Not invented here:

Knowledge transfer and technology licensing from a German public research organization

Guido Buenstorf*

Matthias Geissler

Max Planck Institute of Economics
Evolutionary Economics Group
Kahlaische Strasse 10
07745 Jena (Germany)
Fax: (+49) 3641 686868
E-mail: buenstorf@econ.mpg.de

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Abstract:
Using a new dataset encompassing more than 2,000 inventions made by Max Planck Society researchers from 1980 to 2004, we study the effects of information asymmetry and imperfect knowledge transfer on the licensing and successful commercialization of technologies from public research, distinguishing among types of licensees as well as invention and inventor characteristics. Technologies licensed to foreign firms and spin-offs are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. Our findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

Keywords: Licensing, public science, uncodified knowledge, collaborative invention, spin-offs.
JEL classifications: L26, O32, O34.

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Introduction

Throughout the developed economies, public attention and policy measures are increasingly focusing on the transfer of knowledge and technologies from public research to the private sector. Following the Bayh-Dole Act in the U.S. and similar legislative changes in other countries, technology transfer has been recognized as a primary objective of universities and other public research organizations (Mowery et al, 2001; Phan and Siegel, 2006). Notwithstanding the importance of alternative transfer channels (Bozeman, 2000; Zellner, 2003), commercialization of scientific results based on patents, licensing, and spin-off entrepreneurship has found particularly intensive scrutiny. Yet in spite of the increased emphasis on the protection of universities' intellectual property rights (IPRs) and IPR-based commercialization, we still know little about the underlying processes of knowledge transfer and innovation.

Academic inventions are typically far from being readily marketable. Existing research suggests that the commercialization of results from public science is complicated by uncertainty stemming from the early-stage character of most university inventions (Jensen and Thursby, 2001), information asymmetries between inventor and potential licensee (Shane, 2002), and the uncodified nature of important elements of the knowledge base underlying the traded technology (Lowe, 2002; Agrawal, 2006).

Reflecting this non-trivial nature of technology transfer, conclusive evidence on the effectiveness of alternative kinds of commercialization is lacking. For example, the relative commercialization performance of university spin-offs vis-à-vis external licensees is a contested issue (Shane, 2002; Lowe and Ziedonis, 2006). Other issues, including the effectiveness of international licensing, as well the relationships between alternative channels of technology transfer such as collaborative research and technology licensing, are largely unexplored. Furthermore, most empirical studies are based on U.S. data, and it cannot be taken for granted that their results generalize to other countries and institutional settings.

In the present paper, we exploit a newly assembled dataset with detailed information on the licensing activities of the Max Planck Society, Germany's largest non-university public research organization dedicated to basic science. Unlike German universities, the Max Planck Society has consistently been subject to a Bayh-Dole-like IPR regime since the 1970s. This enables us to draw on a rich set of inventions and licensing activities, which encompasses more than 2,000 inventions and about 700 license agreements closed since 1980. In addition to licensing agreements, the data also contain information on royalty payments, indicating whether or not the technology was successfully commercialized in the marketplace.

We use this dataset to analyze a set of specific issues. First, we study how licensing and commercialization are affected by licensee characteristics. Specifically, we look at licensing across national boundaries as well as spin-off versus external licensees. While less relevant in the U.S. context, licensing to foreign firms is a pertinent issue in the smaller and more open European economies, which has received little prior attention in the research on technology transfer. The effectiveness of inventor spin-offs as commercializers of technologies from public research is an unresolved issue in the existing literature to which we add new evidence. Second, we investigate the effects on technology characteristics on the effectiveness of license-based technology transfer. In this context, we study whether inventions based on collaborative research with private firms differ from “pure” university inventions in their licensing and commercialization patterns. We also analyze whether technologies (co-) invented by senior scientists differ in their licensing and commercialization odds.

Our analysis indicates that information asymmetries and problems in transferring uncodified knowledge indeed are critical determinants shaping the success of license-based technology transfer from public research. Inventions licensed to foreign firms are less often commercialized, while collaborative inventions are more often commercialized. Senior scientists are more successful in licensing, but their inventions are less often commercialized. The findings suggest a specific role of spin-offs in transferring technologies invented by senior scientists.

The paper is structured as follows. The next section discusses the role of information asymmetry and the transfer of uncodified knowledge in the licensing and commercialization of academic inventions. In section 3, hypotheses are derived as to how these factors influence licensing and commercialization outcomes for different types of licensees and inventions. Section 4 provides background information on the technology transfer activities of the Max Planck Society, while section 5 describes the data and methodology of the empirical analysis. Results are presented in section 6 and discussed in section 7.

2. Technology transfer through licensing of academic inventions

Inventions by scientists in public research often provide the foundations of commercially viable innovations. Academic inventions may arise as joint products of research activities (think of instrumentation or lab equipment first used for the researcher's own use), or the same results can both be published in a scientific journal and applied commercially (such "patent-paper pairs" are widespread in the life sciences; cf. Murray and Stern, 2005). In a Bayh-Dole-like institutional setting, academic inventions have to be disclosed to the scientist's employer and become its property. If they are to be used for commercial purposes, the prospective innovator has to obtain a license. Most universities and public research organizations have established technology transfer offices (TTOs) that organize the protection of their IPRs and actively market their inventions.

In addition to their strong links to current science, a common characteristic of academic inventions is their early stage nature. In most cases, they have not been developed beyond the proof-of-concept or prototype stage (Jensen and Thursby, 2001). Accordingly, licensees need to engage in substantial further development efforts to obtain a marketable product. Successful commercialization often hinges on the continued involvement of the academic inventor (Agrawal, 2006). The combination of being science-based and early-stage gives rise to at least three kinds of difficulties for the licensing and commercialization process: uncertainty, information asymmetry, and the need to transfer uncodified knowledge.

Like all inventions, university technologies cannot always be turned into successful products in the marketplace. Potential innovators obtaining licenses for technologies from public science face substantial uncertainty as to whether (i) they will be able to develop a functioning product, (ii) they will do so faster than potential competitors, and (iii) the product will be sufficiently successful with customers to justify the costs of licensing and development.

Problems of asymmetric information further complicate innovation activities based on technology transfer from public science. As opposed to technologies developed in-house, potential licensees lack in-depth knowledge of the prior research and development efforts that underlies the academic invention. This limits their ability to evaluate its commercialization prospects. On the other hand, licensees typically have better knowledge of the markets for the prospective products than the inventor or the TTO representing her. To some degree, these problems of asymmetric information can be reflected in the design of licensing agreements and the payment schemes they provide for (Jensen and Thursby, 2001; Lowe, 2006). However, there is no guarantee that a licensing agreement is closed at all. Typically, only a few potential licensees are interested in a particular technology, and licensing is based on small-numbers bargaining.

Asymmetric information arises as a problem in negotiating licensing agreements because both parties have incentives to withhold information, because this may increase their share in future innovation rents. However, even if both parties faithfully try to share their knowledge (for example, after a licensing agreement providing for sales-based royalties is closed so that inventors have an interest in successful commercialization), substantial obstacles in communicating this knowledge typically have to be overcome. They derive from the nature of the knowledge to be communicated, which tends to be complex and imperfectly codified. Agrawal (2006) argues that academic inventions often draw on multiple fields of knowledge. Potential licensees are unlikely to have substantial prior knowledge in all these fields. Accordingly, their absorptive capacities (Cohen and Levinthal, 1990) may be insufficient to fully understand information related to the invention, even if the inventor and or the TTO disclose all their knowledge. In addition, relevant elements of that knowledge may be uncodified (even if they would in principle be codifiable; in which case they can be characterized as “latent,” Agrawal, 2006; cf. also Lowe, 2002). For example, knowledge that the inventor gained from failed and therefore unreported experiments may frequently be latent and inaccessible for an external licensee.

While some degree of uncertainty about innovative success is irreducible, information asymmetries and communication problems are not equally pronounced for all licensing and commercialization processes. In the next section, we derive hypotheses on how differences in the types of licensees and kinds of technologies affect the severity of these problems. These hypotheses are then tested empirically.

3. Hypotheses

Both information asymmetries and problems of knowledge transfer depend on the cognitive “distance” between licensor (the academic inventor represented by her employer’s TTO) and licensee. This distance is plausibly related to observable characteristics of the licensee and the technology, which consequently are expected to affect the likelihood of closing a licensing agreement and successfully commercializing the invention.

Likelihood of successful licensing

We consider differences in the types of licensees along two dimensions: domestic versus foreign licensees, and inventor spin-offs versus external licensees. As regards the first dichotomy, information asymmetries are expected to be more pronounced in licensing negotiations across national boundaries. Information is harder to obtain for foreign licensees, particularly if they do not come from countries speaking the same language, and the design and monitoring of contracts is more difficult internationally. IPR protection for the target technology may not have been obtained in the county of the potential foreign licensee, exposing it to an enhanced risk of imitation by competitors. The likelihood of agreements with foreign licensees may be further reduced by biases in the TTO's marketing efforts. Possibly, such biases are even due to strategic considerations or political pressure motivated by the goal of maximizing the national payoffs from public science.

These arguments suggest that licensing negotiations with foreign firms are less likely to be successful than negotiations with domestic firms. We cannot test this hypothesis directly since we only have information on the pool of inventions and on licensing agreements that were actually closed. However, we can investigate the relative frequency of licensing agreements with foreign firms, and also their timing as compared to agreements with domestic firms. The following relationship is predicted:

Hypothesis 1: At any given time, the hazard of closing a licensing agreement with a foreign firm is lower than that of closing an agreement with a domestic firm.

The likelihood of successful licensing may also depend on the organizational nature of potential licensees. Following the earlier work on U.S. universities, we study differences between inventor spin-offs and external licensees (established firms and startups without inventor involvement). In the case of spin-offs, information asymmetries should largely be mitigated since inventors licensing back their own inventions know these technologies rather well. This should increase the chances and the speed of arriving at a license agreement:

Hypothesis 2: At any given time, the hazard of closing a licensing agreement with an inventor spin-off is higher than that of closing an agreement with an external licensee.

However, licensing to inventor spin-offs is sometimes characterized as some kind of “last resort” utilized only when attempts to find an external licensee have failed (e.g., Shane, 2002). If this temporal order is widespread, it might compensate the positive relationship predicted by Hypothesis 2.

In addition to the effects of licensee characteristics, we also expect that licensing is affected by the time that a potential licensee learns about a nascent university technology. Particularly relevant in this context appear collaborative inventions based on industry-sponsored research or joint research projects between public and industry partners. Industry involvement at an early stage of technology development is likely to mitigate information asymmetries and problems of knowledge transfer. In a research project sponsored by a commercial firm, the firm will bring some related prior knowledge (motivating its interest in the project), and it will try to monitor the ongoing research efforts. Joint research projects with industry partners likewise presuppose some relevant prior knowledge of the industry partner, and some communication of knowledge between both partners. Both forms of collaborative research therefore come with an increased capacity of industry partners to evaluate the potential of inventions made in the project. If their assessment of the technology is low, they may withdraw from the cooperation even before an invention is arrived at, which would increase the average quality of inventions from sponsored and joint research. In addition, knowing the inventor from the collaborative research project helps to build mutual trust, enhancing the willingness to close a licensing deal in the absence of fully symmetric information. Reputation effects and the prospect of future cooperation further reduce the attractiveness of opportunistic behavior. These considerations lead us to the following hypothesis:

Hypothesis 3: Academic inventions from sponsored research or collaborations with industry partners are more likely to be licensed than other inventions.

Lowe (2002) has suggested an effect that might countervail the prediction of Hypothesis 3. He argues that in the process of collaborative research, industry partners may acquire sufficient knowledge of the invention to render subsequent licensing unnecessary. This argument presupposes that the firm is able to design its innovation around the public partner's intellectual property rights, or that the public partner is unable to enforce them.

Finally, we can also conjecture about an effect of inventor seniority on the likelihood of closing a licensing agreement. The superior reputation and more extensive personal network of senior researchers should enhance the credibility of technologies (co-) invented by them, thus increasing the willingness of potential licensees to enter into a contractual agreement. If negotiations are mediated by a technology transfer office (as is the case in our empirical sample), it is likely that senior scientists have more influence on their employer institution than more junior ones. This may further increase the likelihood of a successful licensing agreement. We accordingly conjecture:

Hypothesis 4: Technologies (co-)invented by senior scientists are more likely to be licensed than those by more junior researchers.

Commercialization of licensed technologies

Not only the likelihood of closing an agreement, but also the likelihood of successfully bringing the technology to the market can be expected to differ according to licensee, technology, and inventor characteristics. Post-agreement inventor involvement in the development efforts has been demonstrated to increase the likelihood of successful commercialization (Agrawal, 2006). If a royalty-based contract has been closed, bringing the product to the market is the interest of both licensor and licensee (Jensen and Thursby, 2001). Accordingly, academic inventors harm themselves if they do not cooperate in post-licensing development efforts. They may nonetheless exert less effort than would be called for because of competing demands on their time, particularly when primarily motivated by the reward mechanisms of public science (Stephan, 1996). Equally important for successful commercialization appears their ability to communicate their knowledge to the licensee.

In the case of foreign licensees, geographic distance and language barriers complicate the transfer of uncodified knowledge. Post-agreement inventor involvement is more costly and possibly less effective if national boundaries have to be crossed. This consideration leads us to predict the following:

Hypothesis 5: Inventions licensed to foreign firms are less likely to be commercialized successfully than inventions licensed to domestic firms.

Spin-offs represent an extreme form of inventor involvement. Transfer of uncodified knowledge to the spin-off firm is mostly realized by personal migration of the inventor and/or associates from her laboratory to the new firm. Even though senior scientists frequently do not enter the active management of spin-offs (co-) founded by them (cf. Buenstorf, 2006), inventor-founders nonetheless have strong incentives for engaging in the spin-off's development activities, and they typically assume at least consulting positions in the new venture. Staff members of the spin-off may moreover be able to informally contact their prior co-workers in the inventor laboratory when in need of additional knowledge.

Commercialization activities by spin-offs are expected to benefit from the facilitated transfer of uncodified knowledge. In addition, given a smaller product portfolio, spin-off survival is typically more dependent on specific technologies than survival of established firms. Spin-offs consequently face stronger incentives for successful commercialization (Lowe and Ziedonis, 2006), and are unlikely to license a technology for purely strategic reasons (i.e., to prevent others from using it). Based on these considerations, we predict the following:

Hypothesis 6: Inventions licensed to inventor spin-offs are more likely to be commercialized successfully than inventions licensed to external licensees.

Effective knowledge transfer clearly is not sufficient to ensure successful commercialization. Existing evidence on the commercialization performance of spin-offs is inconclusive. Counter to Hypothesis 6, Shane (2002) stipulates that spin-offs are inferior in commercialization because they lack the required complementary assets (Teece, 1986). He suggests that licensing to spin-offs is primarily observed when patents are ineffective. In contrast, for their sample of licensed inventions from the University of California system, Lowe and Ziedonis (2006) find neither lower commercialization odds nor lower licensing income for spin-off licensees.

In the case of collaborative research projects, knowledge transfer between inventor and licensee is facilitated by absorptive capacities and shared understandings developed in the prior research process. Pre-existing familiarity with the technology also provides the licensee with a speed advantage, enhancing the odds of successful commercialization (Markman et al., 2005). In addition, licensees that were involved in collaborative research leading to the licensed technology have superior information about this technology. Their ability to evaluate its merits should thus be enhanced, which increases the likelihood that licensed inventions can also be commercialized (the selection effect already suggested above). We accordingly expect the following positive effect:

Hypothesis 7: Inventions from sponsored research or collaborations with industry partners are more likely to result in commercially viable products and processes than others.

Agrawal (2006) studies the same issue in the U.S. context, using a sample of 124 licensed inventions from MIT's mechanical engineering and electrical engineering / computer science departments. He finds positive effects for sponsored research both on the likelihood of successful commercialization and on the level of revenues generated thereby. Neither effect is statistically significant, however.

Finally, the successful commercialization of a university invention may also depend on the seniority of the inventor(s). The more senior an inventor is, the higher are her opportunity costs of post-agreement involvement. *Ceteris paribus*, senior scientists are therefore expected to spend less time on their inventions, which will lower their chances to be successfully commercialized. This will be particularly true for inventions licensed to external licensees. We expect senior scientists to be more willing to spend time with their spin-off firms, the success of which is more relevant both to their income and their reputation. This leads us to the last hypotheses:

Hypothesis 8a: Technologies (co-) invented by senior scientists are less likely to be commercialized than inventions by more junior scientists.
Hypothesis 8b: If senior scientists engage in spin-off activities, the commercialization odds of their inventions increase over those of technologies they license to external licensees.

4. Technology transfer at the Max Planck Society

Public research in Germany is characterized by a distinctive division of labor between universities and non-university public research organizations. The Max Planck Society, whose roots go back to the early 20th century, is the country's largest non-university public research organization dedicated to basic research. It receives more than 80 per cent of its budget from public, institutional funding (Max Planck Society, 2005). 78 individual Max Planck Institutes are dispersed all over the country (in addition, three institutes are located abroad). They currently employ some 4,000 researchers.

The Max Planck Society's mission is to complement the university system by taking up large-scale, interdisciplinary, or particularly innovative activities that are out of reach for individual universities. Its research activities encompass the whole spectrum of the sciences and the humanities. Institutes are organized into three sections: the biomedical section, the chemistry, physics and technology section, as well as the humanities and social sciences section.

The Max Planck Society's internal organization is unique. Its strategy – known as the Harnack Principle – is to put its highest-level researchers, the Max Planck directors, in a particularly autonomous and powerful position. Directors are recruited from the most successful researchers of both German and foreign universities. Their mission is research-oriented, with substantial long-term, institutional funding. Currently, there are roughly 260 active directors in the Max Planck Society.

Academic inventions and technology transfer activities from the Max Planck Society have historically been treated differently from those of German university researchers. In general, employees of German firms are subject to the *Arbeitnehmererfindungsgesetz,* which mandates that employees must disclose inventions to their employer, and assigns the property rights in these inventions to the employer. University researchers used to be exempt from this law. They retained the intellectual property rights (IPRs) in their inventions. This so-called *Hochschullehrerprivileg* or "professors' privilege" was abolished in 2002. Since then, German universities have been the legal owners of the inventions made by their researchers. Consequently they are now responsible for patent applications and the licensing of inventions. In particular they have to bear all costs of the patenting process. The inventing researcher is entitled to 30 per cent of the gross licensing revenues from her invention.

The new IPR regime for inventions by German university researchers essentially replicates the rules that Max Planck researchers have always been subject to. They are required to disclose all their inventions to the Max Planck Society, which can then claim ownership of the technology. In this case, the Society organizes the patent protection for the invention (if possible and deemed adequate), as well as the subsequent negotiation and administration of licenses. The inventing researcher receives 30 per cent of all revenues from licenses and patent sales, and the Max Planck Institute employing the researcher gets an additional third of all income.

To organize the patent application and the marketing of Max Planck technologies, the Society in 1970 established a legally independent technology transfer subsidiary that recently was renamed Max Planck Innovation GmbH (before, its name was Garching Innovation after one of the Society's research campuses). After some early and largely unsuccessful attempts of constructing and selling prototypes based on Max Planck inventions, Max Planck Innovation has for the past three decades focused on patenting and licensing activities.

Disclosure of inventions is actively solicited at the individual institutes. Patents are applied for if the invention is patentable and considered sufficiently promising, even if no licensee for the technology has been identified.[1] Technologies are marketed to both domestic and foreign firms. Systematic support and counseling of spin-off activities was taken up in the 1990s, and spin-off numbers have strongly increased since then. Total returns from the licensing activities amount to some € 180 million, with the bulk of income resulting from a small number of highly successful blockbuster technologies. Annual license revenues contribute 1 to 2 per cent to the Max Planck Society's overall budget (Max Planck Society, 2005).

5. Dataset and econometric approach

Sources

This study is primarily based on two sets of data made available by Max Planck Innovation. The first dataset contains all inventions disclosed by Max Planck researchers from the early 1970s to 2004.[2] In total, it encompasses 2,726 inventions. 1,754 resulted in at least one patent application

[1] In this regard, Max Planck Innovation's patenting policy thus appears to be closer to that of the MIT than that of the UC system (cf. Shane, 2002; Lowe and Ziedonis, 2006)

[2] Researchers employed on a scholarship basis, mostly PhD students and international postdocs, are not subject to the German law on employee inventions. To the extent that these individuals made inventions without other Max Planck researchers being involved, they do not show up in the data.

(Table 1). The database includes the title of the invention, names and institute affiliations of the inventors, day of disclosure and (if eligible) patent application, as well as various information regarding further use of the invention.

We linked these data with a second dataset assembled from Max Planck Innovation's licensing agreements. 793 inventions (583 patented inventions) have been licensed, and because some non-exclusive contracts have multiple licensees, there are in total 1,014 licensing agreements. For each contract, information is available on the licensee name and address, dates of closure and (possibly) termination of the contract, arrangements on licensing fees and royalties, as well as actual dates and amounts of payments. The Max Planck inventions are similar to other datasets on commercialized inventions in that payments (in particular, royalties) are extremely skewed. One single Max Planck invention accounts for more than 75 % of the overall returns.

Patent data is used to control for heterogeneity in the quality of (patented) inventions. Our primary proxy for patent quality is the number of members in the patent family. It indicates the geographical breadth of the IPR protection sought by the patent application and is a widely accepted measure of patent quality (Harhoff et al., 2003). We also experimented with the number of IPC classes and granted patents in the family as quality indicators, but they were less predictive.

To obtain this information, we constructed a unique patent database using *Depatisnet*, the publicly available patent search site of the German Patent Office. First, some 8,000 patent applications by the Max Planck Society were identified. These were grouped according to their priority patents, which were then matched to the patents listed in the invention database.

About one third of the patented inventions could not be found in this way because they were not assigned to the Max Planck Society. For these inventions, the patent listed in the inventions dataset was searched in *Depatisnet*, and the corresponding patent family was retrieved. This procedure yielded about 2,800 additional patents.[3]

We restrict our empirical analysis to the 2,261 inventions disclosed in or after 1980. Earlier inventions are excluded for three reasons. First, the earliest entries in the inventions dataset are not consistently inventions by Max Planck researchers, since at the time Garching

[3] In about 70 cases, no patent information was found even though the inventions database identified them as patented. We suspect that most of these cases reflect cancelled applications. On the other hand, for another 70 inventions patents were found that closely matched the disclosed inventions in terms of title and inventor names, but the respective patents do not show up in the inventions database. We do not use this information in the subsequent analysis.

Innovation was offering its services to a variety of other public research organizations and even commercial firms, whose inventions show up in our data. Second, the quality of the earliest data was below that related to later inventions. Third, systematic support of spin-off activities out of the Max Planck Society only began around 1990, and spin-off activities were of little import in the earliest years of the data.

Variables

Two dependent variables are used in the subsequent models. First, we study whether or not an invention was licensed. Licensing can readily be inferred from the existence of a licensing agreement. 699 (31 per cent) of all inventions disclosed after 1980 have been included in a licensing agreement. This number is comparable to U.S. institutions studied before. For example, Lowe and Ziedonis (2006) study 734 licensing agreements closed by the UC system between 1981 and 1999. Second, we are interested in the factors conditioning successful commercialization. While this information is not directly contained in the data, we derive it from the existence of positive royalty payments. Of course, this restricts the sample for studying commercialization to those inventions where licensing agreements provided for royalty payments (not only fixed fees). In the post-1980 sample, there are 644 cases of this kind, of which 307 (48 per cent) have resulted in positive royalties.

As central explanatory variables, the analysis uses four indicator variables identifying, respectively, foreign licensees, spin-off licensees, collaborative inventions, and senior inventors. To study effects of international licensing, licensees were classified into domestic versus foreign according to the postal address given in the data. Accordingly, German branches and subsidiaries of foreign companies are classified as German licensees. This is in line with our primary interest in potential difficulties arising from information asymmetries and the transfer of uncodified knowledge, which we would expect to depend more on the licensee's physical location than to whether or not it is foreign-owned. International license agreements are commonplace in the Max Planck Society. Of the 896 license agreements for inventions disclosed since 1980, 273 are with foreign licensees. Spin-offs among the licensees were identified on the basis of Max Planck Innovation's spin-off database. There are 211 cases of licenses to spin-offs in the sample.

Collaborative inventions are identified on the basis of patent applications. We define as collaborative all inventions that were not exclusively assigned to the Max Planck Society (i.e., they are either assigned to the Max Planck Society and a private-sector firms, or they are exclusively assigned to a private-sector firm). Their total number is 349. Finally, senior scientist involvement is proxied by technologies (co-) invented by one or (in rare cases) several Max Planck directors, which is justified by the distinctive position directors have in the Max Planck hierarchy. We identified the directors using published sources (Henning and Ullmann, 1998; Max Planck Society, 2000) and information provided by the Max Planck Society's human resource department.

A set of control variables is used. Existence and quality of patents related to an invention is proxied by patent (application) family size. We also control for discipline-specific factors with a dummy variable denoting inventions from the biomedical section of the Max Planck Society. This dummy is zero for inventions out of the chemistry, physics and technology section.[4] Time effects are captured by distinguishing two cohorts of inventions (those disclosed up to and after 1990, respectively).

Methods

To study the incidence of licensing events, two sets of competing risks models are used, which are both based on semi-parametric Cox regressions (Lunn and McNeil, 1995). We alternatively interpret licensing to foreign versus German firms (models 1-3), or licensing to spin-offs versus external licenses (models 4-6), as competing risks. Cox regressions are attractive because as hazard rate models, their coefficient estimates are based on both the occurrence of the event and the time elapsed before it occurs, thus making full use of the available information. Right censoring imposed by the end of the observation period is also taken into account in the Cox regressions. Cox models are preferred over fully parametric hazard models because no assumptions need be made about the time-dependence of the hazard, which would be hard to justify in the present context. The proportionality assumption underlying the Cox regression is in line with the actual shapes of the survivor functions (cf. the Kaplan-Meier graphs in Figures 1 and 2). Since we have daily data, interval censoring and ties are no relevant issues, and continuous-time Cox regressions can be applied. An invention enters the risk pool at the day of

[4] There are a handful of inventions that cannot be assigned to one of these sections, mostly because they were disclosed by staff of the Max Planck Society's general administration. The dummy variable is zero for these inventions. No inventions were disclosed out of the humanities section. We also experimented with individual dummy variables denoting the top seven institutes in the number of commercialized inventions (five of which are from the biomedical section). This had little effect on the results.

disclosure or initial patent application, whichever comes first.[5] It leaves the risk pool at the day that the initial licensing agreement is concluded.

The likelihood of successful commercialization is studied in two steps. First, we estimate a set of logit models where commercialization is the dependent variable, using the set of licensing agreements as our sample.[6] As noted above, commercialization is defined as the existence of positive royalty payments. Obviously, this restricts the sample to those licensing agreements that contain provisions for royalty payments. A shortcoming of this approach is that it does not account for selection effects: Technologies licensed to different kinds of licensees may differ in their characteristics, and these differences may affect their subsequent commercialization odds. To illustrate, it might be possible that a researchers retains her best inventions for spin-off activities, while inferior technologies are licensed to external licensees.

As can be seen from Table 2 for the case of spin-off versus external licensing, there are indeed substantial differences in the values of the explanatory variables for the different subsets of technologies, suggesting that selection into the different kinds of licensing contracts (domestic versus foreign, spin-off versus external) may not have been random. To test whether differences in the commercialization likelihood of different types of licensees are due to differences in observables, we interpret specific kinds of licensing agreements as treatments, and estimate how being treated affected the commercialization likelihood using propensity score matching (Rosenbloom and Rubin, 1983; Heckman et al., 1998; cf. also Sianesi, 2001; Wooldridge, 2002, ch. 18). Specifically, two propensity score matching estimators are employed: in the first one, the treatment consists in being licensed to a foreign licensee. In the second one, licensing to a spin-off is the treatment.

The intuition underlying propensity score matching is as follows. In non-experimental data, for each observation only one outcome (here: commercialization success) is observed. If Y_{i0} denotes observation *i*'s outcome without treatment, Y_{i1} denotes observation *i*'s outcome with treatment, and $T \in \{0, 1\}$ denotes treatment, we would like to know the treatment effect $Y_{i1} - Y_{i0}$,

[5] Particularly for patented inventions that were not assigned to the Max Planck Society, we found a number of instances where the disclosure date is later than the date of patent application. This is explicable by the fact that the industrial partner may have processed the patent application independent of the disclosure process initiated by the Max Planck inventor. The time gap between the dates was mostly small. In a small number of cases, licensing agreements were (technically) concluded before either disclosure or application dates, mostly because options for licenses on nascent technologies were negotiated, or new inventions were included into existing licensing agreements. These cases are excluded from the analysis of licensing hazards.

[6] We also experimented with the corresponding probit models, which yielded very similar results.

but can only observe one of the two outcomes. If selection into treatment is nonrandom, the effect of treatment on the outcome cannot be separated from the selection effect in the data.

Propensity score matching uses the available information on individual observations to generate a counterfactual control group from the untreated observations, such that differences in observable characteristics are minimized between the treated observations and the members of the control group. The basic approach is to calculate the probability of receiving treatment for each observation based on its observable characteristics, using probit or logit models. This conditional probability is the propensity score, which is then used for matching the treated observations to similar non-treated ones. Under the assumption that selection into treatment only depends on observables, the average effect of treatment can then be estimated at the population level. Specifically, both the *average treatment effect* (ATE), $E(Y_{i1} - Y_{i0})$, and the *average treatment effect on the treated* (ATT), $E(Y_{i1} - Y_{i0} \mid T = 1)$, can be estimated.

Various propensity score-based matching methods have been proposed. When large samples of non-treated observations are available, each treated observation can be matched to an "identical twin," i.e. a non-treated observation that is very similar in its propensity score, and the outcomes of both observations are then compared. Alternatively, each treated observation can be matched to a weighted average of untreated observations, where the weights are determined by how similar the propensity scores of the untreated observations are to that of the treated one. We adopt the latter approach below. We report results obtained by estimating propensity scores with logit models, using a Gaussian kernel for matching, where the weights of the untreated observations follow a normal distribution around the propensity score of the respective treated one. The estimations were performed using the *psmatch2* routine for Stata 9.0 (Leuven and Sianesi, 2003).

6. Results

Hazard of licensing

Hypothesis 1 posits that licensing agreements are less likely to be closed with foreign licensees than with domestic firms. This is supported by Figure 1 and by the results of Models 1-3 (Table 3), which find a large and significantly negative coefficient estimate for the variable indicating foreign licensees. The models also find that in the biomedical section of the Max Planck Society, inventions are significantly less likely to be licensed to foreign firms than in the chemical-physics-technology section. In contrast, the effects of neither the size of the patent family nor of the time period of the invention are systematically different for foreign versus domestic inventions.

Models 4-6 (Table 4) find that, overall, the likelihood of licensing to spin-offs is significantly lower than that of licensing to external licensees, which contradicts Hypothesis 2. A possible interpretation of this finding is that spin-off licensing is indeed turned to only when prior attempts to find external licensees have been unsuccessful (Shane, 2002). Again, there are systematic differences in how the control variables in the estimation affect the alternative types of licensees. Inventions from the biomedical sections are not only more likely to be licensed in general, but even more so in the case of spin-off licensees (Model 4). There has moreover been some substitution of spin-off licensing for agreements with external licensees, as the former became more likely after 1990, while the latter became less common (Models 4-6). Finally, the coefficient estimates for patent family size do not suggest that licensing to spin-offs is less affected by patent protection than licensing to external firms, which would be expected if spin-offs were primarily turned to in situations of ineffective property rights protection (Shane, 2002).

As regards collaborative inventions, the evidence from the competing risks models is mixed. Models 2 and 3 indicate that collaborative inventions are less likely to be licensed, but this effect is restricted to domestic licensing. Likewise, Models 5 and 6 (Table 4) find a significantly negative effect of industry cooperation on spin-off licensing, but not on licensing by external firms. Thus, we find that collaborative inventions are disadvantaged in specific licensing situations (domestic, spin-offs), but not in others (foreign, external licensees). Apart from a marginally significant positive coefficient estimate in Model 6, however, no evidence is obtained in support of Hypothesis 3, which predicted a higher licensing likelihood for collaborative inventions.[7] These findings suggest that reduced information asymmetry through prior joint research does not systematically increase the chances of the respective technology to be licensed. They may be explicable by Lowe's (2002) argument suggesting that knowledge transfers during the collaborative project may render licensing unnecessary. Possibly, selection enabled by better information is also counteracting the effect of reduced difficulty in negotiating, and only the most promising technologies from collaborative research are actually licensed.

[7] These findings are corroborated by estimating separate coefficient estimates for the competing risks in stratified models (Lunn and McNeil, 1995, Method B).

In both Model 3 and Model 6 a large and significantly positive effect of director-inventors on the licensing hazard is obtained, indicating that senior scientists are more successful in licensing their inventions, as predicted by Hypothesis 4. Model 6 moreover suggests that the director effect is even stronger in the case of spin-off licensing. In contrast, while the coefficient estimate for director-inventors is positive in the case of foreign licensees, it is not significantly different from zero.

Likelihood of commercialization

As predicted by Hypothesis 5, logit models estimating the likelihood of successful commercialization suggest that foreign licensees are significantly less likely to commercialize a licensed technology (Models 7-11 in Table 5).[8] They thus lend support to the conjecture that international knowledge transfer causes problems hindering the successful development of university technologies. This finding is corroborated by the results of the propensity score matching, which are reported as Model 12 in Table 6.[9] In the original dataset, the commercialization likelihood of technologies licensed to foreign firm is -.133 lower than that of technologies licensed within Germany. Comparing the technologies licensed to foreigners with similar technologies licensed at home reduces this difference to -.105, which is significant at the .05 level. If the whole population of licensed technologies is considered, the average effect of treatment is -.113. We thus conclude that the observable disadvantage of technologies licensed abroad is not primarily due to selection.

Logit models also find that spin-offs are less likely to commercialize inventions than external licensees (Models 9-11). Apparently, enhanced inventor involvement in spin-off licensees is not sufficient to ensure the success of these firms. However, propensity score matching indicates that the poorer commercialization record of spin-offs reflects substantial effects of selection. When selection into spin-off licensing is controlled for (Model 13 in Table 6), the average treatment effect on the treated (ATT) is reduced from -.174 to -.049, which is not significantly different from zero. In contrast, the average treatment effect on all population members is -.112 and significant at the .05 level.

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[8] All logit models were alternatively estimated as probit models, which yielded qualitatively identical results.

[9] To obtain propensity scores, a logit model for the likelihood of being licensed to a foreign licensee was estimated first, using as explanatory variables the patent family size, dummies denoting collaborative inventions, director-inventors, post-1990 invention and inventions from the biomedical section, as well as seven additional dummy variables denoting the institutes that had the largest number of commercialized inventions. Kernel-based matching of treated and untreated observations was then adopted (cf. also section 5).

In line with Hypothesis 7, we find that collaborative inventions have significantly higher chances of being commercialized (Models 8-11). This indicates that knowledge transfer is indeed facilitated by prior joint research activities. It is moreover consistent with the possibility that licensed collaborative inventions are a pre-selected sample from all collaborative inventions.

If Max Planck directors are among the inventors of a technology, its subsequent commercialization odds are reduced, which is consistent with the opportunity cost argument underlying Hypothesis 8a (Model 10). Adding the director-inventor variable to the model reduces the coefficient estimate of the spin-off dummy by less than 20 per cent, suggesting that spin-off licensees may be inferior in commercialization even when controlling for the involvement of senior scientists.

To probe this further, in Model 11 we replace the overlapping dummy variables denoting spin-off licensees and director-inventors by three separate, non-overlapping dummies denoting, respectively, director-inventions licensed to spin-offs, other inventions licensed to spin-offs, and director-inventions licensed to external licensees. The results indicate that these three groups of inventions are all similarly disadvantaged in their commercialization likelihood (relative to non-director inventions licensed to external licensees, and after controlling for the other explanatory variables). Thus, if inventions by directors are licensed to spin-offs, the negative effects found for both variables do not seem to be cumulative. While these findings are not consistent with Hypothesis 8b, a weaker version of the Hypothesis would be supported: in the case of director inventions, licensing to a spin-off does not reduce the commercialization likelihood further. Possibly, this result is due to two counteracting influences: higher incentives for inventor collaboration, but less business experience by the spin-off. Relatively speaking, spin-offs are then more suited to commercialize inventions by senior scientists than those made by more junior ones.

Even though they are not in the focus of the study, the control variables finally deserve some attention. Patent family size, our proxy of invention quality, has no effect on commercialization. Inventions from the biomedical section, which were licensed more often, seem to have lower odds of commercialization (Models 7 and 8), but this effect loses its significance after controlling for spin-off licensees and director-inventors, both of which are more widespread in the life sciences. Finally, all commercialization models find a sizeable and highly significant negative effect of later inventions. This is to be expected since later inventions had less time to be commercialized, particularly since the logit model cannot control for right censoring. It cannot be ruled out, however, that at least some of the difference in commercialization odds between older and younger inventions may reflect a decreasing trend in the commercial values of Max Plank inventions.

7. Discussion

Our findings on foreign licensees and collaborative inventions are largely in line with the theoretical considerations of sections 2 and 3. They suggest that license-based technology transfer from public research is complicated by information asymmetry and problems of ensuring post-agreement inventor involvement, which is essential due to the partially uncodified character of knowledge in early-stage technologies.

Licensing agreements with foreign licensees were found to be less frequent and less successful in commercialization than agreements with domestic firms. In contrast, our findings paint a largely positive picture regarding the licensing of cooperative inventions. While they are less likely to be licensed to spin-offs and to (undifferentiated) domestic licensees, no negative effects could be discerned regarding the licensing of collaborative inventions to domestic incumbents or foreign firms. In addition, they consistently had higher chances of commercialization than “pure” university inventions. In evaluating these findings, it has to be considered that industry cooperation may itself lead to the transfer of knowledge to the private sector (irrespective of subsequent licensing), thus the present results can be considered as lower bound estimates of effective knowledge transfer through collaborative research. A caveat also has to be made in this context: our identification strategy based on patent applications underestimates the extent of industry cooperation, as we cannot identify collaborative inventions unless they result in patent applications.

In contrast, the results on spin-off licensees are less compatible with the conjectured role of information asymmetry and uncodified knowledge, as spin-offs had lower licensing hazards than external licensees, and were not more likely to commercialize licensed technologies. While this pattern might be consistent with interpreting spin-offs as a kind of last resort licensees, we found spin-off licensing to be unaffected by the extent of patent protection. This is not in line with Shane’s (2002) suggestion that spin-offs are turned to when knowledge transfer problems frustrate the negotiation of contracts with established firms.

Propensity score matching suggests that selection effects underlie the inferior commercialization performance of spin-offs. The trend toward spin-off licensing instead of external licensing discernible in the data may nonetheless be problematic. This is because our results indicate a conflicting relationship between industry cooperation on the one hand and domestic licensing, particularly to spin-offs, on the other. Possibly, cooperative research, a successful form of technology transfer, is adversely affected by the increasing spin-off activities. In our view, such interdependencies between the different forms of technology transfer warrant closer scrutiny in the future.

Finally, when singling out the most senior scientists of the Max Planck Society, we found their inventions more likely to be licensed, yet less likely to be commercialized. Again, this pattern is easy to reconcile with the theoretical considerations. Network and reputation effects enhance the chances of finding a licensee, while senior scientists face the highest opportunity costs of engaging in post-agreement involvement.[10]

The findings on director-inventors may also provide a new perspective on the spin-off process. Director-inventions are particularly likely to be licensed to spin-offs, and their commercialization likelihood is not further reduced by spin-off licensing. This suggests a specific role for spin-offs in the commercialization of the knowledge of "star scientists," (Zucker and Darby, 1996) who have little incentive to engage in more traditional forms of licensing.

A general limitation of this study was that commercialization success was not measured in monetary terms. A preliminary analysis of the payments flows based on licensing of Max Planck Society inventions indicates that alternative criteria of commercialization success, in our case the hazard of commercialization versus the flow of licensing revenues, do not necessarily move together. We will explore this more thoroughly in future work. There are of course further limitations. Among them is that the present analysis only covered a single organization, which moreover follows a dedicated mission to focus on basic research. This clearly restricts the possibility to generalize the results. Also on the agenda is a closer look at developments over time. Given that the Max Planck Society was a pioneer of IPR-based technology transfer even by international standards, we plan to study in more detail the evolution of these activities.

[10] In the long run, this pattern should of course not be stable.

References

Agrawal. A. 2006. "Engaging the inventor: Exploring licensing strategies for university inventions and the role of latent knowledge." *Strategic Management Journal*, 27: 63-79.

Bozeman, B. 2000. "Technology transfer and public policy: a review of research and theory." *Research Policy*, 29: 627-655.

Buenstorf, G. 2006. "Is commercialization good or bad for science? Individual-level evidence from the Max Planck Society." Max Planck Institute of Economics: Papers on Economics and Innovation # 0617.

Cohen, W. M. and D. A. Levinthal. 1990. "Absorptive capacity: a new perspective of learning and innovation." *Administrative Science Quarterly*, 35: 128-152.

Harhoff, D., F. M. Scherer and K. Voper. 2003. "Citations, family size, opposition and the value of patent rights." *Research Policy*, 32: 1343-1363.

Heckman, J. J.m H. Ichimura and P. Todd. 1998. "Matching as an Econometric Evaluation Esitmator." *Review of Economic Studies,* 65: 261-294.

Henning, E. and D. Ullmann. 1998. *Wissenschaftliche Mitglieder der Max-Planck-Gesellschaft zur Förderung der Wissenschaften im Bild.* Berlin: Duncker & Humblot.

Jensen, R. and M. Thursby. 2001. "Proofs and Prototypes for Sale: The Licensing of University Inventions." *American Economic Review*, 91: 240-259.

Leuven, E. and B. Sianesi. 2003. "PSMATCH2: Stata module to perform full Mahalanobis and propensity score matching, common support graphing, and covariate imbalance testing." http://ideas.repec.org/c/boc/bocode/s432001.html.

Lowe, R. A. 2002. "Entrepreneurship and Information Asymmetry: Theory and Evidence from the University of California." Carnegie Mellon University, mimeo.

Lowe, R. A. 2006. "Who Develops a University Invention? The Impact of Tacit Knowledge and Licensing Policies." *Journal of Technology Transfer*, 31: 415-429.

Lowe, R. A. and A. A. Ziedonis. 2006. "Overoptimism and the Performance of Entrepreneurial Firms." *Management Science*, 52: 173-186.

Lunn, M. and D. McNeil. 1995. "Applying Cox Regression to Competing Risks." *Biometrics*, 51: 524-532.

Markman, G. D., P. T. Gianiodis, P.H. Phan and D. B. Balkin. 2005. "Innovation Speed: Transferring University Technology to Market." *Research Policy*, 34: 1058-1075.

Max Planck Society. 2000. *Handbook of Scientific Members.* Munich.

Mowery, D. C., R. R. Nelson, B. N. Sampat and A. A. Ziedonis. 2001. "The growth of patenting and licensing by U.S. universities: an assessment of the effects of the Bayh-Dole act of 1980." *Research Policy*, 30: 99-119.

Murray, F. and S. Stern. 2005. "Do Formal Intellectual Property Rights Hinder the Free Flow of Scientific Knowledge? An Empirical Test of the Anti-Commons Hypothesis." *NBER Working Paper* 11465.

Phan, P. H. and D. S. Siegel. 2006. "The Effectiveness of University Technology Transfer." *Foundations and Trends in Entrepreneurship*, 2: 77-144.

Rosenbloom, P. R. and D. B. Rubin. 1983. "The central role of the propensity score in observational studies for causal effects." *Biometrika*, 70: 41-55.

Shane, S. 2002. "Selling University Technology: Patterns from MIT." *Management Science*, 48: 122-137.

Sianesi, B. 2001. "Implementing Propensity Score Matching Estimators with STATA." Prepared for the UK Stata Users Group, VII Meeting, London, May 2001.

Stephan, P. 1996. "The Economics of Science." *Journal of Economic Literature*, 34: 1199-1235.

Teece, D. J. 1986. "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy." *Research Policy*, 15: 285-305.

Wooldridge, J. W. 2002. *Econometric Analysis of Cross Section and Panel Data.* Cambridge MA: MIT Press.

Zellner, C. 2003. "The Economic Effects of Basic Research: Evidence for Embodied Knowledge Transfer via Scientists' Migration." *Research Policy*, 32: 1881-1895.

Zucker, L. G. and M. R. Darby. 1996. "Star Scientists and Institutional Transformations: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry." *Proceedings of the National Academy of Science (USA)*, 93: 12709-12716.

Table 1: Inventions disclosed by Max Planck researchers, 1970-2005

	Full sample	*1980-2005 Inventions*
Inventions	2,726	2,261
(patented)	*1,754*	*1,454*
Licensed inventions	793	699
(patented)	*583*	*507*
Collaborative (patented only)	389	349
First licensed to foreign firm	206	178

Table 2: Descriptive statistics

	All inventions			*Licensing contracts providing for royalties*		
				All	*External licensees*	*Spin-off licensees*
	(mean)	*(min)*	*(max)*	*(mean)*	*(mean)*	*(mean)*
Collaborative invention	.151	0	1	.127	.139	.103
Director-inventor	.133	0	1	.408	.323	.595
Biomedical section	.600	0	1	.763	.732	.831
Patent family size	2.550	0	45	4.731	4.432	5.395
Post 1990 invention	.748	0	1	.669	.584	.856
Commercialization				.463	.517	.344
Spin-off licensee				.311	--	--
Foreign licensee				.301	.363	.164

Table 3: Licensing hazards 1: domestic versus foreign (competing risks Cox models)

	Model 1	*Model 2*	*Model 3*
Foreign licensee	-1.783*** (.274)	-1.724*** (.277)	-1.705*** (.269)
Collaborative invention		-.708** (.304)	-.608** (.279)
Collaborative*foreign		.793** (.333)	.732** (.310)
Director-inventor			1.398*** (.208)
Director*foreign			.298 (243)
Biomedical section	1.168*** (.211)	1.100*** (.210)	.924*** (.215)
Biomedical*foreign	-.619*** (.234)	-.542** (.234)	-.606** (.246)
Patent family size	.066*** (.007)	.079*** (.009)	.055*** (.010)
Patent family*foreign	-.012 (.155)	-.026** (.011)	-.033** (.013)
Post 1990 invention	-.019 (.183)	.048 (.187)	-.155 (.190)
Post 1990*foreign	-.138 (.206)	-.212 (.210)	-.216 (.216)
Observations (events)	2245 (630)	2245 (630)	2245 (630)
Log-likelihood ($p > chi^2$)	-4926.874 (.0000)	-4923.125 (.0000)	-4789.436 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 4: Licensing hazards 2: spin-off versus external (competing risks Cox models)

	Model 4	*Model 5*	*Model 6*
Spin-off licensee	-2.499*** (.315)	-2.438*** (.319)	-2.353*** (.302)
Collaborative invention		.189 (.134)	.225* (.131)
Collaborative*spin-off		-.999*** (.352)	-.856*** (.288)
Director-inventor			1.407*** (.119)
Director*spin-off			.684*** (.214)
Biomedical section	.574*** (.107)	.598*** (.108)	.431*** (.110)
Biomedical*spin-off	.456** (.220)	.361 (.223)	.136 (.228)
Patent family size	.057*** (.005)	.053*** (.005)	.031*** (.007)
Patent family*spin-off	.007 (.008)	.028*** (.011)	.009 (.011)
Post 1990 invention	-.446*** (.102)	-.462*** (.102)	-.629*** (.102)
Post 1990*spin-off	1.573*** (.261)	1.664*** (.268)	1.499*** (.266)
Observations (events)	2245 (612)	2245 (612)	2245 (612)
Log-likelihood ($p > chi^2$)	-4790.771 (.0000)	-4784.471 (.0000)	-4649.138 (.0000)

Robust standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 5: Likelihood of commercialization (logit models)

	Model 7	*Model 8*	*Model 9*	*Model 10*	*Model 11*
Foreign licensee	-.547*** (.192)	-.532*** (.193)	-.658*** (.199)	-.596*** (.202)	-.588*** (.202)
Collaborative invention		.586** (.260)	.518** (.264)	.518* (.266)	.541** (.267)
Spin-off licensee			-.538*** (.198)	-.438** (.204)	
Director-inventor				-.414** (.186)	
Director*spin-off licensee					-.711*** (.252)
Director * external licensee					-.649*** (.227)
Non-director * spin-off licensee					-.780*** (.277)
Biomedical section	-.425** (.205)	-.389* (.206)	-.340 (.208)	-.284 (.211)	-.268 (.211)
Patent family size	-.007 (.014)	-.014 (.014)	-.011 (.014)	-.005 (.015)	-.006 (.015)
Post 1990 invention	-1.143*** (.183)	-1.110*** (.210)	-1.080*** (.191)	-1.051*** (.192)	-1.087*** (.195)
Constant	1.136*** (.210)	1.098*** (.210)	1.173*** (.213)	1.204*** (.214)	1.285*** (.220)
Observations	628	628	628	628	628
Log-likelihood (p > chi^2)	-402.364 (.0000)	-399.798 (.0000)	-396.071 (.0000)	-393.605 (.0000)	-391.881 (.0000)
Pseudo-R^2	0.072	0.078	0.087	0.092	0.096

Standard errors in parentheses; *;**; and *** denote significance at the .10; .05; and .01 levels, respectively.

Table 6: Likelihood of commercialization (propensity score matching)

	Model 12 (foreign vs. domestic)			*Model 13 (spin-off vs. external)*		
	Unmatched	*ATT*	*ATE*	*Unmatched*	*ATT*	*ATE*
Treated	.370	.370		.344	.344	
Untreated	.503	.476		.517	.392	
Difference	-.133	-.105	-.113	-.174	-.049	-.112
S.E. (bootstrapped)		.046	.047		.048	.048
95% Confidence interval		-.197	-.206		-.016	-.207
		-.014	-.021		.047	-.145

Note: Kernel matching (Gaussian kernel; bandwidth = .06); standard errors obtained through bootstrapping (n = 100)

Figure 1: Licensing hazards: domestic (0) versus foreign (1) licensees

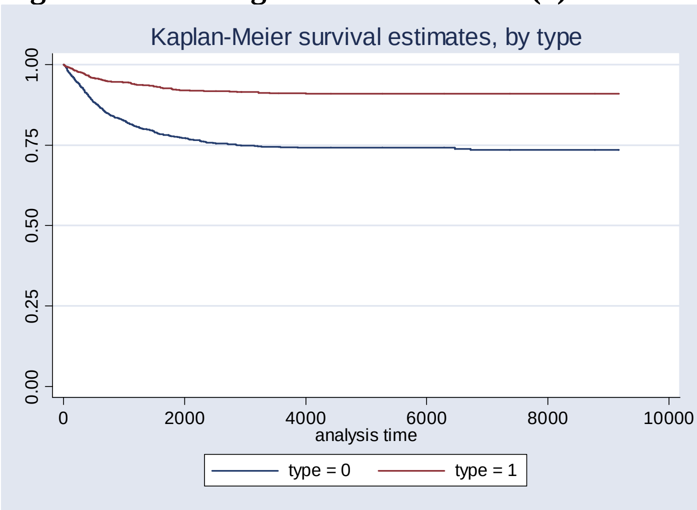

Figure 2: Licensing hazards: external (0) versus spin-off (1) licensees