

# The Paper Trail of Knowledge Transfers

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hy do firms and inventors tend to locate in dense, costly areas? One intriguing hypothesis is that such geographic clustering lets them benefit from local knowledge spillovers. As Nobel laureate Robert Lucas has noted, the benefits of one person's knowledge spilling over to others play a central role in economic growth and the existence of cities: "What can people be paying Manhattan or downtown Chicago rents for, if not for being near other people?" Proximity may improve the sharing of knowledge, the matching of ideas to firms, or the rate of learning.<sup>1</sup> If dense clustering indeed confers these benefits, then that raises the possibility that individuals and firms may not be fully taking them into account when deciding where to locate, resulting in underinvestment in new ideas.

A key counterargument to the importance of knowledge spillovers is that firms might prefer to keep their work secret from competitors. For example, many firms include nondisclosure and noncompete clauses in employment contracts for researchers and scientists. Yet, as Alfred Marshall suggested, knowledge is difficult to keep secret: "The mysteries of the trade become no mysteries; but are as it were in the air."

So are, in fact, knowledge spillovers an important reason why inventors tend to locate near one another? We know that other factors might also encourage firms and inventors to locate near one another. For example,

<sup>1</sup> Gerald A. Carlino's 2001 *Business Review* article discusses such mechanisms.

firms might benefit from better matches with specialized workers.<sup>2</sup> They may benefit from the sharing of local production inputs such as cheap electrical power or hard-to-find machinery and parts. Or skilled inventors may be attracted to superior amenities such as restaurants, shopping, or safety.

A key challenge, then, is to account for these alternative explanations so that we do not erroneously infer that knowledge spillovers are empirically important. To explore this challenge, I review the empirical literature regarding evidence of knowledge spillovers contained in patent citations and nonpatent data. I then describe the evidence that Ina

<sup>2</sup> See my 2009 *Business Review* article.

Ganguli, Nick Reynolds, and I found using a novel measure — cases of simultaneous invention that result in rival claims known as patent interferences. First, let us look at what researchers have found by studying routine patent applications.

## EVIDENCE FROM PATENT CITATIONS

At its most basic, the challenge of verifying the existence of knowledge spillovers was observed by Paul Krugman — namely, that knowledge flows are invisible: "They leave no paper trail by which they may be measured or tracked." Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson tackled this problem by observing that the flow of knowledge from one inventor to another could, in fact, be tracked using patent citations.<sup>3</sup> Their paper and ones that followed have provided the best evidence to date that local knowledge spillovers might be one important mechanism contributing to the geographic proximity of inventors.<sup>4</sup> They exploit the fact that patents include citations to older patents. If a new patent cites a previous patent, this citation is evidence that the older patent contains knowledge upon which the new patent relies.

Though a citation to a nearby inventor is at first glance evidence that knowledge has passed from the earlier inventor to the citing inventor, it does

<sup>3</sup> Robert M. Hunt's 2001 *Business Review* article discusses patents as a measure of knowledge production.

<sup>4</sup> See also the work by Jaffe (1986) and Keller (2002), and the surveys by Rosenthal and Strange (2004) and Audretsch and Feldman (2004).



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not necessarily indicate that geographic proximity has facilitated this transfer of knowledge. It might simply be the case that inventors are located nearby for some other reasons besides the opportunity to take advantage of knowledge spillovers, such as to be near some common physical input to the invention process. For example, if a patent awarded to researchers at a University of Pennsylvania hospital is cited in a subsequent application for a patent awarded to researchers at Temple University, that might be because of local knowledge spillovers. But it could also be the case that these patentees are near each other simply because many hospitals are needed to serve the large population of the Philadelphia area, and proximity offers no advantage in transmitting knowledge.

**Expected proximity.** To address this inference problem, Jaffe and his coauthors develop a clever matching strategy. They measure the distance between an earlier “originating” patent and a subsequent “citing” patent that references the originating patent as an important knowledge input. Then they compare this distance to the distance between the originating patent and a matched “control” patent. The control patent is similar to the matched citing patent in terms of the date of invention and technological classification, but it does not cite the matched originating patent. Thus, the control patent represents the expected proximity of inventors working in the same research field and time period, not conditioned on a citation link. If the inventors of the citation-linked patent pair are observed in closer proximity versus this benchmark, then this is strong evidence that a local knowledge spillover has occurred, especially since we have accounted for the underlying geographic distribution of research activity and hence other reasons why inventors might be located together. In fact, Jaffe and his coauthors find that

originating patentees are much more likely to be from the same metropolitan area as citing patentees, compared with a matched control patentee.

Despite this clever study design, subsequent researchers have identified several limitations of this analysis. First, there are the standard drawbacks to using patent data: Not all inventions are patented, and some patents do not represent valuable or worthwhile inventions. More recent papers have tried to correct these problems by, for example, measuring the quality of patents based on patent renewals or subsequent citations. Second, many patent citations are actually added by patent examiners, not inventors. Thus, citations may not actually represent true knowledge flows for inventors, but rather noise introduced by the patent office.<sup>5</sup> Third, Peter Thompson and Melanie Fox-Kean note that Jaffe’s results are sensitive to the selection of an appropriate control patent. By varying how broadly the technology classifications and dates of application are specified for the sample of matched control patents, Thompson and Fox-Kean found that imperfect matching explained a significant part of Jaffe’s original result.

A final issue, which Jaffe and his coauthors acknowledged in their original paper, is that many knowledge inputs are not actually reflected in citations. This is significant because we might expect that geographic proximity is especially important for the transfer of tacit, operational knowledge — that is, knowledge that is not necessarily codified in a written patent application. This is the kind of knowledge transmitted in hallways and over coffee, rather than through literature searches of previous work. Because many more knowledge spillovers may

occur than are reflected in citations, Jaffe and his coauthors suggest that their findings may actually represent a lower bound for the occurrence of knowledge spillovers among inventors.

## EVIDENCE FROM RESEARCH AND NONPATENT DATA

Other papers have sidestepped patents altogether.<sup>6</sup> Bruce Weinberg found that physicists who moved to cities where Nobel laureates were already working were more likely to begin their own Nobel Prize-winning work there. Gerald A. Carlino, Jake K. Carr, Robert M. Hunt, and Tony E. Smith have shown that research and development labs are highly geographically concentrated, substantially more so than the corresponding industry concentration patterns. In my previous work, I showed that new activities related to the implementation of new knowledge are concentrated in metropolitan areas with highly educated populations. Finally, Petra Moser has shown localization among prize-winning inventors at World’s Fairs in the 19<sup>th</sup> century, although these patterns weakened over time.

Of course, as with inventors, scientists may locate near each other for reasons besides knowledge spillovers. Thus, we cannot be certain whether an increase in their productivity might stem from knowledge spillovers from nearby scientists or from some other reason. Fabian Waldinger investigated local knowledge spillovers among scientists in Germany. Waldinger relies on evidence from the expulsion of Jewish and certain other scientists from Germany under the Nazis. Some university departments experienced many expulsions, while other departments had not employed Jewish scholars and were therefore unaffected. If knowledge

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<sup>5</sup> See the papers by Juan Alcácer and Michelle Gittelman and by Peter Thompson (2006).

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<sup>6</sup> See the survey article by David Audretsch and Maryann Feldman.

spillovers are important, one might expect the productivity of the remaining scientists in the affected departments to decline following the expulsion of their Jewish colleagues. Waldinger finds that the publishing activity of the scientists whose departments suffered losses did not decline compared with that of other scientists. Thus, he concludes that there is no evidence for local knowledge spillovers among German scientists in this period.

## EVIDENCE FROM PATENT INTERFERENCES

In my work with Ina Ganguli and Nick Reynolds, I have been using patent interferences to try to provide new evidence on the relevance of local knowledge spillovers for invention. Patent interferences are especially valuable for measuring local spillovers of tacit or uncodified knowledge that is missing in traditional patent studies.

Patent interferences are a unique historical feature of the U.S. patent system. Until 2011, the United States had a “first to invent” rule for assigning priority of invention, versus the “first to file” rule more common in the rest of the world.<sup>7</sup> When the U.S. patent office received applications from multiple parties with identical claims at roughly the same time, it was obligated to investigate the competing claims to determine which party was entitled to patent protection. This investigation, known as a patent interference proceeding, determined who had conceived of the invention and reduced it to practice first. Typically, the parties submitted dated laboratory notebooks, testimony by associates, and media reports as evidence of first invention.

There are many famous examples

<sup>7</sup> More details about the patent interference proceedings can be found in Calvert and Sofocleous (1982), Cohen and Ishii (2006), de Simone et al. (1963), and Kingston (2004).

of patent interferences in U.S. history, including Alexander Graham Bell’s and Elisha Gray’s simultaneous invention of the telephone. Because Bell’s and Gray’s applications arrived at the patent office on the same day and contained nearly identical claims, an interference proceeding was declared. Eventually, Bell was determined to have conceived of the idea and reduced it to practice first, and he was awarded the patent.

**Knowledge in common.** Importantly for economists, patent interferences create a record of instances when the same invention is created by inventors working independently, a phenomenon that is highly suggestive

interference is evidence of a knowledge spillover among the inventors.

Several details about the interference process support the argument that these proceedings are a good measure of common, independent knowledge inputs. First, interferences were declared by a patent examiner specializing in a particular technological area. Thus, interfering claims were likely to be detected. (In some cases, the examiner was alerted to a possible interference by one of the applicants. Note that an interference is different from patent infringement, in which the holder of an existing patent sues an infringing party. Private parties cannot sue for an interference.)

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of common knowledge inputs. In other words, inventors involved in an interference are likely to have command of similar knowledge. For example, interfering inventors may have similar backgrounds in chemistry, or they may have similar knowledge of market conditions. This is especially true if certain inventions require highly specific knowledge. For example, for Bell and Gray to have both invented the telephone contemporaneously, they must have had similar knowledge about electrical conductivity and the properties of various conductive metals, as well as similar expectations about market demand for a device that transmitted voices in real time. For Jon Merz and Michelle Henry, a patent interference is an indication that “discovery has become ordinary.” That is, its occurrence suggests that certain knowledge is shared among several inventors. In other words, a patent

Second, interferences involved parties with roughly the same date of patent application. An inventor who delayed filing an application in order to conceal an invention would lose the priority contest. Thus, interferences are less likely to reflect secrecy or other legal strategies of the participants and are more likely to reflect genuinely independent, simultaneous inventions versus infringements or patent “racing” by inventors who believed that rival applications were imminent.

Third, during the interference proceedings, circumstances that suggested stealing, espionage, or collaborative invention typically led to dismissal with prejudice. In other words, worker poaching and espionage that is independent of shared knowledge are unlikely explanations for the bulk of cases of patent applications interfering with each other. Note that recruiting other firms’ researchers or spying

on them does seem to involve shared knowledge inputs — a shared desire to solve a common problem, for example. In addition, patent judges had been compelled by statute to rule against applicants found to have stolen a competitor’s idea, deterring would-be spies from pursuing an interference. In fact, in our examination of case decisions, no more than a small handful of judgments mention espionage as a relevant factor in decisions.

Fourth, competing claims that are similar but not identical did not result in a completed interference case. Fifth, the patent office verified that interfering parties had independent financial interests (for example, that they were not different branches of a multinational conglomerate); otherwise, the case was dismissed. Thus, interferences are not the result of knowledge sharing *within* organizations. Finally, the separate applications were required to have been made roughly at the same time, often within a year. Thus, copying subsequent to publication and disclosure of an older patent are unlikely to have occurred.

Interferences improve on traditional patent studies in a number of ways. One, interferences involve patents that are more valuable than the average patent. Since an interference requires parties to actively contest for priority, it is unlikely that inventors would spend time or money in pursuit of a worthless patent. Two, we have information on patent interferences over a long period, from the 19<sup>th</sup> century to 2011. Three, patent interferences do not rely on citations to prove common knowledge inputs and are thus not subject to some of the weaknesses noted earlier. Specifically, while patent citations necessarily capture the spillover only of written, publicly available knowledge, simultaneous invention is evidence that *some* kind of spillover, whether written or not, is likely to

have occurred. Thus, interferences capture spillovers of tacit knowledge. As I noted earlier, we might expect that tacit knowledge is especially sensitive to geographic proximity. If so, then we expect results on the localization of interferences to be stronger than on the localization of citations.

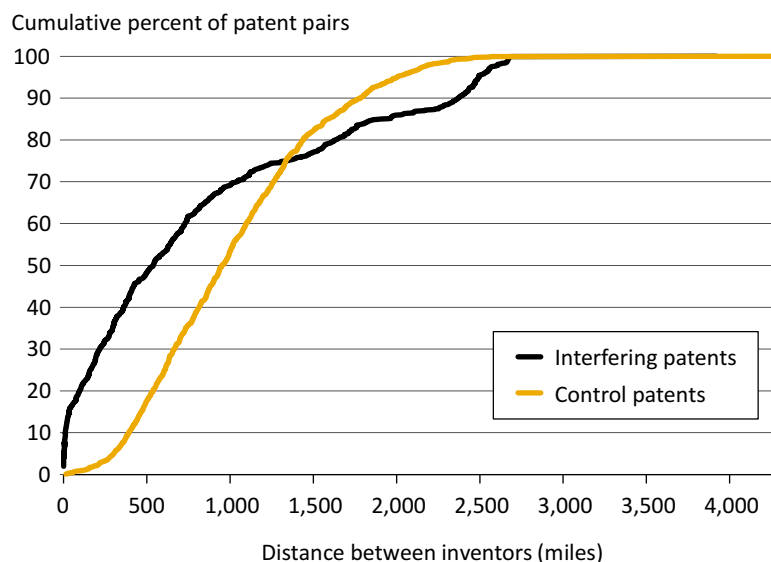
We have constructed a database of over 1,000 interference cases from the early 1980s to 2011 from the U.S. patent office. This database includes the names of the inventors involved in the interference, their patent and application numbers, and the date of the interference. We match this information to a database of inventor locations (based on their Zip codes) produced by the Harvard Business School.

**Testing geographic concentration.** If local knowledge spillovers are important, one possible test is to see whether patent interferences, as measures of shared, possibly tacit knowl-

edge, are more likely to occur between inventors who are located close to each other versus those located farther apart. The black line in Figure 1 shows this pattern for only the interference cases involving pairs of U.S.-based inventors. The horizontal axis measures the distance in miles as the crow flies between the observed locations of the two parties involved in a patent interference. (Since a single patent application can be made on behalf of multiple inventors, we measure the minimum distance between inventors of the different parties to the interference.) The vertical axis shows the percent of interfering inventor pairs in our database that are separated by *at most* the distance indicated by the horizontal axis. Thus, as we move to the right, we accumulate our inventor pairs until 100 percent of our pairs are within 4,258 miles — the maximum distance observed between two interfering U.S. inventors.

**FIGURE 1**

### Interfering Inventors More Geographically Concentrated



Sources: U.S. Patent and Trademark Office, Harvard University Patent Network Dataverse.

Despite the large possible range of distances between inventors, the black line shows that 20 percent of interfering inventors are within only 100 miles of each other, and half of interfering inventor pairs are within 540 miles of each other. While this is a good starting point for showing that proximity matters for shared knowledge inputs, it still might be true that inventors are located close to each other to take advantage of some other factor. Similar to the logic of the patent citation studies, we can compare the localization of interferences with the localization of noninterfering patents in the same technology classification and year. In that way, we can control for the underlying distribution of research activity that doesn't rely on common knowledge inputs, as interferences do.

For each pair of interfering patents, we selected up to 10 control patents. Our goal was to control for the underlying geographic distribution of inventive activity by selecting patents that were similar to the interfering patents but not involved in the interference case. We selected control patents based on two criteria. First, a control patent had to share at least one of the many possible three-digit technological classification codes assigned by the patent office that the two interfering patents had shared. Second, the control patent's application date had to fall

between the application dates of the two interfering patents. If no eligible control patent was found, we then expanded the selection window incrementally by 10 days before the earlier interfering application and 10 days after the later interfering application until an eligible control patent was found. Finally, we randomly chose one of the two interfering patents to match with the control patent. We then compared the distance between the interfering inventors with the distance between the randomly selected interfering inventor and the control inventor.


**The results.** The gold line in Figure 1 shows our results for the proximity of interfering inventors to control patent inventors. It represents the expected distribution of distances between inventors working in technology fields and time periods similar to those of our sample of patent interferences, but it is not conditioned on an interfering link between inventors.

Comparing the distribution of distances between interfering inventors with the control distribution of noninterfering inventors, it is clear that interfering inventors are more geographically concentrated. While 20 percent of interfering inventors are within 100 miles of each other, less than 1 percent of noninterfering inventors are within 100 miles of each other. And while half of interfering inventors are within

540 miles of each other, the same is true of less than 21 percent of noninterfering inventors.

Interfering inventors are especially more likely to be geographically concentrated at small distances. For example, more than 3 percent of interfering U.S. inventors are in the same Zip code, versus none of the noninterfering inventor-control pairs. Eleven percent of interfering inventors are within 15 miles of each other, compared with less than 1 percent of noninterfering inventors. These results are consistent with a growing literature documenting that knowledge spillovers attenuate rapidly with distance.

## CONCLUSION

Although local knowledge spillovers are of central interest to economists, the evidence to date on their existence is mixed. Patterns in our data on patent interferences suggest that inventors working independently but using common knowledge inputs are substantially more geographically concentrated than other inventors working in the same field and time period who are not linked by common knowledge inputs. These results suggest that localized knowledge spillovers may be especially salient for forms of tacit or uncodified knowledge, which is difficult to observe using citations but more likely detectable from interferences. 

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