We need to talk â€“ or do we? Geography and the commercialization of technologies from public research

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Abstract

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1. Introduction

Research and development (R&D) as well as creation and application of new knowledge are the engine of technological change and are responsible for economic growth and employment in modern economies. Policy makers have undertaken considerable efforts to increase the linkage between public research institutes and industry. For instance the Bayh-Dole Act in the U.S. and other similar legislative changes advanced technology transfer as one of the main objectives of public research institutes. Beside transfer channels such as publications, conferences, consulting, and scientist's migration (Cohen et al., 2002; Agrawal and Henderson, 2002), patenting and licensing has become one of the most common instruments to commercialize scientific results (Bozeman, 2000; Shane, 2002).

A substantial fraction of research examines the contribution of public research institutes on regional development and technological innovations in the U.S. and elsewhere (e.g. Jaffe, 1989; Acs et al., 1992; Jaffe et al., 1993; Anselin et al., 1997; Fritsch and Slavtchev, 2007). These studies suggest a strong regional agglomeration effect that reflects proximity to public research institutes. As part of this broader literature, some studies investigate the influence of geographic distance on the likelihood of licensing and commercialization (Santoro and Gopalakrishnan, 2001; Mowery and Ziedonis, 2001; Agrawal, 2006). We explore how commercial success of licensing activities is related to geographical distance taking into account different licensee and technology characteristics and controlling for potential sample selection.

Commercializing academic inventions is a difficult task since inventions are far from being readily marketable: The difficult character of academic research (Jensen and Thursby, 2001), the issue of information asymmetry between the inventor and the potential licensee (Shane, 2002; Siegel et al., 2003), as well as the problem of non-codified knowledge which is essential for the commercialization process (Agrawal, 2006) are major difficulties which have to be taken into account. Especially the first and the third argument are highly relevant in the literature on technology management and the economics of innovation to explain the necessity of geographical proximity between the inventor and the potential licensee. Thus, even though the knowledge flows from inventors to licensees are not really spillovers but can be internalized by the contracting parties (Breschi and Lissoni, 2001), proximity may play a facilitating role for these flows in quite similar way as has been proposed for Marshallian knowledge spillovers.

To pursue these issues empirically, we use a dataset with detailed information on licensing activities of the Max Planck Society, Germany's largest non-university public research organization. Whereas German universities changed its intellectual property rights (IPRs) and IPR-based commercialization with the introduction of the so-called "Arbeitnehmererfindergesetz" (ArbEG) in 2002, the Max Planck Society has already been subject to a Bayh-Dole-like legislation since the 1970s. This circumstance gives us a rich set of inventions and licensing activities which allows us to fall back on more than 2,300 invention and about 770 license agreements for the time period 1980-2005. In addition to the license agreements the data set includes information on royalty payments, i.e. whether or not an invention has been commercialized successfully as well as the magnitude of the returns. To identify the geographic distance between the licensor and the licensee the data set also includes detailed information on the location of both, the licensor and the licensee.

We use this data to analyze how the probability and the magnitude of commercial success are affected by geographic distance including licensors' and licensees' characteristics. Most of the empirical studies on licensing and commercialization are based on U.S. data which cannot be projected for other countries or other public research institutes (Beise and Stahl, 1999). Whereas U.S. studies are mainly focused on licensing inventions to domestic licensees this circumstance cannot be devolved in the more open European economy (Arundel and Geuna, 2004). Moreover, empirical studies examine only exclusive licenses (Dechenaux, et al., 2003; Elfenbein, 2004) and often only patented inventions (Shane, 2002; Elfenbein, 2004). Furthermore we lack evidence how firm types such as spin-offs vs. external licensees differ with regard to their commercial performance and how it is influenced by geographic distance. We contribute to that observing both patented and unpatented inventions, and both exclusive and non-exclusive licenses. Additionally we are able to differentiate between spin-offs and external licensees (start-ups, incumbents).

We do not find evidence that geographic distance influences commercial success estimating our models jointly for spin-offs and external licensees. However, investigating spin-offs and external licensees separately results indicate substantial differences between the two types of licensees. For the technologies licensed to spin-offs, a significantly negative relationship between distance to the inventors and commercialization success is estimated. In contrast, the relationship is significantly positive for the external licensees.

The remainder of the paper is organized as follows: The next section discusses properties of licensing and the (potential) importance of geographic proximity on commercial success. We derive hypotheses about the effects of geographical distance on successful commercialization based on theory. Section 3 provides information about the technology transfer process of the Max Planck Society. Section 4 describes our data and the research design for the empirical analysis, whereas results are discussed in section 5. We conclude our analysis and discuss implications in section 6.

2. Does geographic proximity matter for successful commercialization of university inventions?

In a world of heterogeneous firms, the allocation of licenses to suitable licensees constitutes a matching problem. Ideally, negotiations between inventors (or technology licensing offices as their agents) on the one hand and potential private-sector licensees on the other would result in perfect matching: the most suitable licensee (in terms of capabilities and complementary assets) will submit the highest offer for a license and thus become the actual licensee. If technologies are licensed non-exclusively, the same considerations apply in principle. Among all firms interested in licensing a technology, all those willing to pay at least as much as the licensor asks become licensees. Under ideal conditions, this will again allocate licenses to those firms that can expect to gain most from the license because they command superior capabilities and/or better suited complementary assets than other potential licensees.

Where are licensees of academic inventions expected to be located? Prior research on university inventions and their commercialization has established a variety of findings that provide some guidance in answering this question. Perhaps most importantly, it is a well-established property of academic inventions that they are often not developed beyond the proof of concept or a lab scale prototype stage. Based on a survey of technology transfer managers of U.S. universities, Jensen and Thursby (2001) find that more than 75 percent of all licensed inventions were at an early stage of development. In this case, it is necessary for licensees to bring in additional efforts to obtain a marketable product. However, several studies identified that additional efforts for further development and successful commercialization are highly dependent on the continued involvement of the academic inventors (Jensen and Thursby, 2001; Thursby and Thursby, 2004; Agrawal, 2006).

One explanation why inventor involvement is important for successful commercialization of technologies from public research is that licensees cannot easily absorb all knowledge related to an academic invention. Agrawal (2006) emphasizes that not all elements of knowledge commanded by researchers at public research institutes are accessible to licensees in the same way. Licensees' absorptive capacities (Cohen and Levinthal, 1990) may be insufficient to fully appreciate all information related to academic inventions. Since academic inventions tend to be highly complex and to involve knowledge from overlapping disciplines, they are often far from the knowledge base of the licensee (Agrawal, 2006). In addition, relevant knowledge may be partially "tacit" (Polanyi, 1966; Arora, 1995), i.e. it cannot adequately be codified using publications or blueprints. According to Agrawal (2006), much of the uncodified knowledge in public research could in principle be codified; he refers to this type of knowledge as "latent" knowledge. For example, academic inventions are often based on long series of experiments. These are characterized by failures and disappointments that are usually unreported, i.e. remain uncodified. It might be valuable for licensees to have an overview over the whole development process of a scientific invention with all its throwbacks and proceedings.

Direct personal interaction is generally required for the transfer of tacit knowledge. Even video-conferencing or e-mails as new ways of sharing knowledge all over the world cannot fully substitute for face-to-face communication and collaboration (McDonough and Kahn, 1996). Technology transfer has therefore been described as a "contact sport" in which the transfer of knowledge necessitates the participation of the inventor and requires face-to-face communication (Mowery and Ziedonis, 2001).

Geographic proximity facilitates face-to-face interaction. It increases the likelihood of coincidental encounters and, more importantly, reduces travel time and thus the costs of deliberate personal interaction (Beise and Stahl, 1999; Santoro and Gopalakrishnan, 2001). This should be most important for high-level scientists with high opportunity costs of time used for interaction with licensees rather than for doing research (Stephan, 1996). Therefore, geographic proximity fosters the transfer of tacit knowledge and facilitates ongoing dialogue due to reduced travel costs and time losses.

Adding to the challenges involved in the transfer of tacit and latent knowledge, further problems of uncertainty and asymmetric information may complicate the licensing of academic inventions. Due to the fundamental uncertainty involved in innovative activities, neither the inventor nor the licensee can perfectly predict the payoff of an invention

(Czarnitzki and Toole, 2006). Furthermore, the available knowledge is unequally distributed between both parties. On the one hand licensees have limited information about the quality of academic inventions, what exact efforts are behind them and which practical benefit they could deliver. On the other hand, compared to the inventor or their TTO licensees tend to have a better understanding of markets and the needs of potential customers (Shane, 2002). Complementing institutional setups (Colyvas et al., 2002) and monetary instruments alleviating problems of asymmetric information and opportunism, their impact can be mitigated by trust and reciprocity between the parties (Nooteboom, 2002). This suggests another channel through which geographic proximity can facilitate licensing activities. It can help parties to build up trust and reciprocity more easily which in turn leads to more personal and embedded relationships (Granovetter, 1985).

These considerations suggest that all other things equal, it may be attractive for licensees to be in the proximity of academic inventors, even in a world where technology has dramatically improved the possibilities and reduced the costs of codifying and transmitting knowledge across the world by electronic communication superhighways. However, all licensees are not equally mobile. In particular, spin-off licensees can be expected to be more flexible in their location decisions than external licensees, which in the German case are mostly established firms tied to existing locations. Generally being less well equipped with capabilities and complementary assets (Teece, 1986; Teece et al., 1997; Shane, 2002) spin-offs may moreover be more reliant on inventor cooperation, particularly since successful commercialization outcomes may be more relevant for corporate survival than in the case of established external licensees (Lowe and Ziedonis, 2006). These differences across licensee types inform our first hypothesis to be tested in the empirical analysis.

> *Hypothesis 1: Geographic distance is a more relevant impediment for licensing to spin-off firms, which is therefore realized at shorter distances than licensing to external licensees.*

If the matching process of inventions and licensees works perfectly, more distant firms should have factored in whatever costs arise from being located far away from the inventors. Firms that are tied to their pre-existing locations should then be observable as licensees only if their superior capabilities and/or complementary assets compensate for the disadvantages of their locations. In contrast, inherently inferior firms might end up licensing a technology because they are more suitably located or willing and able to locate in the vicinity of the inventors. It can therefore be argued that the costs of distance are equilibrated by the matching process. In this case, no performance differences should be observed between licensees located at different distances from academic inventors. This conjecture leads to the next testable hypothesis:

> *Hypothesis 2: All costs of geographic distance between inventors and licensees are reflected in the matching decisions of the involved parties and the terms of the realized license agreements. Accordingly, commercialization outcomes are unaffected by geographic distance.*

The prediction of Hypothesis 2 finds substantial support in the available evidence on university-industry interaction. Studies such as Audretsch and Stephan (1996), Beise and Stahl (1999), and Agrawal (2006) do not find evidence indicating that geographic closeness matters for knowledge transfer. Audretsch and Stephan (1996) show that the majority of links between university scientists and biotechnology firms are non-local. Surveys by Sternberg (1999) as well as Grotz and Braun (1997) find similar results for Germany. In their survey of 2,300 German companies, Beise and Stahl (1999) do not detect a higher likelihood to innovate for firms that are located close to universities or polytechnics. They conclude that closeness to public research institutes does not influence the probability of public research-based innovations.[1] Finally, Agrawal (2006) finds that geographic distance does not influence the likelihood and extent of commercial success using a dataset of license agreements associated with inventions from the Massachusetts Institute of Technology (MIT).

There are, however, theoretical reasons to expect that the matching of technologies to licensees is often less than perfect in reality, and that Hypothesis 2 may therefore be too optimistic. Markets for technologies from public research are usually thin: the number of firms interested in, and capable of, further developing and marketing academic inventions is in most cases small (Contractor, 1981). Uncertainty, information asymmetry and imperfect knowledge may also lead to imperfect matching and leave room for opportunistic behavior. In this case, the disadvantages of geographically distant licensees in securing inventor engagement and absorbing latent inventor knowledge may not fully be equilibrated in the

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[1] However, this result might be driven due to the geographical differences between Germany and the U.S. pointed out by Salter and Martin (2001).

matching process. This conjecture informs a competing hypothesis to Hypothesis 2 developed above:

> *Hypothesis 3a: In real-world markets for technology, increasing distance between academic inventors and licensees is negatively related to commercialization success.*

Problems in knowledge transfer and efficient collaboration caused by geographic distance may be further increased for foreign licensees as international travel tends to be more costly and time consuming than domestic travel. Cultural and linguistic differences also play an important role, particularly if frequent face-to-face contact is required to access tacit knowledge (Maskell and Malmberg, 1999; Leamer and Storper, 2001). This is particularly important in a more open European Union, where licensees in border regions can be geographically close to a public research institution but separated by a different language and culture (Arundel and Geuna, 2004). We therefore predict the following:

> *Hypothesis 3b: For foreign licensees there is a more pronounced negative relationship between geographic distance and commercialization success than for domestic licensees.*

Finally, in line with the opportunity cost considerations outlined above, more senior researchers may be more sensitive to increasing travel times than their less senior peers. In this case, we would expect their inventions to suffer more from licensing to distant licensees than the inventions of more junior researchers:

> *Hypothesis 3c: For technologies (co-) invented by senior researchers there is a more pronounced negative relationship between geographic distance and commercialization success than for technologies invented by more junior researchers,*

Since the empirical evidence is mixed with regard to the importance of geographical distance to successfully transfer knowledge from public research to firms, substantial empirical support can also be mustered for the predictions of Hypothesis 3. Mansfield and Lee (1996) find that firms prefer to work with university researchers who are less than 100 miles away from the firm's R&D laboratories. Based on a survey of R&D laboratories in the U.S., Adams (2002) concludes that geographic proximity plays a bigger role in case of university-firm interactions compared to firm-firm interactions. The work by Mowery and Ziedonis (2001) compares the geographic reach of two important knowledge flows, namely patent citations and licenses. They conclude that licenses are more geographically localized than patent citations. Further work by Santoro and Gopalakrishnan (2001) identifies that geographic proximity positively influence technology transfer activities between universities and firms. Recently, the study of Buenstorf and Geissler (2009) finds that foreign licensees are less likely to commercialize Max Planck technologies compared to domestic licensees which might be influenced by the geographic distance.

3. Empirical context: the Max Planck Society

We test the hypotheses developed above in the context of the German Max Planck Society. Public research in Germany is characterized by a distinctive division of labor. Non-university public research organizations play an important role in this system, with the Max Planck Society being the largest organization focusing on basic research. Its primary task is to complement university research by engaging in large-scale, interdisciplinary, or particularly innovative activities in science, (parts of) engineering and the humanities. The Max Planck Society gets almost 80 per cent of its budget from public, institutional funding and employs close to 5,000 researchers (Max Planck Society, 2008). These work in 80 disciplinary or topical institutes. Geographically these institutes are dispersed throughout the country; in most cases they are located close to a public university. This geographical dispersion reflects the federalist character of the German political system, as federal and regional governments (*Bund* and *Länder*) share the costs of supporting the Max Planck Society.

Before 2002 inventions by Max Planck researchers were treated differently from those made by German university researchers. Max Planck researchers, just like the employees of private-sector firms were (and still are) subject to the law on employee inventions, according to which employees have to disclose their inventions to their employer, which is the legal owner of the intellectual property.[2] To manage its patent applications and technology

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[2] Due to what was known as the “professors’ privilege”, university researchers used to be exempt from this law; they retained the intellectual property in inventions made in their research. The professors’ privilege was abolished in 2002 (cf. von Ledebur et al., 2009, for more details).

licensing, the Max Planck Society in 1970 established a legally independent technology transfer subsidiary, which is presently named Max Planck Innovation GmbH. Staff members of Max Planck Innovation, which is co-located with the Society’s central administration in Munich, regularly visit the individual institutes to solicit the disclosure of new inventions. Patent applications are handled in cooperation with external patent attorneys. Technologies are marketed to domestic and foreign firms, including spin-offs, which have been actively supported since the early 1990s. Max Planck Innovation has concluded more than 1,500 license agreements since 1979 (Max Planck Innovation, 2007). Accumulated returns from technology transfer activities exceed € 200 million, with most income resulting from a handful of “blockbuster” inventions. In case of successful licensing, academic inventors receive 30 per cent of all revenues, and the Max Planck Institute employing the researcher gets an additional third of all income.

4. Data and methods

Data

The present study is based on information provided by Max Planck Innovation GmbH that has been analyzed in earlier work by Buenstorf and Geissler (2009). The dataset covers all inventions disclosed by Max Planck researchers from the mid-1960s to 2005. In total 3,012 inventions have been disclosed to the Max Planck Society from which 1,885 resulted in a patent application. Information are available about the date of disclosure and patent application, the institute that the respective invention comes from, invention-specific characteristics such as the involvement of a Max Planck director, as well as whether an invention has been licensed or not.

Our empirical analysis focuses on the subset of all 864 inventions that have been licensed to private-sector firms. Since a number of inventions are licensed non-exclusively to multiple licensees, there are in total 1,172 license agreements. Furthermore, a substantial amount of license agreements cover multiple inventions licensed to a single licensee in form of a bundle. Lacking more detailed information on the value of the individual inventions covered in such bundles, we treat them as separate observations in the empirical analysis, dividing observed royalty payments (if any) equally among the bundled inventions and including an indicator variable denoting “license bundling” in the model specifications. For each license agreement, information is available about the name, type and the location of the licensee, the dates of conclusion and (possibly) termination, as well as all amounts and dates of payments based on the license agreement.

To minimize right censoring problems, we restrict the sample to inventions disclosed 2004 or earlier while using information about payments up to 2007. The empirical analysis is further restricted to inventions disclosed 1980 or later for two reasons: First, before 1980 Garching Innovation GmbH not only managed inventions disclosed by Max Planck researchers, but also offered its services to external customers, mostly other public research organizations. Second, information available for the pre-1980 inventions is inferior to that related to the later inventions. These restrictions leave us with a total of 2,376 disclosed inventions. From these 773 have been licensed; they are subject to a total of 1,047 license agreements. The sample size is further reduced by restricting the analysis to license agreements providing for variable royalty payments in the case of successful commercialization by the licensee. This restriction is necessary because the commercial success of a licensed technology s not directly observably but has to be deduced from the incidence and level of positive royalty payments. Our data include yearly payments for all individual contracts from conclusion to 2007 or prior termination.[3] In total, 731 inventions provide royalty payments (with or without fixed fees) from which 365 (50 percent) have been successfully commercialized (Table 1). Accumulated royalty payments for the individual license agreements are highly skewed (Figure 1).

Variables

The subsequent empirical analysis employs two different indicators of successful commercialization. First, we constructed a binary variable indicating all license agreements leading to positive royalty payments for the Max Planck Society. Second, to also account for differences in the returns from license agreements, we employ the logged sum of discounted payments as an alternative indicator of commercial success.[4]

The principal explanatory variable in the empirical analysis is the geographic distance between a licensee and the institute where the respective invention was licensed. Our measure

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[3] Royalty payments are discounted to the base year 2000 and are adjusted to the currency “Deutsche Mark”.

[4] In unreported empirical analyses we also exploited information about the time required to successfully commercialize licensed inventions. The results of these estimations are consistent with those obtained with the alternative performance measures. They are available from the authors upon request.

of geographic distance was constructed as follows. We used postal addresses to derive latitude and longitude measures of the locations of licensors and licensees. Employing the method suggested by Sorenson (2004), these were then transformed into radian values to calculate geographic distances.[5] In total, 720 distances were calculated for the restricted sample between all licensing Max Planck Institutes and their corresponding licensees. Since the Max Planck Society licenses its inventions on a global scale, geographic distance ranges from 0 to more than 16,000 kilometers. As the distribution of distance is highly skewed we employ the natural logarithm of this variable (Figure 2a). To study international licensing, licensees are further classified in domestic and foreign according to their postal address. Because our theoretical considerations focus on physical distance between the parties to a license agreement, foreign subsidies located in Germany are counted as German licensees. Of the 731 licenses for inventions disclosed between 1980 and 2004, 227 are identified as foreign and 502 as domestic. Figure 2b depicts log distance for both domestic and foreign licensees.

The analysis includes further information about licensees as well as inventions and their inventors. Licensees are classified into spin-offs (i.e., firms started by Max Planck researchers) and external licensees on the basis of the Max Planck Innovation's spin-off database. In total 199 license agreements with spin-offs and 499 with external licensees have been identified. We also employ an indicator variable denoting repeat licensees for which earlier license agreements with the Max Planck Society can be found. (This includes a number of spin-offs). This variable is motivated by the conjecture that if later license agreements are related to earlier ones, their odds of commercialization may be due to already established contacts and accumulated knowledge.

Inventions are classified according to the section of the Max Planck Society from which they originate (biomedical section versus chemistry/physics/technology section)[6] and whether or not a Max Planck director is among the inventors. We use the latter distinction to identify inventions by senior researchers. Directors are the top-level researchers employed at the Max Planck Society. Depending on its size, each institute has from two to about twelve directors, who can often be considered as star scientists (cf. Buenstorf, 2009, for a more detailed account). The dataset includes 282 cases of director involvement in the licensed invention. Time effects (older inventions are longer exposed to the hazards of licensing and

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[5] Even though Germany is a relatively small country, accounting for the earth's curvature is relevant in our context because of the presence of international, particularly intercontinental license agreements.

[6] The Max Planck Society also has a third, social science, section. However, no invention in our dataset originated from this section.

commercialization than are younger ones) are recorded by an integer variable denoting the time of disclosure starting with a zero in 1980.

We also employ information about patent applications related to licensed inventions. Patent applications indicate that intellectual property on the underlying technology can in principle be obtained. This could facilitate commercialization because it is less risky for the licensee to spend money on the further development of the technology. On the other hand, with patented inventions, strategic use of the intellectual property and “shelving” become options for the licensee, which may be reflected in reduced commercialization rates. For the subset of inventions related to patent applications further information could be derived from patent statistics. First, we identified collaborative inventions on the basis of patent assignment. Inventions are defined as collaborative if they are not (exclusively) assigned to the Max Planck Society but (co-) assigned to a private-sector firm (often the licensee, which indicates prior knowledge the licensee has about the licensed invention, which would be expected in increase the likelihood of successful commercialization).[7] Patent family size and a dummy that indicates triadic patent applications in the U.S., EU and Japan are employed as proxies of patent quality. Descriptive statistics and correlations are summarized in Tables 2a-b through 4a-b.

Empirical approach

The empirical analysis proceeds in two steps. We first use simple OLS regressions to identify how distances between licensors and licensee are related to technology and licensee characteristics. The general model is:

$$DIST_{fi} = \beta_0 + \boldsymbol{L}_f\beta_1 + \boldsymbol{T}_i\beta_2 + u_{fi} \qquad (1)$$

where DIST stands for the geographic distance between firm f which licensed invention i and its licensor, and L and T are, respectively, matrices of licensee- and technology-specific characteristics.

To study the potential influence of geographic distance on commercialization outcomes, we subsequently estimate a set of models where we regress our measures of

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[7] We realize that this is a restrictive definition of collaborative inventions (cf. Fontana and Geuna, 2009).

commercial success on a variety of licensee and technology characteristics, controlling for time effects. This leads to the general model:

$$y_{fi} = \beta_0 + \beta_1 DIST_{fi} + \boldsymbol{L}_f \beta_2 + \boldsymbol{T}_i \beta_3 + u_{fi} \qquad (2)$$

where y measures commercial success of invention i licensed to firm f. Specifications of model (2) vary according to dependent variables. To analyze the likelihood of successful commercialization, a series of Probit models is estimated in which the dependent variable takes the value of one if positive royalty payments have been realized and zero otherwise. Tobit models are employed to estimate models in which accumulated royalty payments are the dependent variable. Royalty payments are left-censored at zero which is taken into account in the Tobit models. Given that royalty payments are highly skewed, we employ the natural log of the accumulated payments. Throughout the analysis, standard errors clustered by inventions are estimated to control for the occurrence of multiple licensing of the same technology.

Selection bias is a potentially relevant concern for our analysis. Selection bias may be caused by two different processes. First, commercialization outcomes are only observable for the subset of *licensed* inventions, which certainly are not a randomly selected sample of all inventions. To control for the bias that could result from the non-random selection into licensing, we applied the two-stage estimation procedure proposed by Heckman (1979). As we show in more detail in the appendix, inventor characteristics are well-suited to explain selection into licensing. However, the empirical results of the Heckman models (reported in Table A1 in the appendix) indicate that non-random selection into licensing is not of major concern in our sample. In particular we find that the null hypothesis that commercialization outcomes are independent of selection into licensing cannot be rejected throughout.

The second potential selection problem concerns licensee characteristics. Specifically, the above theoretical considerations suggest that licensing decisions of spin-offs may differ substantially from those of external licensees. This is consistent with the empirical results obtained by Buenstorf and Geissler (2009) in the empirical context of the present study. To allow for differences in the factors shaping commercialization outcomes, we estimate our principal models jointly for spin-offs and external licensees, and also separately for the two types of licensees. At the same time, this sample split also helps to limit the problem that locations of licensees may not always be exogenously given. It seems plausible to expect that endogenous location choices driven by the objective to be close to the origins to the licensed technology are a more relevant concern in the case of (first-time) spin-off licensees, but much less so in the case of pre-existing external licensees.

5. Results

What factors are related to differences in the distances between Max Planck inventors and the firms licensing their inventions? Results of OLS regressions addressing this question are reported in Table 5. Three different models were estimated, which primarily differ with regard to the analyzed set of inventions. Model 1a includes all 974 license agreements in the dataset. It indicates that spin-off licensees are systematically located more closely to the institute from which an invention originated than are external licensees. Patented inventions also tend to be licensed more locally than unpatented ones, whereas both inventions from the biomedical section and technologies that are licensed in bundles tend to find more distant licensees.

All these patterns are reproduced for the subset of 685 license agreements providing for royalty payments (Model 1b). For this sample, we also find that inventions from the leading institutes (in terms of invention disclosures), as well as those (co-) invented by Max Planck directors, are on average licensed to more distant licensees. Finally, in Model 1c the sample from Model 1b is further restricted to inventions related to patent applications, which allows us to include patent-based proxies of invention quality (patent family size, triadic patents) as well as an indicator variable for patents not (exclusively) assigned to the Max Planck Society. None of these variables are significantly related to the distance between inventors and licensee. In addition, for the sample of patented inventions, no difference in distances is observable between inventions from the biomedical and the chemistry-physics-technology section. Otherwise, the results from Model 1a are reproduced.

These results support Hypothesis 1 predicting higher geographic proximity of spin-offs. They are consistent with the above conjecture that spin-offs may be more dependent than external licensees on the close interaction with academic inventors. As noted above, to account for potentially relevant differences in the activities of spin-offs and external licensees, we estimate the empirical models of commercialization outcomes both jointly and separately for the two types of licensees. We begin by analyzing factors predicting the likelihood that a licensed invention is successfully commercialized (indicated by positive royalty payments).[8] Model 2a estimated for the full population of licensed inventions finds no evidence that commercialization outcomes vary with the distance between inventors and licensee, with the type of licensee, or characteristics of the invention. Significant marginal effects are obtained for only two of the variables included in the model. First, we find that patented inventions are less often commercialized than those for which no patent application is documented. This result is robust throughout our further analysis. It suggests that both spin-offs and external licensees obtain a substantial share of licenses for strategic reasons. Second, more recent inventions are less likely to be commercialized than older ones. This finding (which also is reproduced in the subsequent models) may reflect some effects of the right-censored nature of our data. However, we suspect that it also indicates a reduced average quality of inventions, which may result from new entry of inventors and firms into the market for technology.[9]

Model 2b and 2c, respectively, re-estimate the same model separately for spin-offs and external licensees. The results indicate substantial differences between the two types of licensees. For the technologies licensed to spin-offs, a significantly negative relationship between distance to the inventors and commercialization success is estimated. In contrast, the relationship is significantly positive for the external licensees. These findings may be due to the more flexible location decision of inventor spin-offs compared to incumbents at time of licensing. We moreover find that spin-offs do worse in commercializing biomedical inventions than they do in commercializing inventions from the chemistry/physics/technology section. This might reflect heterogeneity within the group of spin-offs, where biotechnology startups pursue more ambitious and risky business models than other entrepreneurial ventures by Max Planck scientists.

These results are further probed in Models 3a-3c (Table 6), where the continuous (log) distance variable is replaced by indicator variables denoting ranges of distances from 50-100, 100-500 and 500+ kilometers. (Inventions licensed within a 50-kilometer range from the inventors form the omitted reference group.) In Model 3a, no significant variation of commercialization chances is found over the various distance ranges. For the spin-off sample, Model 3b suggests a non-linear relationship between distance and commercialization outcomes. Licensees located in the 100-500 kilometer range have higher commercialization

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[8] We report marginal effects at the means in Tables 6 and 7. The corresponding coefficients of the Models are presented in Tables B1 and B2 in Appendix B.

[9] Similar temporal patterns have been found in the U.S. (c.f. Thursby and Thursby, 2002).

odds than regional licensees, while a negative coefficient is estimated for licensees in the 500+-kilometer range.[10] In contrast, among the external licensees, those in the highest distance range are more likely to successfully commercialize than the local licensees (and also compared to those located in the 100-500 kilometer range; p>0.070). A marginally significant positive effect is also estimated for external licensees located in the 50-100 kilometer range.

These results are not fully compatible with either perfect matching (Hypothesis 2) or negative effects of geographic distance on commercialization outcomes (Hypothesis 3a). If all licensed technologies are analyzed jointly, distance does not predict commercialization outcomes, which is consistent with perfect matching. However, the positive relationships between distance and commercialization success obtained for the sub-sample of external licensees is hard to square with either perfect matching or negative effects of distance on commercialization. As regards the latter (predicted by Hypothesis 3a), the only supportive evidence is the negative coefficient for long-distance spin-off licensees obtained in Model 3b.

To further probe theses patterns, we estimate two more sets of Probit models. In Models 4a-4c (Table 6), the continuous distance measure from Models 2a-2c is split up into separate measures for domestic and foreign licensees. Results from these models lend some support to the prediction of Hypothesis 3b that distances across national borders have more adverse effects than domestic distances. For the full dataset analyzed in Model 4a, a significantly positive marginal effect is estimated for the domestic distances confirming the conclusion of Beise and Stahl (1999) that public research-based innovations in Germany are not necessarily locally restricted. The marginal effect for log distances to foreign licensees is significantly smaller (p > 0.003; it is not significantly different from zero). For the spin-offs, we see that the negative effect estimated above was exclusively due to foreign licensees, while the effect for domestic distances now becomes significantly positive also for them. In contrast, for the external licensees, both variables are positive, significant and similar in size.

In Models 5a-5c (Table 7) we take a closer look at Hypothesis 3c which predicts more adverse effects of distance for senior researchers, who presumably face higher opportunity costs of interacting with distant licensees. In all previous models, we did not find any evidence suggesting that technologies (co-) invented by senior scientists (Max Planck directors) fare worse than inventions by lower-ranking researchers. In Models 5a-5c we include an interaction term that effectively separates the additional effect of distance on

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[10] There are no spin-off licensees located in the 50-100 kilometer range, so no coefficient can be estimated for this range.

inventions by Max Planck directors. For Models 5a and 5b we do not find a significant marginal effect for log distance, director involvement and the corresponding interaction term. In Model 5c a significant negative effect is estimated for the director involvement. This suggests that inventions (co-) invented by Max Planck directors are less likely commercialized than inventions by lower-ranking researchers in case the log distance close to zero. However, since the interaction effect is significantly positive, the reductive effect of director involvement decreases with rising log distances. This result is contradictive to what we expect, namely that Max Planck directors are less likely to interact with distant licensees. Overall, results of Models 5a-5c do not support Hypothesis 3c.

To check whether the above findings are dependent on our choice of a binary measure of commercialization success, we estimate a set of Tobit models using (logs of) accumulated royalty payments as a continuous performance measure. Results of these models are reported in Table 7; they are qualitatively very similar to those obtained before. Models 6a-6c correspond to Models 2a-2c. In signs and significance levels, estimates for these models are virtually identical to the earlier ones. Furthermore, results for Models 7a-7c with indicator variables denoting ranges of distances from 50-100, 100-500 and 500+ kilometers are in accordance with result of Models 3a-3c. Finally, results for Models 8a-8c with separate distance measures for domestic and foreign licensees are very similar to those obtained for the corresponding Models 4a-4c. The major difference is that in Model 8c analyzing external licensees, coefficient for the log domestic distance is not positively significant compared to Model 4c in Table 6.

6. Conclusions: a regional mission for technology licensing from public research?

In this paper investigate potential effects of geographic distance on the chances of commercialization of inventions made in public research and licensed to private-sector firms. Of the two alternative potential relationships between distance and commercialization outcomes, the conjecture of perfect matching is better supported by the empirical results than the conjecture of uncompensated costs of distance. However, positive effects of non-local licensing hard to explain in either theoretical perspective.

Not finding evidence suggesting that distance to the inventors has harmful effects on commercialization outcomes is also interesting against the backdrop of earlier results regarding the effects of post-licensing interaction between inventors and licensees. While we cannot directly measure inventor engagement, results by Agrawal (2006) indicate is plays a crucial role for commercialization. If the same holds for our data, then our results suggest that inventor engagement is not seriously impaired by geographical distance, not even for senior and "star" scientists.

From a policy perspective, our results do not suggest that preferential licensing to regional firms is an efficient strategy for technology transfer offices at universities and public research organizations. This is in line with the finding of Belenzon and Schankerman (2009) that U.S. universities that pursued strong local development objectives generated about a third less income per license than those that did not. It runs counter, however, to the importance that policy makers and university administrations often attribute to the role of interactions with regional firms.

Besides leaving open many important questions about the geography of IPR-based technology transfer from public research, the above analysis is also characterized by several limitations. First, even though endogeneity issues seem a relevant concern only for first-time spin-off licensees, we could not offer a cure for this issue but could only "quarantine" it by analyzing the different types of licensees separately. Second, based on the regional economics and economic geography literature, it would seem plausible that regional characteristics at the location of the licensee might affect commercialization outcomes. These were excluded in the above analysis, as were firm characteristics other than the spin-off / external licensee distinction. We hope to extend the analysis along these lines in future work.

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Table 1: Disclosed and licensed inventions, 1980-2004

Inventions (patented)	2,376 (1,504)
Licensed inventions (patented)	773 (546)
License agreements (patented)	1,047 (728)
License agreements with royalties (patented)	731 (513)
Commercialized (patented)	365 (218)

Table 2a: Descriptive statistics of disclosed inventions, 1980-2004

	All inventions				Patented inventions			
	obs	mean	min	max	obs	mean	min	max
Time (1980=0)	2,376	14.503	0	24	1,504	14.527	0	24
Biomedical section	2,264	0.604	0	1	1,440	0.601	0	1
Director involvement	2,376	0.130	0	1	1,504	0.169	0	1
Patent application	2,376	0.633	0	1	--	--	--	--
Patent family size	--	--	--	--	1,504	5.214	1	120
Triadic Patent family	--	--	--	--	1,504	0.237	0	1
Collaborative invention	--	--	--	--	1,459	0.201	0	1

Table 2b: Descriptive statistics of licensed inventions, 1980-2004

	License agreements providing for royalties				License agreements providing for royalties (patented)			
	obs	mean	min	max	obs	mean	min	max
Commercialization	731	.500	0	1	513	.425	0	1
Log royalties	731	4.783	0	19.109	513	4.161	0	19.109
Log distance	720	5.380	0	9.692	505	5.313	0	9.179
Time (1980=0)	731	13.432	0	24	513	13.647	0	24
Biomedical section	719	0.776	0	1	508	0.797	0	1
Director involvement	731	0.386	0	1	513	0.435	0	1
Patent application	731	0.702	0	1	--	--	--	--
Spin-off licensee	698	0.285	0	1	503	0.328	0	1
Foreign Licensee	729	0.311	0	1	511	0.303	0	1
Bundle	731	0.294	0	1	513	0.370	0	1
Repeat licensee	729	0.757	0	1	511	0.818	0	1
Patent family size	--	--	--	--	513	9.125	1	74
Triadic Patent family	--	--	--	--	513	0.380	0	1
Collaborative invention	--	--	--	--	509	0.143	0	1

Table 3a: Correlations between covariates (all inventions), 1980-2004

2,264 observation	Time	Biomed	Director involvement	Patent
Time	1.000			
Biomed	0.071	1.000		
Director involvement	0.026	0.168	1.000	
Patent	0.003	-0.010	0.156	1.000

Table 3b: Correlations between covariates (patented inventions), 1980-2004

1,395 observation	Time	Biomed	Director involvem.	Patent family	Triadic Pat. Family	Collab. invention
Time	1.000					
Biomed	0.069	1.000				
Director involvement	0.033	0.201	1.000			
Patent family	-0.022	0.149	0.218	1.000		
Triadic Patent Family	-0.183	-0.035	0.137	0.448	1.000	
Collaborative invention	0.090	-0.121	-0.028	0.112	0.194	1.000

Table 4a: Correlations between covariates (license agreements providing for royalties), 1980-2004

685 observations	Time	Ln distance	Biomed	Dir. Inv.	Patent	Spinoff	Foreign	Bundle	Repeat Lic.
Time	1.000								
Ln distance	-0.141	1.000							
Biomed	0.161	.092	1.000						
Director involvement	0.114	.058	0.203	1.000					
Patent	0.029	-.067	0.087	0.123	1.000				
Spinoff	0.252	-.350	0.078	0.240	0.154	1.000			
Foreign	-0.030	.713	0.183	0.134	-0.045	-0.192	1.000		
Bundle	-0.018	.116	0.026	0.170	0.244	0.240	-0.030	1.000	
Repeat licensee	0.048	-.133	0.140	0.155	0.186	0.215	-0.160	0.342	1.000

Table 4b: Correlations between covariates (Patented licensed inventions providing for royalties), 1980-2004

493 observations	Time	Ln distance	Biomed	Dir. Inv.	Patent family	Triade	Collaborative invention	Spinoff	Foreign	Bundle	Repeat Lic.
Time	1.000										
Ln distance	-0.180	1.000									
Biomed	0.191	-0.018	1.000								
Director involvement	0.095	-0.029	0.151	1.000							
Patent family	-0.103	0.147	0.153	0.172	1.000						
Triadic Patent Family	-0.183	0.144	-0.040	-0.003	0.443	1.000					
Collaborative invention	0.077	-0.026	-0.091	-0.099	0.015	0.125	1.000				
Spinoff	0.221	-0.316	0.108	0.283	-0.087	-0.046	-0.047	1.000			
Foreign	-0.126	0.714	0.092	0.056	0.180	0.098	-0.124	-0.174	1.000		
Bundle	-0.081	0.172	-0.032	0.135	0.226	0.221	0.067	0.206	-0.035	1.000	
Repeat licensee	0.050	-0.188	0.130	0.133	0.121	0.115	0.052	0.207	-0.235	0.335	1.000

Table 5: Distance between licensor and licensee (OLS), 1980-2004

Log distance	Model 1a (all license agreements)		Model 1b (license agreements providing for royalties)		Model 1c (patented inventions; lic. agr. prov. for royalties)	
Time	-0.018	(0.014)	-0.021	(0.017)	-0.027	(0.022)
Biomedical section	0.596***	(0.199)	0.431*	(0.233)	-0.006	(0.299)
Patented invention	-0.540***	(0.210)	-0.413*	(0.237)		
Patent family size					0.005	(0.111)
Triadic patent family					0.394	(0.280)
Co-assigned patent					-0.426	(0.308)
Director involvement	0.234	(0.189)	0.527**	(0.228)	0.161	(0.273)
Spinoff	-2.330***	(0.242)	-2.312***	(0.267)	-1.987***	(0.316)
Bundle	0.965***	(0.184)	1.144***	(0.234)	1.168***	(0.267)
Top 5 institute	0.159	(0.201)	0.455**	(0.226)	0.365	(0.287)
Constant	5.766***	(0.270)	5.519***	(0.293)	5.495***	(0.370)
Number of obs. (inventions)	974	(720)	685	(540)	493	(391)
P > F	0.0000		0.0000		0.0000	
R^2	0.198		0.204		0.179	

Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Table 6: Likelihood of commercialization (Probit), marginal effects, 1980-2004

Comm = 1	Model 2a (all licensees)		Model 2b (spin-offs)		Model 2c (external licensees)		Model 3a (all licensees)		Model 3b (spin-offs)		Model 3c (external licensees)	
Time	-0.016***	(0.004)	-0.025***	(0.009)	-0.016***	(0.004)	-0.015***	(0.004)	-0.021**	(0.010)	-0.017***	(0.004)
Log distance	0.005	(0.009)	-0.041**	(0.017)	0.251**	(0.125)						
50-100 km							0.202	(0.127)			0.248*	(0.120)
100-500 km							0.087	(0.057)	0.290***	(0.100)	0.065	(0.075)
> 500 km							0.054	(0.062)	-0.363***	(0.089)	0.170**	(0.077)
Biomedical section	-0.091	(0.059)	-0.334***	(0.010)	-0.039	(0.070)	-0.081	(0.061)	-0.389***	(0.106)	-0.009	(0.073)
Patented invention	-0.248***	(0.048)	-0.293***	(0.102)	-0.231***	(0.055)	-0.254***	(0.048)	-0.363***	(0.111)	-0.238***	(0.055)
Repeat licensee	-0.005	(0.055)	-0.057	(0.158)	-0.000	(0.059)	-0.011	(0.056)	0.070	(0.170)	-0.001	(0.060)
Director involvement	-0.025	(0.049)	-0.075	(0.086)	-0.017	(0.061)	-0.021	(0.050)	-0.009	(0.090)	-0.027	(0.061)
Spinoff	0.010	(0.053)					0.033	(0.053)				
Bundle	0.086	(0.053)	0.234**	(0.112)	0.073	(0.064)	0.085	(0.053)	0.117	(0.104)	0.087	(0.065)
Top 5 institute	0.013	(0.051)	0.145	(0.087)	-0.025	(0.061)	0.011	(0.052)	0.166*	(0.092)	-0.028	(0.062)
Number of obs. (inventions)	685	(540)	198	(183)	487	(369)	685	(540)	198	(183)	487	(369)
P > chi^2	0.0000		0.0005		0.0000		0.0000		0.0000		0.0000	
Pseudo R^2	0.076		0.124		0.078		0.080		0.231		0.084	

Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Table 6: Likelihood of commercialization (Probit), marginal effects, 1980-2004 (continued)

Comm = 1	Model 4a (all licensees)		Model 4b (spin-offs)		Model 4c (external licensees)	
Time	-0.015***	(0.004)	-0.033***	(0.012)	-0.016***	(0.004)
Log domestic distance	0.376***	(0.013)	0.062***	(0.024)	0.039**	(0.019)
Log foreign distance	0.011	(0.009)	-0.090***	(0.021)	0.030**	(0.013)
Biomedical section	-0.067	(0.060)	-0.335**	(0.127)	-0.032	(0.071)
Patented invention	-0.249***	(0.049)	-0.385***	(0.109)	-0.230***	(0.055)
Repeat licensee	-0.015	(0.055)	-0.103	(0.196)	-0.006	(0.059)
Director involvement	-0.007	(0.052)	0.015	(0.089)	-0.012	(0.062)
Spinoff	0.036	(0.053)				
Bundle	0.057	(0.054)	0.088	(0.111)	0.068	(0.064)
Top 5 institute	0.007	(0.052)	0.177*	(0.094)	-0.029	(0.062)
Number of obs. (inventions)	685	(540)	198	(183)	487	(369)
P > chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.086		0.324		0.079	

Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Table 7: Likelihood of commercialization (Probit), marginal effects, 1980-2004

Comm = 1	Model 5a (all licensees)		Model 5b (spin-offs)		Model 5c (external licensees)	
Time	-0.016***	(0.003)	-0.023***	(0.009)	-0.017***	(0.004)
Log distance	0.003	(0.013)	-0.016	(0.029)	0.000	(0.017)
Log dist * dir involve	0.003	(0.015)	-0.031	(0.027)	0.059**	(0.023)
Biomedical section	-0.091	(0.059)	-0.306***	(0.104)	-0.029	(0.070)
Patented invention	-0.246***	(0.048)	-0.305***	(0.101)	-0.208***	(0.055)
Repeat licensee	-0.005	(0.055)	-0.048	(0.154)	-0.007	(0.060)
Director involvement	-0.045	(0.095)	0.057	(0.138)	-0.409**	(0.146)
Spinoff	0.010	(0.053)				
Bundle	0.086	(0.053)	0.235**	(0.110)	0.074	(0.064)
Top 5 institute	0.013	(0.051)	0.148*	(0.088)	-0.023	(0.060)
Number of obs. (inventions)	685	(540)	198	(183)	487	(369)
P > chi^2	0.0000		0.0005		0.0000	
Pseudo R^2	0.076		0.131		0.088	

Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Table 8: Level of royalty income (Tobit), 1980-2004

Log royalty payments	Model 6a (all licensees)		Model 6b (spin-offs)		Model 6c (external licensees)		Model 7a (all licensees)		Model 7b (spin-offs)		Model 7c (external licensees)	
Time	-0.338***	(0.071)	-0.435***	(0.137)	-0.349***	(0.078)	-0.334***	(0.075)	-0.301**	(0.136)	-0.365***	(0.079)
Log distance	0.115	(0.198)	-0.724**	(0.307)	0.451*	(0.264)						
50-100 km							3.596	(2.413)			4.655*	(2.616)
100-500 km							1.357	(1.086)	4.076***	(1.561)	0.871	(1.460)
> 500 km							0.959	(1.297)	-7.451***	(2.258)	2.914*	(1.636)
Biomedical section	-1.596	(1.072)	-6.142***	(1.943)	-0.424	(1.260)	-1.371	(1.090)	-5.888***	(1.897)	0.154	(1.295)
Patented invention	-4.105***	(1.000)	-5.366***	(1.783)	-3.533***	(1.175)	-4.187***	(1.015)	-5.850***	(1.866)	-3.620***	(1.169)
Repeat licensee	0.349	(0.977)	-1.026	(2.682)	0.547	(1.037)	0.177	(0.987)	0.239	(2.574)	0.489	(1.049)
Director involvement	-1.115	(1.031)	-1.372	(1.585)	-1.368	(1.288)	-1.045	(1.068)	-0.101	(1.450)	-1.579	(1.290)
Spinoff	0.105	(1.034)					0.398	(1.009)				
Bundle	1.316	(1.095)	4.445**	(2.042)	0.785	(1.306)	1.354	(1.064)	2.470	(1.653)	1.139	(1.308)
Top 5 institute	0.406	(1.048)	2.239	(1.684)	-0.106	(1.253)	0.378	(1.070)	2.007	(1.601)	-0.082	(1.269)
Constant	8.904***	(1.585)	17.552***	(3.723)	6.125***	(1.884)	8.424***	(1.532)	12.350***	(3.665)	7.061***	(1.759)
Number of obs. (inventions)	685	(540)	198	(183)	487	(369)	685	(540)	198	(183)	487	(369)
P > chi^2	0.0000		0.0005		0.0000		0.0000		0.0000		0.0000	
Pseudo R^2	0.076		0.044		0.025		0.027		0.079		0.027	

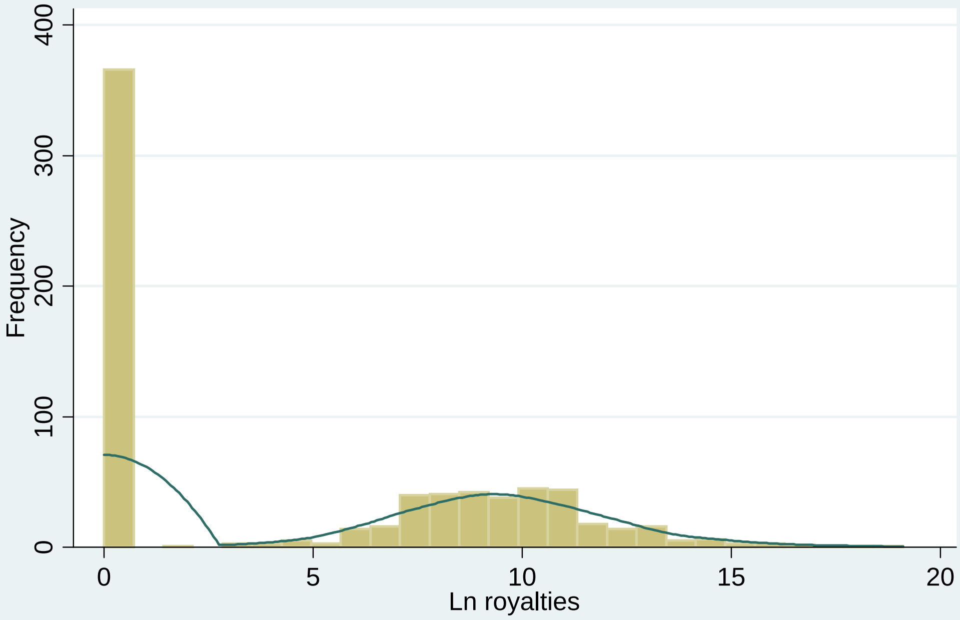
Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Table 8: Level of royalty income (Tobit), 1980-2004 (continued)

Log royalty payments	Model 8a (all licensees)		Model 8b (spin-offs)		Model 8c (external licensees)	
Time	-0.327***	(0.074)	-0.405***	(0.120)	-0.349***	(0.079)
Log domestic distance	0.565**	(0.252)	0.911***	(0.324)	0.450	(0.360)
Log foreign distance	0.192	(0.196)	-1.525***	(0.287)	0.450*	(0.263)
Biomedical section	-1.257	(1.069)	-4.631**	(1.801)	-0.424	(1.261)
Patented invention	-4.027***	(1.009)	-5.089***	(1.549)	-3.534***	(1.165)
Repeat licensee	0.176	(0.977)	-2.161	(2.552)	0.547	(1.038)
Director involvement	-0.787	(1.109)	0.629	(1.354)	-1.368	(1.344)
Spinoff	0.359	(1.016)				
Bundle	0.899	(1.074)	1.713	(1.555)	0.785	(1.289)
Top 5 institute	0.301	(1.076)	1.778	(1.538)	-0.106	(1.270)
Constant	7.067***	(1.802)	13.876***	(3.846)	6.128***	(2.241)
Number of obs. (inventions)	685	(540)	198	(183)	487	(369)
P > chi^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.027		0.117		0.025	

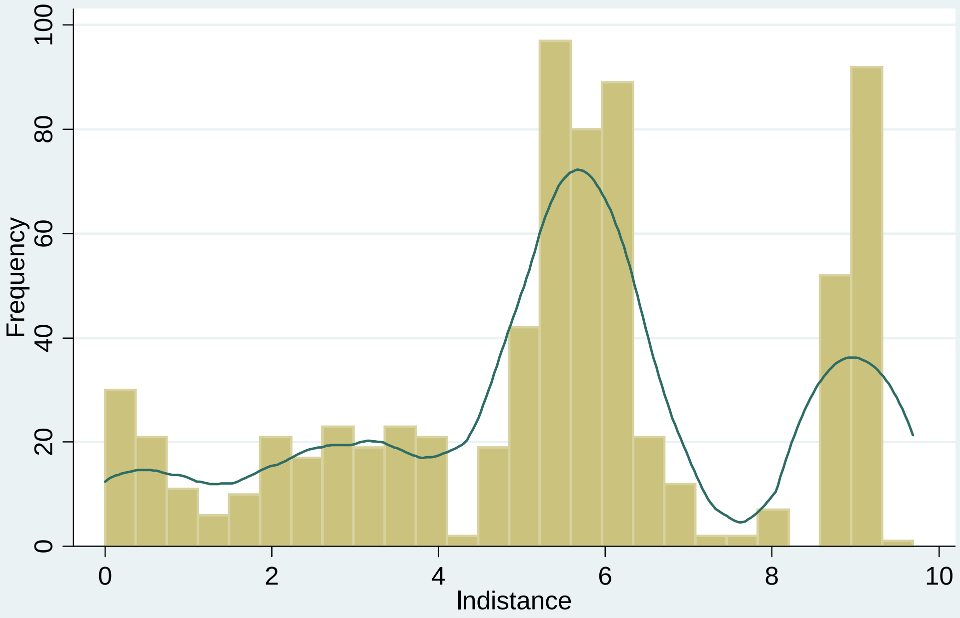
Standard errors (clustered by invention) in parentheses; *;**; and *** denote significance at the 0.10; 0.05; and 0.01 levels, respectively.

Figure 1: Cumulated log royalties, 1980-2007



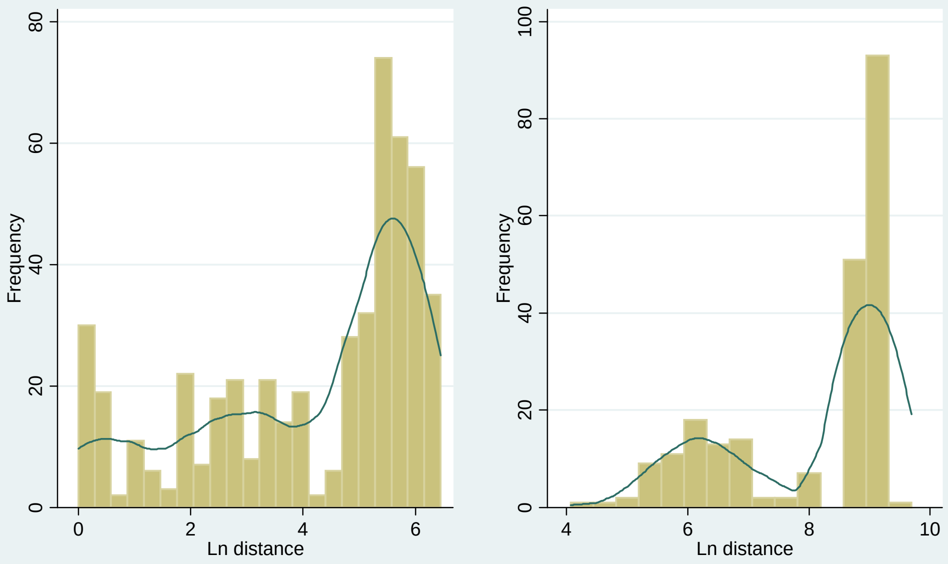
Note: The graph pictures a histogram of the log of cumulated royalty payments from 1980 through 2007 for licensed inventions where licensing agreements provided for royalty payments. Additionally, a kernel density function is plotted.

Figure 2a: Log distance, 1980-2004



Note: The graph pictures a histrogram of log distances with a kernel density function of licensed inventions disclosed from 1980 through 2004 where licensing agreements provided for royalties.

Figure 3b: Log distance separated by domestic and foreign licensees, 1980-2004



Note: The graph pictures two histograms of log distances with a kernel density function of licensed inventions disclosed from 1980 through 2004: The left histogram depicts the log distance for inventions licensed to domestic licensees where licensing agreements provided for royalties. The right histogram pictures the log distance for inventions licensed to foreign licensees where licensing agreements provided for royalties.

Appendix A

Commercialization of technologies from public research is a two-stage process. Technologies first have to be licensed. The attempt to sell products based on the licensed technology then constitutes the second stage, particularly because inventions from public research are often embryonic in nature (Jensen and Thursby, 2001; Agrawal, 2006). Not all inventions from public research are licensed, and selection of technologies into licensing is most likely not a random process. It therefore seems a valid concern that non-random may lead to biased results when the commercialization odds of licensed technologies are analyzed.

In this appendix we show that the empirical analysis presented above is not invalidated by non-random selection into licensing. To this purpose, the two-stage methodology developed by Heckman (1979) is adopted. An equation for selection into licensing is estimated first, which then informs the second stage equation estimating commercialization outcomes.

In the first stage, the selection equation predicts the likelihood that an invention becomes licensed. The underlying selection equation looks as follows:

$$s = 1[\boldsymbol{z}\gamma + v \geq 0] \qquad \text{(A1)}$$

where z are observable variables and v is an unobserved error term. s is equal to 1 if an invention has been licensed and commercial success is observable and zero otherwise. The prediction from the first stage is used to calculate the inverse Mills ratio as $\lambda(\boldsymbol{z}_{fi}\gamma)$. The inverse Mills ratio is then included as an additional exogenous variable in the modified version of commercialization equation (2):

$$y_{fi} = \beta_0 + \beta_1 DIST_{fi} + \boldsymbol{L}_f\beta_2 + \boldsymbol{T}_i\beta_3 + \rho\lambda(\boldsymbol{z}_{fi}\gamma) + u_{fi} \qquad \text{(A2)}$$

For the Heckman model to be consistent, the selection equation must include exogenous variables that determine sample selection, i.e. the probability of licensing, but do not directly affect the outcome of interest, i.e. successful commercialization. Results by Buenstorf and Geissler (2009) indicate that technologies (co-) invented by Max Planck directors have higher chances of being licensed, while their commercialization odds are not different from other inventions. This suggests an impact of reputation effects on the chances of technologies to be licensed. Second, explanatory variables in the outcome equation should also be included in the selection equation provided they are observable. Explanatory variables that are not observable in the first stage have to be excluded from the selection equation.

In line with the empirical strategy employed above, two types of models are employed to control for selection bias: To investigate the likelihood of commercial success we initially employ Probit models at both the selection and the outcome stages. Subsequently, Probit models are employed in the selection stage whereas the outcome stage estimates the magnitude of cumulated royalties.

Results of the various model specifications are reported in Table A1-A2.[11] The inverse mills ratios as an additional exogenous variable are not significant in each regressed model. This implies that the null hypothesis that both, the likelihood and the magnitude of commercial success are independent of selection into licensing cannot be rejected throughout. Estimations obtained in the outcome models are quite similar to the corresponding Probit and Tobit models reported above with respect to directions and significance levels. However, some exceptions can be found in Table A2. More precisely, in Model 5c the variable log distance of external licensees is not significant compared to Model 6c (Table 8). Furthermore, in Model 6c the indicator variables denoting ranges of distances from 50-100 and 500+ kilometers are not significant compared to Model 7c in Table 8. Both results confirm the conjecture of perfect matching (Hypothesis 2).

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[11] Available upon request from the authors (DRUID size limitations).