(0.373)	(0.270)
Years	Yes	Yes	Yes
Industries	Yes	Yes	Yes
Observations (firms)	1844 (872)	1844 (872)	1844 (872)
Log pseudo likelihood	-2310.61	-2593.61	-2724.91

Note: The dependent variable is the average quality index of a firm's annual patent applications. Tobit estimation with standard errors clustered at the firm-level. Reference category for year is 2001. Analysis is at firm-year level. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels.

6. Discussion

6.1 Policy implications

We derive two main policy implications. First, as China's government policy has incentivized increases in the quantity of applications to the detriment of quality, Chinese patent applications and citations thereof are questionable measures of innovation levels and quality. Our analysis shows clear differences in the properties of foreign, domestic, and self citations as economic indicators in the Chinese context. While we find a significant relation of $index_F$ (which is exogenous to national policy) with R&D stocks of Chinese firms, this relation cannot be established for $index_{FD}$ and $index_{FDS}$ (which are endogenous to national policy and biased upwards). Thus, our results conform to the seminal critiques of Goodhart (1975) and Lucas (1976), who postulate that indicators fail as reliable measures if they become the target of policy. Overall, it depends on the specific national policy-setting whether all three citation types can be employed as valid economic indicators or if domestic citations are to be avoided. We show for the case of Germany that all three citations types can be used given that policy distortion is not a concern.

Second, our results may be of interest to policy makers in China. Having achieved a vast expansion in the number of applications made both domestically and abroad, the government should rethink its patent policy. The patent subsidies' initial role of getting firms used to the patent system is now achieved. Instead of being targeted at firms facing financial constraints, patent subsidies are currently offered to all firms, which rewards low quality patents with no economic benefit. Considering the high costs of subsidies and examination efforts, the government should ensure that inventions patented with the support of subsidies contribute to productivity. SIPO's proposal to replace application-based subsidy schemes with grant-based ones and the call for stricter examination standards are steps into the right direction (SIPO 2013, 2014). More generally, governmental patent targets should be removed as patents should only be filed if, according to the applicants' judgment, the underlying inventions show sufficient commercial promise.

6.2 Wider applicability of the indices

The ISR indices are applicable in a wide variety of settings, e.g. at the country-, industry- or firm-level or with a focus on specific technologies. For example, one could compare the development stage of leading technological areas, such as green technologies or advanced manufacturing, among countries. Further, the $index_F$ is particularly useful for ex-post policy evaluation if it cannot be ruled out that indicators derived from the national patent system are endogenous to policy-driven changes in applicant behavior.

While cross-country comparisons of patent quality are of high relevance for certain research settings, in some investigations domestic comparison may be sufficient. In these cases, the citation intensity of patent applications, i.e. average number of citations per patent, is a well-established measure of patent quality. Using an intensity instead of the index poses less demand on data availability because it is not necessary to calculate the year- and technology-specific international benchmark. Econometrically, using an intensity is equivalent to not controlling for time-variant technology specific effects.

Beyond the analysis of PCT patents in this study, ISR indices may be used to measure the quality of national patents for any country included in the minimum documentation required for prior art search by ISAs during the international phase. As prior art search for PCT applications is not restricted to previous PCT applications but encompasses the patent literature from a large number of patent offices, it is possible to use ISR citations as quality measure for those applications that are included in the systematic search for prior art. Among others, it is possible to investigate and compare the quality of patents from the USA, Japan, the European Patent Office, and the Republic of Korea. Analysis of patent quality is also possible for countries for which national citation data is not publicly available, e.g. for China.

7. Conclusion

In recent years China's patent applications have risen faster than R&D expenditures, resulting in decreasing R&D inputs per patent. Given that China's patent expansion is policy-driven, we validate domestic citations in comparison to foreign ones, which are invariant to China's policy, as economic indicators. We derive internationally comparable citation data from ISRs and extend the ISR index from considering only foreign citations to also considering domestic and self citations, as the inclusion of different citation types provides a more comprehensive analysis of patent quality.

Whereas foreign citations show that Chinese PCT applications reach only a third of the non-Chinese quality benchmark, the extension towards domestic and self citations suggests an increasing quality level that is closer to the international benchmark. Taken at face value, these findings suggest that Chinese inventions build more on prior art originating from a domestic and within-organization context. However, the differences among indices can also be the result of policy-driven citation inflation in China. We investigate these differences based on firm-level regressions and find that only foreign citations, but not domestic and self citations, have a significant and positive relation to R&D stocks. Taking German firms as a counterexample, we show that all three citations types may be used as an economic indicator if policy distortion is not a concern. As Chinese citations appear to suffer from an upward bias, Chinese patent data should be employed with caution if it is interpreted as an economic indicator. In conclusion, we confirm that indicators fail as reliable measures if they become the target of policy.

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