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Same Place, Same Knowledge & Same People? Evidence from Non-Patent Citations in Dutch Polymer Patents.

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Abstract

Citations to non-patent literature (NPL) in 2,385 Dutch polymer patents filed from 1968 to 2008 are used to study knowledge flows between public research and industrial R&D. Our study builds on the substantial prior literature that analyzed patent citations to find evidence for localized knowledge spillovers. We focus on citation lags as information about the temporal dimension of knowledge flows. In line with theoretical predictions, citations lags are shorter on average if Dutch rather than foreign NPL is cited (as indicated by author affiliations). A more detailed analysis shows that a substantial share of the domestic NPL is cited with very short time lags, which is conjectured as evidence of in-house research and local collaboration. To test this conjecture, two types of self-citations are identified in the dataset: NPL patent pairs with at least one author/inventor in common and NPL patent pairs that share applicant and author affiliations. Excluding these self-citations from the dataset the previously estimated difference in localized versus distant citation lags disappears. Excluding only one type of self-citation, shorter citation lags are still observed for local universities. This shows the importance of taking all NPL into account that are related to the inventor. We also find that (local) universities play an important role as collaboration partners for industry researchers.

Jelcodes:O33,R10

Same Place, Same Knowledge – Same People?

The Geography of Non-Patent Citations in Dutch Polymer Patents

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Abstract

Citations to non-patent literature (NPL) in 2,385 Dutch polymer patents filed from 1968 to 2008 are used to study knowledge flows between public research and industrial R&D. Our study builds on the substantial prior literature that analyzed patent citations to find evidence for localized knowledge spillovers. We focus on citation lags as information about the temporal dimension of knowledge flows. In line with theoretical predictions, citations lags are shorter on average if Dutch rather than foreign NPL is cited (as indicated by author affiliations). A more detailed analysis shows that a substantial share of the domestic NPL is cited with very short time lags, which is interpreted as evidence of in-house research and local collaboration. To test this conjecture, two types of self-citations are identified in the dataset: NPL patent pairs with at least one author/inventor in common and NPL patent pairs that share applicant and author affiliations. Consistent with the conjecture, the estimated difference in localized versus distant citation lags disappears when these self-citations are excluded from the dataset. Excluding only one type of self-citation, shorter citation lags are still observed for local universities. The patterns suggest that labor mobility rather than Marshallian spillovers underlie the localization of citations.

Keywords: Non-patent literature, citation lags, knowledge spillovers, university-industry interaction, polymer industry.

JEL Codes: O 33, R 10, L 65.

1. Introduction

The past two decades have witnessed a rapidly growing interest in university-industry interaction as governments have aimed at increasing the economic returns to public research. One central question in this context is whether the spillovers from public research to private industry are geographically localized, be it at the regional level (e.g. a U.S. state or a German Land) or the level of a small country (e.g., the Netherlands or Switzerland (Jaffe 1989; Fritsch and Slatchev 2007). Such spillovers are expected to be most pronounced in science-based industries with high degrees of co-location of industry with university labs.

Close interaction between industry and university, however, is not a new phenomenon. Ties between them date back at least 150 years, for example, as in the German chemical industry (Murmann 2003, 2013). A particularly interesting case is the polymer industry that largely preceded polymer science. Instead of being a science-based industry, the early stages of polymer research are better described as industry-based science, as laboratories of large companies played a major role in the development of a scientific understanding of polymers (Walsh 1984). Later, polymer science became institutionalized at universities as well, and firms started to increasingly profit from public research carried out at universities.

In this study, we are interested in the time lag between patented technology and closely related public available knowledge (mostly scientific literature) as well as its the determinants. The theory of localized knowledge spillovers would suggest that Dutch firms active in polymer patenting should be quicker to absorb domestic academic knowledge compared to foreign academic knowledge. Using patent citations as a measure of knowledge flows (Jaffe et al. 1993), the main question we ask is whether these spillovers are indeed observable. We also discuss alternative mechanisms (in-house research and local collaborations) that could cause a faster local knowledge exchange. Looking at citation lags to non-patent literature (NPL for short) in all Dutch corporate polymer patents since 1960, we find that Dutch NPL is indeed cited more quickly than foreign NPL. However, controlling for self-citations, this effect largely disappears, which suggests that localized knowledge flows are mainly intra-personal, rather than between co-located individuals. Interestingly, we also find that, while controlling for self-citation, geographic co-location still matters for the subset of university NPL, while no such effect can be found anymore for firm NPL. These results suggest that innovation policies should be more oriented towards mobility schemes of researchers as carriers of knowledge, rather than towards co-location in clusters, because co-location per se may have little effect on knowledge spillovers (Breschi and Lissoni 2001, 2009).

2. Localized knowledge spillovers from public research

The idea of localized knowledge spillovers as an explanation for the regional concentration of industries dates back to Alfred Marshall (1920). In his famous expression, in regions that have a high concentration of firms active in the same industry, industry-specific knowledge may be “as it were in the air” and provide producers in these regions with significant advantages vis-à-vis more isolated competitors. Localized knowledge spillovers have become a cornerstone of theories of industrial agglomeration – notwithstanding the fact that they are notoriously difficult to identify empirically.

Jaffe et al. (1993) first used patent citations as a proxy of knowledge spillovers. Patent applications contain citations to those earlier technologies that are most closely related to the citing patent. If localized knowledge spillovers exist, patent citations will concentrate within regions. This is indeed found by Jaffe et al. (1993) for different geographic scales, even after controlling for the uneven geographic concentration of firms within an industry. Also consistent with localized spillovers, these authors find that the localization of citations is reduced with an increasing time lag between the cited and the citing patent. In addition, there is stronger evidence of localization at smaller geographic scales (U.S. statistical regions versus countries and U.S. states and countries), as well as for the citation of university-owned patents.

Besides refining the methodology pioneered by Jaffe et al. (1993), subsequent contributions[1] have challenged the interpretation that patent citations reflect unmediated knowledge spillovers. Breschi and Lissoni (2001) argue that the localization of patent citations is difficult to explain by knowledge spillovers as the cited patents are codified knowledge having public-goods characteristics and should therefore be available even at longer distances. They also suggest that the benefits of knowledge flows can often be internalized by the affected parties. For example, knowledgeable employees can negotiate higher wages when changing jobs. In addition, social networks and interpersonal contacts play an important role in turning knowledge from a public good into a club good (see also Geroski 1995). Breschi and Lissoni (2001) suggest that tacitness of knowledge may be deliberately increased by inventors to restrict the usability of the knowledge disclosed in their patents. In this case, only those agents (i.e., the members of the "club") are able to utilize the knowledge who have access both to the patent itself and to the complementary non-public insights. These insights are personally bounded and are shared only within the network. Localization of citations may then result from the localization of social networks, while mere co-location (without being member of the network or "club") does not allow outsiders to access the knowledge. Indeed, using a variant of the empirical design developed by Jaffe et al. (1993), Breschi and Lissoni (2009) show that substantial shares of patent citations are made within networks of inventors linked by co-inventorships, as well as by inventors having patents with different applicants. Since social networks are often geographically localized, the citation flows are geographically localized; however, the citations do not stem from co-location per se, but from proximity of inventors in social networks and through labor mobility.

While the main focus of the original paper by Jaffe et al. (1993) focused on intra-industry knowledge flows, the idea of localized knowledge spillovers has also been applied to the diffusion of knowledge from universities and other public research organizations. Again, patent citations can be used to proxy for these knowledge flows, as was for instance done by Jaffe and Trajtenberg (1996) in a follow-up paper analyzing the citations to university-owned patents. They assume that the likelihood to be cited by a given patent depends positively on the time lag, because over time the underlying knowledge gets increasingly well known. At the same time, it negatively depends on the time lag because knowledge becomes obsolete with an increasing time lag. Both effects are shown to be significant, resulting in a skewed inversely u-shaped distribution of the citation lag. The maximum number of citations is found for a lag of about three years. The authors also report a positive location effect on the country level. This effect is decreasing with increasing time lags.

In the institutional framework of open science, publications rather than patents are the primary channel of disclosing new knowledge. As patents often contain citations to NPL, which indeed mostly consists of scientific publications (Callaert et al. 2006), knowledge flows from public research can also be traced by studying the citations to NPL found in patent documents. Adopting this approach, several prior studies have found that patents are often co-located with the non-patent literature they cite. Narin et al. (1997) report for U.S. patents a tendency of inventors to cite scientific literature from the U.S. Cited authors working in the U.S. are most often affiliated to universities, but researchers from some major companies (i.e. DuPont, IBM, Merck Inc.) also receive substantial numbers of citations. The cited scientific literature is characterized as basic and recent. In related work on biotechnology and information technology, Verbeek et al. (2003) likewise find a strong national bias in patent citations to NPL, which is interpreted as evidence of localized knowledge spillovers.

[1] For instance, Thompson and Fox-Kean (2005) show that results are sensitive to the level of technological disaggregation in selecting uncited control patents . Alcacer and Gittelman (2006) highlight the role of citations added by patent examiners.

Similar to the discussion in Breschi and Lissoni (2001), a variety of factors other than spillovers could indeed underlie the localized character of NPL citations. First, regional characteristics may induce both (publishing) university researchers and (patenting) R&D staff at private-sector firms to work in the same fields of research. This could for instance result from the support of specific fields of research as parts of regional or national R&D policy initiatives, coordination of universities' research profiles and research needs of regional firms, or even more simply a regional demand for solving specific problems. Second, localized R&D citations might reflect mobility of researchers or graduates from public research to private-sector R&D, when the respective individuals continue to work on similar issues. This, as well as other forms of collaboration between universities and industries, resonates with the findings by Breschi and Lissoni (2009) that social networks are the main carrier of patent citations. Finally, NPL citations might even reflect that the same individuals or research groups both publish and patent closely related results. [2]

Additional insights into the factors underlying the localization of patent citations can be gained from taking a closer look at the timing of citations, which will be in the focus of the empirical analysis presented in this paper. It was an early insight by Jaffe et al. (1993) that the localization of spillovers should fade out over time as knowledge diffuses in space via direct interaction and/or is increasingly codified. The same rationale suggests that if localization of patent citations is due to spillovers, we should observe a direct relationship between and geography and the timing of citations: earlier citations should be more likely to be from geographically close patents than from more distant ones. This conjecture leads to our first hypothesis:

H1: On average, NPL citations by patents from the same region have shorter citation lags than NPL citations by non-regional patents.

Shorter citation lags of co-located patents as predicted by H1 need not be caused by unmediated localized spillovers, however. An alternative explanation could be collaborative work on the same issues by groups of researchers in the same regions. One indication of collaborative work within one region would be provided by finding extremely short citation lags for co-located NPL. Developing and patenting a new technology typically requires a substantial amount of time. Scientific results as well are in most cases published only after a significant amount of time was spent on research. Short citation lags could therefore be interpreted as evidence for a temporal overlap in local private and public research efforts – the new scientific and technological knowledge may have been created within the same time period, and the citing inventors may have known about the results of the cited research before they were published.

Since very short citation lags are unlikely to be caused by localized knowledge spillovers, we take a more detailed look the respective citations. If co-located firms and universities collaborate in knowledge production, we would expect to find the same individuals listed as authors and inventors, or at least the same organizations as affiliations of publishing authors of NPL and as applicants of patents citing the same articles. The patented technology is in these cases closely related to scientific findings produced in a similar time period by the same researchers. Another potential cause of self-citations is that firms may themselves be active in scientific research. Prior research suggests that if firms believe that the knowledge about a certain field will lead to valuable innovations but a scientific foundation of the technology is not existent yet, they may get active themselves (Stephan 1996). These considerations suggest that short citation lags of co-located patent-NPL-pairs may be driven by self-citations. Eliminating self-citations should then reduce the differences in citation lags between co-located and distant citations.

[2] Real patent-paper pairs in the sense of Murray and Stern (2007) are less likely to be observed in our empirical context because papers would normally be published after the patent application and thus not qualify as prior art cited in the patent.

H2: If self-citations are excluded, the finding of shorter lags of local NPL citations disappears.

3. Using NPL citations to identify knowledge flows and their causes

Before utilizing patent citations to trace knowledge diffusion it is required to understand some details of the patent system since citations in patents differ from citations in scientific publications in some critical aspects. Using NPL in particular requires some further understanding how and for what reason they are cited.

While most patent citations refer to other patents, in general all publicly available knowledge can be cited in a patent. The only important condition is that it has to be public before the priority date of application. The priority date of a patent is of great importance for the patent granting process and thus for the patentability search itself. The priority date is the date of the first filing of the patent application. According to the description of the state of the art all publicly available knowledge is considered that was available before the application was filed (Michel and Bettels 2001).

Most citations of non-patent literature refer to scientific literature (Callaert et al. 2006). A NPL document is cited if no relevant patent literature can be found and the document is considered either to contribute significant to the state of the art or to be a relevant piece of knowledge making the invention of the patented technology possible (Tijssen 2002). Because citing patent documents is typically favored over citing NPL, finding an NPL citation indicates that the patent contributes to a technological field where no (patented) technology existed at the time when the patent application was filed. In addition, NPL represents citations of non-patentable knowledge such as scientific theories or discoveries (Grupp and Schmoch 1992). Since NPL is often scientific literature, NPL citations can serve as indicators of the extent to which a technology is science-based (Schmoch 1993).

Patent citations are a "noisy" indicator for (direct) technological impact and knowledge spillovers (Henderson, Jaffe, and Trajtenberg 1998). Citations cannot be treated as indicators of "intellectual debt", which raises the question for an appropriate interpretation. Research aiming specifically at this point indicates that the scientific publications that are cited are not normally the origin of the idea of the invention patented (Meyer 2000). The scientific citation is more likely indicating that the patent is in a field where no patent as prior art is existing. The cited non-patent literature is the closest related publicly available knowledge existing at the time of application.

If NPL citations are interpreted as the closest existing public available literature, it is of less concern who included the citation in the patent document. While there are differences between patent offices on what kind of literature has to be submitted by the applicants, the final decision whether a document is cited or not is made by the patent examiner (Criscoulo and Verspagen 2008). Independently of where the citation originated, the cited literature is seen as relevant by the examiner (either because it proves the newness or because it limits the claims of the patent). This allows us to use all citations that belong to a patent application independently of the publishing patent office.

4. Dataset

A new dataset on NPL citations in the Dutch polymer industry was developed to test the hypotheses formulated above. It originates from the PATSTAT patent database published by the EPO (version April 2008) and is restricted to patent applications by the major Dutch organizations active in polymer technology, including both companies (AkzoNobel, Koninklijke DSM, Philips, Royal Dutch Shell, Stamicarbon, Unilever) and public research institutions (universities and the public research organization of applied scientific research - TNO).

A two-stage process was applied to retrieve the patent data from PATSTAT. First, all world-wide polymer patent applications were obtained by searching for patent documents with an international patent classification (IPC) related to polymer technology.[3] In the second step all patent documents associated to one of the selected Dutch companies were filtered out. A total of 31,679 patent documents was obtained from the patent search. Patent documents were grouped according to DOCDB patent families,[4] which condensed the dataset to 9,003 DOCDB patent families. (In what follows, we will refer to these families as "patents".) Information corresponding to the patents (e.g., the year of filing) was obtained from the priority patent document. The further process of data assembly followed the basic procedure of Narin et al. (1997). First, information about patent references was retrieved from the patent documents. Second, citations were searched in a database of scientific literature and categorized by type of publication. Finally, characteristics of the cited patent document were related to those of the cited NPL.

The empirical analysis focuses on the patents' backward citations, using all citations of all members of the respective patent family. In our sample we found 1,088 patents referencing 3,104 NPL citations. NPL can include any kind of publicly available information source (other than patents). There is also no convention on citation rules for the inclusion of an NPL citation. As a result, NPL citations are included in a very unsystematic manner and substantial manual standardization efforts were required. Further information about the NPL was collected from Scopus and Web of Science. If an NPL was not listed in these databases a web-based search was undertaken.[5] By using DOCDB patent families duplicated patent-NPL-pairs might arise if a NPL is cited on several patent documents belonging to the same patent family. In our sample we identified 41 duplicates that had to be excluded from the sample. Furthermore, all citations referring to patents were excluded from the dataset. Altogether 122 NPL actually referred to patent documents and were identified and excluded.

To investigate the origin of NPL citations in more detail, the bibliographic information was categorized in several groups. According to the type of the document the NPL was first grouped into (i) scientific journals, (ii) handbooks, (iii) encyclopedias, (iv) symposia and conference proceedings, (v) company bulletins and (vi) others. Scientific publication databases were used for the identification of journals. Conference proceedings and publications related to symposia were identified by the name of the respective documents, which commonly contain the word "conference" or "symposium". It was impossible to distinguish between scientific and non-scientific conferences. Therefore the category symposium refers to any kind of publication related to a meeting. Handbooks and encyclopedias were identified by a manual web-based search. Encyclopedias are treated as a separate category because often several editions of one encyclopedia are cited. Encyclopedias collect knowledge over a long time period and contain entries on

[3] The following IPC were included in the query: C08F, C08G, C08K, C08L, C09D

[4] The DOCDB patent families combine all patent documents related to the same priority patent applications. This proceeding is necessary to avoid double counting since worldwide patent documents are used. Duplicated patent applications arise if a patent is filed in several countries. For every country a separate patent application has to be submitted at the country's patent office. For the patent examination the priority date of the original filing will be used. If adjustments on the patent application are required new documents are included as well.

[5] A similar search was undertaken for the chemical abstracts listed as NPL citations. Chemical Abstracts (CA) show summarized information about all kinds of chemical publications. They are built on a major information source in chemistry about chemical procedures and substances. 359 of the NPL listed are chemical abstracts. In many cases only the abstract identification number is cited. The SciFinder database was used to gain the information of the originating document. CA can refer to any kind of literature. Mostly scientific articles are cited, but also patent information is summarized. In many cases Japanese patents are found to be the disclosing source of the CA (this corresponds to the findings of Grupp and Schmoch (1992).

knowledge created in different times. This makes it almost impossible to calculate the correct citation lag for them. Because of these difficulties all 115 citations made to encyclopedias were excluded. Company bulletins include direct publications of the companies as well as specific journals for defensive publishing.[6] All other documents such as PhD theses, reports of industrial and scientific associations, standards and internet sources were summarized in the category “others”. In any case of doubt a web based research was undertaken. All NPL was manually checked after the categorization procedure.

The NPL was also categorized according to the affiliation of the authors. Because many publications have several authors that are affiliated to different organizations, NPL can be associated with multiple affiliations. If an author was affiliated to several institutions, all of them were taken into account. Three types of organizations were distinguished: universities, non-university research organizations (private and public), and companies. Some affiliations could not be identified unambiguously and were categorized as “no affiliation”. In addition, it proved impossible to clearly distinguish between private and public research organizations. The location of the affiliations is assumed to be the place where the knowledge was created. In most cases the country information was directly taken from the original document. If no further information was available the headquarter country for companies and research institutes was used. All information was manually checked after the processing. In addition to Dutch NPL, we also identify NPL from the neighboring countries, Germany and Belgium. Because Shell and Unilever are partly located in the UK, another dummy for the UK is implemented.

For a few NPL not all required information for the analysis could be retrieved. Because of the central importance of timing for this study, all citation pairs had to be excluded for which either no date of the NPL publication or no date of the patent filing was available. This reduced the dataset by another 88 pairs.

The final sample contains 828 patents with 2,344 NPL citations. On average each patent contains 2.83 NPL citations. This is higher than the average number of 2.25 citations found by Callaert et al. (2006) for European patents, possibly reflecting the variety of patent offices in our dataset as well as industry differences (Callaert et al. (2006) find that with an average of 2.68 citations, chemistry patents have the highest number of citations among all examined disciplines.)

Descriptive statistics of the main variables are presented in Table 1. A total of 181 NPL (7.72%) are Dutch affiliated. U.S. NPL is dominant with 38.31% of all citations. Universities account for over 50% of the NPL while companies appear as author affiliations on almost 30% of the NPL. This shows that companies contribute a significant share of all scientific publications relevant to (patented) commercial applications. Separated by country and institutional type Dutch affiliated NPL are more often company affiliated than foreign citations. The ratio of Dutch company publications to Dutch university publications (0.76) is substantially higher than that for foreign publications (0.45). With over 75% journal publications are the most prominent type of outlet. For the mean citation lag, strong variation can be observed between the different NPL categories. The average citation lag of Dutch affiliated NPL is with 5.54 far below the average citation lag. In contrast, more distant locations such as the USA show above average citation lags. This seems to confirm our expectations. In general citation lags of university affiliated citations are slightly below, and company affiliated citations are slightly above, the overall average. Separated by Dutch and non-Dutch institutions Dutch universities are found to have a very low average citation lag of 3.82 years.

[6] To some extent these journals serve similar purposes for companies as patents do. Companies publish their invention to prevent competitors from entering the market. They signal that they are already active in this field and prevent competitors from filing patents on the same technology (Grupp and Schmoch 1992).

Some NPL citations date far back in time, reaching a maximum lag of 105 years. Dutch NPL is more recent with a maximum lag of 37 years.

	number of NPL	share of NPL	mean citaion lag	median citation lag	stdev of citation lag	min citation lag	max citation lag	mean patent application year	mean NPL publication year
full sample	2344	100.00%	11.40	7	12.36	0	105	1995	1984
affiliation_nl	181	7.72%	5.54	3	7.45	0	37	1996	1991
affiliation_bel	17	0.73%	6.59	3	8.83	0	29	1999	1993
affiliation_ger	312	13.31%	12.46	7	14.39	0	105	1995	1982
affiliation_uk	193	8.23%	13.56	6	16.02	0	96	1995	1982
affiliation_usa	898	38.31%	12.37	8	12.68	0	91	1995	1983
affiliation_uni	1263	53.88%	10.28	6	11.80	0	105	1997	1986
affiliation_comp	652	27.82%	11.65	7	12.96	0	96	1995	1984
affiliation_inst	275	11.73%	9.52	7	8.87	0	43	1996	1986
affiliation_nluni	106	4.52%	3.82	3	5.00	0	37	1995	1992
affiliation_nlcomp	81	3.46%	7.42	4	9.29	0	35	1998	1991
affiliation_uninotnl	1157	49.36%	10.87	6	12.07	0	105	1997	1986
affiliation_compnotnl	520	22.18%	12.72	8	13.63	0	96	1995	1983
no_affil	439	18.73%	14.19	11	13.22	0	91	1993	1979
journal	1776	75.77%	11.57	7	12.83	0	105	1996	1984
handbook	220	9.39%	14.60	12	12.98	0	91	1992	1977
sympos	122	5.20%	7.48	6	4.88	0	27	1997	1990
comp_bull	93	3.97%	8.14	6	8.02	0	35	1993	1985
others	133	5.67%	9.68	7	10.39	0	58	1994	1984

Table 1: Descriptive statistics of NPL subgroups

The development of NPL citations over time is presented in Figure 1. Annual numbers of patent publications with NPL citations are shown as the black line. NPL has been cited since 1968, whereas the first patent application in the sample dates back to the 1920s. The number of applications citing NPL increases during the 1980s and reaches a peak at the end of the 1990s. After 2006 the data are not interpretable anymore, as patent applications are published only 18 months after filing. The dotted line describes when the cited NPL was published. The first cited NPL dates back to the beginning of the twentieth century. The general trend of NPL publications seems to follow the trend of the citing patents with a time lag. Dutch NPL appears first in 1962 and becomes more widespread in the mid 1970s, when the number of patents citing NPL rise.

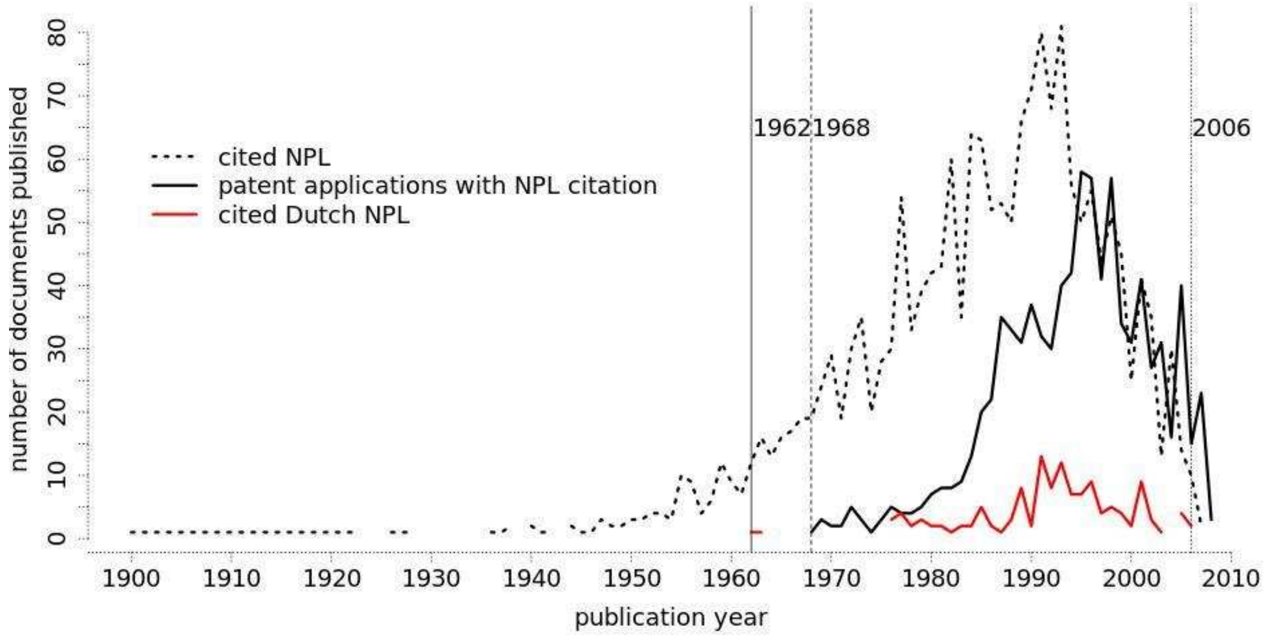

Figure 1: Number of publications (patent and NPL) per year

Since we are interested in the time lags of NPL citations, the distribution of the citation lags is presented in Figure 2.[7] The maximum citation lag is 105 years. The use of priority dates also leads to a total of 49 NPL citations with negative citation lags. Negative lags emerge for different reasons. Beside some wrong entries that could not be detected it is possible that the cited literature was already publicly available when the patent application was filed (e.g., in form of a working paper) but the official publication was launched afterwards. In addition, some citations are listed in patents even though they were published after the priority date. Citation can be included if they are seen as important for the understanding of the technology that is claimed to be protected. Such citations do not affect the newness of the invention (Akers 2000). We correct the negative lags to zero because we assume the cited work was existent but unpublished (or published as working paper) when the patent application was submitted. The solid line in figure 2 visualizes the impact of the correction of the negative lags. Only five NPL with a negative lag above four years were found. Because no plausible explanation for these observations could be found, they were interpreted to be wrongly included citations and consequently deleted from the dataset.

The lag distribution of all NPL is consistent with the conjecture developed by Jaffe and Trajtenberg (1996) that published knowledge becomes better known over time. In addition, older knowledge is also more likely to be obsolete and thus to be cited less often. However, the Dutch NPL shows a different distribution. Besides the shorter tail the high percentage of zero-lag citations is striking. These citations are included in the same year in which the patent application was filed. While this finding is consistent with our first hypothesis – Dutch affiliated NPL are cited faster than foreign NPL – it may also be due to mechanisms other than unmediated knowledge spillovers.

[7] Using the priority date of the patent family causes a slightly different distribution of the citation lag than the calculation on the basis of the patent documents date would provide. The cited literature is shifted closer to the application dates of the citing patents.

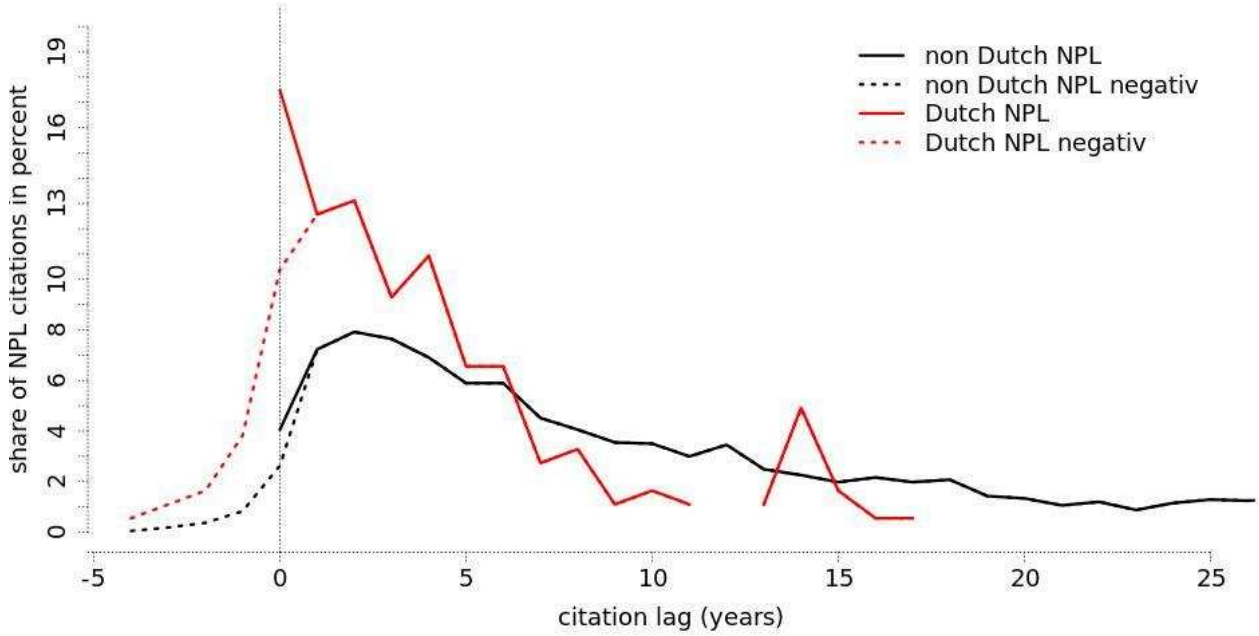

Figure 2: Distribution of the citation lags

5. Econometric analysis

We use the patent-NPL citation pairs identified in the PATSTAT data and employ hazard models to estimate whether Dutch NPL is cited systematically faster by Dutch polymer patents than NPL originating from other countries. Since citation lags as the outcome of interest are available only in annual intervals, we estimate complementary log-logistic hazard models, which are in widespread use as discrete-time hazard models (Jenkins, 1995). These are specific with a logarithmic link function. Because some patents refer to several NPL citations we calculate significance levels based on clustered standard errors in order to take heteroscedasticity into account.

Beside the variables described above we include several control variables in the analysis. First, the number of other NPL and other (patent) citations was calculated for each patent. Many patents include more than one citation. The number of NPL cited in a patent might serve as an indicator for the relatedness to science of the patented technology (Branstetter 2005). In addition, Tijssen (2002) reports that patents with many references have more claims and therefore more technical applications. They are more complex, consequently more literature needs to be included to define the state of the art. The number of patent citations might also reflect the complexity of the patented technology. More complex and scientific technologies tend to go in line with more recent scientific findings.

Second, the dataset includes many patent families that contain an EPO application. In comparison with single national applications the European patent application is more expensive (in terms of direct and indirect i.e. lawyer costs). Applicants might file only those applications at the EPO that are of a higher expected value or have a higher probability to be granted. Besides this potential bias for European patents local examiners might cite more local literature (Collins and Wyatt 1988). As noted above, inventors have been found to cite scientific literature from their home country more often than expected (Narin et al. 1997). This might be a result of a better and deeper knowledge of the local scientific environment. If examiners have better knowledge about the existing local literature they might also cite more recent literature than their colleges at foreign patent offices do. To control for such biases, variables indicating NPL citations originating from the EPO and the Dutch patent office, respectively, are included in the model.

Third, the dataset includes all polymer patents filed by the major Dutch companies active in polymer production, by Dutch universities and by the TNO. University and TNO patents might systematically cite more recent scientific literature. The main objective of universities and TNO is to do publishable research and not to file patents. Particularly for universities, patents have traditionally been seen as byproducts of research than the primary activity of the institution. We therefore expect their inventions to be more closely related to recent scientific findings.

Finally, Van Vianen et al. (1990) point to differences in the age distribution of patent citations in different technological fields. Polymers can be used in many different technological fields. Even if the dataset is restricted to polymer patents there might be differences between the chemical subfields where polymers are used. Therefore control variables for the sub-disciplines in chemistry are introduced. The technology classes (IPC) of the patents are classified into industrial fields as suggested by Schmoch (2008). The following nine dummies are included. (Numbers in parentheses show how often the class is represented in the dataset. A given patent can be the member of different subgroups): organic fine chemistry (840), biotechnology (91), pharmaceuticals (76), food chemistry (14), basic materials chemistry (671), materials, metallurgy (198), surface technology, coating (143), micro-structural and nano-technology (2), chemical engineering (205) and environmental technology (6).

Regression results are presented in Table 2. In the first model we find a significantly positive coefficient for the variable denoting Dutch NPL. In the searches for related literature to a patent's technology, Dutch affiliated NPL face a higher risk to be cited. This suggests that Dutch affiliated NPL is more likely to get cited earlier and therefore is closer related to the patented technology. This result supports our first hypothesis.

Compared to company-affiliated NPL, NPL by authors affiliated to universities is cited more rapidly. In models 2 and 4 we separate between university and company NPL in combination with Dutch and non-Dutch affiliation. A significantly positive coefficient is estimated for NPL affiliated to Dutch universities, indicating a higher hazard (compared to institute-affiliated NPL, the omitted control group). For Dutch companies a positive coefficient is obtained as well. However, the coefficient is found to be smaller. If an NPL is affiliated to a non-Dutch company it faces a significantly lower hazard to be cited in comparison with research institute affiliated NPL.

In order to treat all citations equally we adjust our dataset further. Since Dutch publications have been relevant only since the 1960s we limit all observed NPL citations to those published after 1960 (see Figure 1). While we have no real explanation why relevant Dutch publications are not cited before 1960 we decide to give both groups (NL and non-NL affiliated) the same chance to be cited independently of the reason why Dutch literature was not cited. We further exclude all university and TNO patents because they might also have a different kind of citation behavior. (In the first two models universities were found to cite NPL earlier than companies. Table 3 also indicates a stronger dependence on very recent publications of university patent applications.)

Results for the adjusted dataset are presented in models 3 and 4. Even though the coefficient of Dutch affiliated NPL is reduced, it is still positive and significant at the one percent level. University affiliated NPL are found with systematic lower citations lags as estimated in model 1. However, the effects of Dutch company publications and non-Dutch university publications are no longer significant. Only the coefficient of Dutch university NPL is positive and significant as in model 2.[8]

	full sample		excluding NPL published 1960 and later as well as university and TNO patents	
	model 1	model 2	model 3	model 4
(Intercept)	30.1903 **	26.2681 **	29.8954 **	25.7141 *
	(9.5613)	*(9.2687)*	*(10.8406)*	*(10.5631)*
log(base_hazard)	0.1581 **	0.1441 **	0.2885 **	0.2791 **
	(0.0307)	*(0.0309)*	*(0.036)*	*(0.0356)*
affiliation_nl	0.5423 **		0.3070 **	
	(0.0964)		*(0.1187)*	
affiliation_nluni		0.8196 **		0.6514 **
		(0.151)		*(0.2134)*
affiliation_nlcomp		0.2963 *		0.1769
		(0.1343)		*(0.1541)*
affiliation_uninotnl		0.0885		0.1108
		(0.069)		*(0.0707)*
affiliation_compnotnl		-0.2049 **		-0.0928
		(0.0678)		*(0.0726)*
affiliation_bel	0.0983		-0.1441	
	(0.2836)		*(0.4623)*	
affiliation_ger	-0.1313		-0.0937	
	(0.075)		*(0.0742)*	
affiliation_uk	-0.1989 *		-0.1311	
	(0.0916)		*(0.1065)*	
affiliation_usa	-0.2570 **		-0.2265 **	
	(0.0487)		*(0.0524)*	
affiliation_uni	0.2696 **		0.2032 **	
	(0.0578)		*(0.0625)*	
affiliation_inst	0.1950 **		0.0646	
	(0.0663)		*(0.0708)*	
handbook	-0.2589 **	-0.3248 **	-0.3155 **	-0.3744 **
	(0.071)	*(0.072)*	*(0.0688)*	*(0.0676)*
sympos	0.5430 **	0.5221 **	0.3741 **	0.3408 **
	(0.1009)	*(0.1038)*	*(0.1033)*	*(0.1058)*
comp_bull	0.4451 **	0.3285 *	0.2465	0.1924
	(0.1479)	*(0.1502)*	*(0.1636)*	*(0.1667)*
no_affil	-0.2330 **	-0.3393 **	-0.2359 **	-0.2404 **
	(0.0663)	*(0.0792)*	*(0.0674)*	*(0.0832)*
chem_abs	-0.2568 **	-0.2129 **	-0.2693 *	-0.2285 *
	(0.0789)	*(0.0776)*	*(0.1049)*	*(0.1013)*
others	0.1756	0.1355	0.1727	0.1376
	(0.1019)	*(0.1026)*	*(0.1104)*	*(0.1107)*
nr_cit	-0.0010	-0.0014	-0.0009	-0.0018
	(0.0025)	*(0.0025)*	*(0.0029)*	*(0.0029)*
nr_npl	-0.0055	-0.0058 *	-0.0011	-0.0006
	(0.0029)	*(0.0028)*	*(0.0037)*	*(0.0037)*
pat_year	-0.0165 **	-0.0144 **	-0.0164 **	-0.0143 **
	(0.0048)	*(0.0047)*	*(0.0054)*	*(0.0053)*
nl	-0.1141	-0.1468 *	-0.0076	-0.0490
	(0.0766)	*(0.0746)*	*(0.0906)*	*(0.0891)*
ep	0.0730	0.0645	0.0810	0.0683
	(0.0582)	*(0.0584)*	*(0.0635)*	*(0.0646)*
tno	0.2268	0.2034		
	(0.1592)	*(0.1604)*		
uni	0.4926 **	0.4960 **		
	(0.1243)	*(0.1196)*		
tech_dummy	TRUE	TRUE	TRUE	TRUE
n	2344	2344	2006	2006
logLik	-7936.3152	-7950.9723	-6560.6582	-6568.1607
Chisq	0.0000	0.0000	0.0000	0.0000

*: $p < 0.05$ regression coefficient (standard errors in brackets)
**: $p < 0.01$

Table 2: Estimation of the citation lag

[8] The major changes between the models 2 and 4 are caused by excluding such NPL published before 1960. Using two distinct datasets (one only excluding NPL published before 1960 and one excluding only TNO and university patents) revealed publications made before 1960 caused the changes in significance by reducing the estimated coefficients. This was already suggested in table 1 where the max citation lag for non-NL companies and universities is reaching substantially higher.

In section 2 above, we argued that shorter citation lags of Dutch NPL need not be caused by localized spillovers, particularly if co-located citations tend to occur very soon after the patent is filed. We suggested self-citations at the institutional and individual level as a possible factor explaining shorter citation lags. To probe into these possibilities, we took a closer look at the Dutch-affiliated NPL citations in our dataset. We searched for NPL authors having the same affiliation as the citing patent and identified self-citations (at least one inventor is also listed among the authors of the NPL). To this purpose, family names of inventors and authors were matched by patent. Inventor names were first cleaned. Where positive matches were found, a manual check for false positive matches was made by comparing initials. As most names in the dataset are Dutch and frequently contain several initials, this method allowed for reliable identification of individuals. Affiliations of the authors of Dutch NPL were manually standardized and matched with patent applicant names. For non-university affiliations that were not in the list of applicants we checked whether the affiliation is a branch or subsidy of one of the patent applicants in the dataset.

129 Dutch NPL are cited by the companies in our sample. For 52 one of the authors' affiliations is similar to the patent applicant. For 23 NPL at least one author is listed as inventor on the patent. The overlap of the two sets is 16 NPL, which share the affiliation and one author. These numbers indicate that more than half of the citations made to Dutch affiliated NPL are either affiliated to the patenting company or have at least one inventor and author in common. Remarkable is the high number of university affiliations found for NPL patent pairs with one common author. Altogether 18 of the 23 NPL have at least one author listed who is affiliated to a university. This is especially true for citations with low citation lags. The same is found for university patents. 54 NPL citations are made by Dutch universities. Eight NPL citations are affiliated to the patenting university. 15 of them share at least one author and 13 have another university as affiliation listed as affiliation.

The large share of local collaboration events seems to confirm our second hypothesis. Hypothesis 2 suggests that self-citations may be (partially) responsible for the shorter time lags of co-localized NPL citations. To test this hypothesis we re-estimate various variants of the earlier models with one or both types of self-citations excluded from the dataset. In this way we hope to estimate only "real" local spillover effects, since all internal knowledge sources (same inventor and/or author and same affiliation) are excluded. The results of the estimations are presented in Table 2.

As proposed in the second hypothesis, the coefficient of Dutch affiliated NPL is no longer significant. This holds for all three tested variants of the dataset. What appeared to be the result of localized knowledge spillovers in the earlier models is thus found to depend strongly on citations that are closely related to the patenting company. The larger number of early citations is due to very small lags corresponding with collaborative publications and publications of same institution. In the separated model no significant influence is found for Dutch universities as well.

However, we still find significant coefficients in models eight and ten that exclude only one of the types of self-citations. This suggests that not controlling for all internal knowledge sources leads to faulty conclusions about the existence of local knowledge spillovers. It is moreover conceivable that even where no relations are observable, closely related publications may be due to previous collaboration. Earlier collaborative work might be related to following inventions made, but do not list authors as inventors anymore.

	excluding self citations (same author and same affiliation)		excluding self citations (same author)		excluding self citations (same affiliation)	
	model 5	model 6	model 7	model 8	model 9	model 10
(Intercept)	31.9232 **	29.1697 **	32.7522 **	28.7164 **	30.7105 **	28.1532 **
	(11.0085)	*(10.7589)*	*(10.9508)*	*(10.6951)*	*(10.8461)*	*(10.5677)*
log(base_hazard)	0.3105 **	0.3013 **	0.3084 **	0.2983 **	0.3040 **	0.2953 **
	(0.0361)	*(0.0357)*	*(0.0362)*	*(0.0357)*	*(0.0355)*	*(0.0352)*
affiliation_nl	0.1454		0.1649		0.1990	
	(0.1426)		*(0.1164)*		*(0.144)*	
affiliation_nluni		0.4040		0.4962 *		0.4834 *
		(0.2362)		*(0.2196)*		*(0.2302)*
affiliation_nlcomp		-0.2601		-0.0226		-0.2232
		(0.2239)		*(0.1505)*		*(0.2247)*
affiliation_uninotnl		0.0995		0.1061		0.0997
		(0.0727)		*(0.0707)*		*(0.0723)*
affiliation_compnotnl		-0.1121		-0.1060		-0.1102
		(0.0739)		*(0.0729)*		*(0.0737)*
affiliation_bel	-0.2414		-0.1364		-0.2511	
	(0.4757)		*(0.4687)*		*(0.4748)*	
affiliation_ger	-0.0785		-0.0747		-0.0874	
	(0.0761)		*(0.0757)*		*(0.0756)*	
affiliation_uk	-0.1495		-0.1610		-0.1292	
	(0.104)		*(0.1036)*		*(0.1021)*	
affiliation_usa	-0.2241 **		-0.2251 **		-0.2231 **	
	(0.0536)		*(0.053)*		*(0.0532)*	
affiliation_uni	0.1871 **		0.2042 **		0.1868 **	
	(0.0635)		*(0.0627)*			
affiliation_inst	0.0634		0.0700		0.0605	
	(0.0719)		*(0.072)*		*(0.0714)*	
handbook	-0.3241 **	-0.3877 **	-0.3133 **	-0.3706 **	-0.3290 **	-0.3937 **
	(0.0708)	*(0.069)*	*(0.0695)*	*(0.0684)*	*(0.0706)*	*(0.0686)*
sympos	0.3842 **	0.3470 **	0.3784 **	0.3449 **	0.3870 **	0.3503 **
	(0.1077)	*(0.11)*	*(0.105)*	*(0.1073)*	*(0.1065)*	*(0.109)*
comp_bull	0.2352	0.1816	0.2482	0.1869	0.2335	0.1827
	(0.1644)	*(0.1687)*	*(0.1653)*	*(0.1684)*	*(0.1633)*	*(0.1676)*
no_affil	-0.2458 **	-0.2585 **	-0.2327 **	-0.2513 **	-0.2516 **	-0.2618 **
	(0.0666)	*(0.0836)*	*(0.0672)*	*(0.0831)*	*(0.0666)*	*(0.0834)*
chem_abs	-0.2844 *	-0.2507 *	-0.2757 **	-0.2385 *	-0.2772 *	-0.2437 *
	(0.111)	*(0.1064)*	*(0.1065)*	*(0.1021)*	*(0.1108)*	*(0.1066)*
others	0.1679	0.1399	0.1690	0.1377	0.1703	0.1421
	(0.1141)	*(0.1149)*	*(0.112)*	*(0.1126)*	*(0.1134)*	*(0.1141)*
nr_cit	-0.0006	-0.0013	-0.0006	-0.0014	-0.0009	-0.0015
	(0.0031)	*(0.0031)*	*(0.003)*	*(0.003)*	*(0.003)*	*(0.0031)*
nr_npl	-0.0003	0.0002	-0.0003	0.0002	-0.0005	-0.0001
	(0.0038)	*(0.0037)*	*(0.0037)*	*(0.0037)*	*(0.0038)*	*(0.0038)*
pat_year	-0.0174 **	-0.0160 **	-0.0178 **	-0.0158 **	-0.0168 **	-0.0155 **
	(0.0055)	*(0.0054)*	*(0.0055)*	*(0.0054)*	*(0.0054)*	*(0.0053)*
nl	-0.0308	-0.0500	-0.0112	-0.0452	-0.0428	-0.0594
	(0.0915)	*(0.0903)*	*(0.0905)*	*(0.0893)*	*(0.0912)*	*(0.0897)*
ep	0.0943	0.0889	0.0832	0.0743	0.0914	0.0866
	(0.065)	*(0.0664)*	*(0.0643)*	*(0.0656)*	*(0.0647)*	*(0.0659)*
tno						
uni						
tech_dummy	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
n	1920	1920	1956	1956	1954	1954
logLik	-6314.9959	-6322.6838	-6424.9268	-6433.4749	-6408.7153	-6416.0781
Chisq	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

*: p < 0.05 regression coefficient (standard errors in brackets)
**: p < 0.01

Table 3: Estimation of the citation lag (reduced sample)

As regards differences between kinds of publication outlets, no significant effect is found for company bulletins. This is rather unexpected since company bulletins function as a kind of faster equivalent to patents (defensive publication to protect against patenting by competitors). Handbooks are less likely to be cited with increasing time than journal publications. This is not surprising because handbooks contain general knowledge that sets the standard for longer time periods. More interesting is the positive effect of symposia. They seem to be an important publication medium in polymer science. The knowledge published in those symposia is not only related to the patented technology it is also quite recent. This is especially striking since only 6 of the 122 symposia are Dutch affiliated. Publications related to conferences and symposia seem to outweigh the local disadvantage.

The cited literature in the sample is not only very close to technology in terms of knowledge. Also for location and time a close relatedness is found. One might therefore suspect that the cited literature is sufficiently close to compromise the patentability of the technology. This would speak more in favor of an unintended effect than for an intended output of successful knowledge exploitation. To test this conjecture, we estimated whether patent grant rates are affected by the presence contemporary local NPL citations. Using only citations with a lag of zero and one year no evidence supportive of this conjecture could be found.

6. Conclusion - Is there still some knowledge in the air?

Summarizing the results obtained above we observed that NPL with Dutch affiliation are more likely to be cited early than geographically distant NPL. While this might be interpreted as evidence of localized knowledge spillovers, the lag distribution of locally published NPL indicates that different mechanisms give rise to the local lag bias. We found that a large share of localized NPL citations has a lag of zero, which is indicative of simultaneous production of scientific and technological knowledge within a region. A closer look into the local NPL citations revealed that collaborative research projects are indeed a major factor helping explain the above results. Inventors and authors of recent NPL citations often share the same affiliation. This is more likely to reflect the efficient use of in-house knowledge production than the presence of knowledge spillovers.

NPL citations to work authored by inventors are a complementary explanation for shorter local citation lags. Here collaborative production of knowledge by different organizations (public and private) seems to be an important factor. But not only is collaboration important for industry, researchers are also active themselves. Authors affiliated to the patenting company are often found on the cited NPL. These NPL are mostly scientific publications. Being present in the scientific community is not only necessary to understand recent publications, it is also important to "[...] barter for information about research in other institutions", as reported by Smith and Hounshell (1985: 436) for the case of DuPont. This underlines that new knowledge is treated as a commodity between researchers.

So do these findings suggest that Marshall was wrong when he stated that knowledge diffuses "as it were in the air"? To become clear on this point we revisit the paragraph that includes the famous expression:

> "When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from near neighbourhood to one another. The mysteries of the trade become no mysteries; but are as it were in the air, and children learn many of them unconsciously. Good work is rightly appreciated, inventions and improvements in machinery, in processes and the general organization of the business have their merits promptly discussed: if one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas." (Marshall 1920: 322).

Two important aspects of Marshall's statement should be pointed out here: first, Marshall assumes a preexisting concentration of locally specialized knowledge. He argues that this concentration brings many advantages for the local industry and guarantees that it will be concentrated over time. Second, he suggests that knowledge sharing between people who have a deep understanding of the subject is fruitful.

Specialized knowledge is learned from the experts in the field. New ideas are shared and enhanced within the community. Marshall never claimed that all this is for free. The local concentration persists because it supports the emergence of new and better ideas. The localization advantage remains even if the new knowledge is mediated, but not as spillovers. Collaborations between industry and science are found to be mediated by researchers (scientific and industrial researchers). These researchers are not only contributing with scientific publications to the inventions made. They seem to be active in industrial research as well since they are mentioned as inventors on the patents. “Thus, scientists may have been more important to technological change than science itself.” (Mokyr 1990: 73).

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