ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Working Paper Series

Why do patents facilitate trade in technology? Testing the disclosure and appropriation effects

Gaétan de Rassenfosse
Alfons Palangkaraya
Elizabeth Webster

April 2016

Institute for Technology and Public Policy
Working Paper series no. 2

Available at: https://ideas.repec.org/p/iip/wpaper/2.html

Why do patents facilitate trade in technology?

Testing the disclosure and appropriation effects

Gaétan de Rassenfosse

Alfons Palangkaraya

Elizabeth Webster

Abstract

Evidence suggests that patents facilitate technology transactions but the reasons for the effect are unclear. Patents may assist trade in technology by either: (i) protecting buyers against the expropriation of the idea (the 'appropriation effect'); or (ii) increasing information sharing during the negotiation phase through publication of technical details contained in the patent document (the 'disclosure effect'). We estimate the strength of both effects using exact matching analysis on a novel dataset of 860 technology transaction negotiations. We find evidence for the appropriation but not the disclosure effect. Technology transaction negotiations involving a granted patent instead of a pending patent (our test for the appropriation effect) are significantly more likely to be successfully completed. The appropriation effect is stronger in technology fields where patent protection is known to be more effective such as biotech, chemicals, drugs and medical.

Keywords: appropriability; disclosure; licensing; market for technology; patent

1. Introduction

This paper studies the mechanisms through which intellectual property (IP) rights affect the success of negotiations to trade technology. Trade in technology has become a central part of today's highly-specialized and opened innovation process (Arora, Fosfuri, and Gambardella 2001; Chesbrough 2003). Data from the United States (US) National Science Foundation, for example, show that the ratio of US business research and development (R&D) contracted out to external enterprises trebled between 1981 and 2007 from about two per cent to seven per cent (NSB, 2008). Technology trade improves welfare as it allows for the emergence of specialized inventors, which increases the innovation quality, speeds up development time, and enhances knowledge diffusion (Lamoreaux and Sokoloff 2001; Spulber 2008). However, as in the case of tangible goods, the realization of welfare gains from technology trade rests upon well-functioning markets.

Several authors have argued and provided evidence that markets for technology suffer from imperfections, often leading to transaction failures (Caves, Crookell and Killing 1983; Zeckhauser 1996; Arora, Fosfuri and Gambardella, 2001; Gans and Stern 2010; Zhang, Agrawal, and Cockburn 2013). Imperfections include, but are not limited to, high search costs and other transaction costs, lack of market thickness, and incomplete information (and related concerns about information asymmetry such as in a market for lemons). Although the literature provides ample evidence that patents assist technology transactions (Lamoreaux and Sokoloff 2001; Arora and Ceccagnoli 2006; Branstetter, Fisman, and Foley 2006; Gans, Hsu, and Stern 2008), there is still a need for a better understanding of *how* patents help innovative firms and technology traders in overcoming frictions in the market for technology. There is little empirical evidence that can explain the mechanisms through which patents facilitate technology trade.

In this paper, we empirically investigate the relative importance of two reasons why patents are helpful in technology market. As Gans, Hsu, and Stern (2008: 987) observe "...patent rights can have a significant impact on the *risk of expropriation* and the willingness of licensors to *disclose* unprotected information" (italics added). The former part of the statement means that patents facilitate technology trade protecting the buyer against expropriation. In this 'traditional' role of patents, possession of a valid patent may help assure the prospective buyer that his or her future profits will be protected. We refer to this reason as the 'appropriation effect' hypothesis. On the other hand, the latter part of the statement implies that patents facilitate technology trade by increasing information sharing during the negotiation phase since pending patent applications are published 18 months after the filing date. We refer to this reason as the 'disclosure effect' hypothesis.

To the best of our knowledge, existing studies on markets for technology have not provided any formal empirical examination of these hypotheses. Most studies have so far sought to provide evidence that patents matter, without seeking to disentangle the actual mechanisms through which patents operate. Yet understanding the mechanisms would shed light on the causes of transaction failures and would help in proposing appropriate policy responses to market imperfections. From the perspective of our research question, a limitation of the existing studies is the absence of information to predict the relevant counterfactuals for estimating the two effects: they either focus only on patented technologies or on technologies that will ultimately become licensed. For example, Shane (2002) studies Massachusetts Institute of Technology's patents and finds that inventions are more likely to be licensed when patents are an effective mechanism for appropriating the returns to innovation. Similarly, studying patented technologies of Harvard University's faculty, Elfenbein (2007) finds that a patent more than doubles the likelihood of finding a license partner. Gans, Hsu, and Stern (2008) obtain a similar result in their study of 200 technology licensing deals announced between 1990 and 1999. Two recent studies by Hegde and Luo (2013) and Drivas, Zhen and Wright (2013) provide some insights on part of the mechanism: they find that patent disclosure accelerates the licensing of technologies by reducing search costs.

A key distinguishing feature of the present study is that it uses a novel survey data of technology transaction negotiations in which *not all* negotiations involve a patent, and *not all* negotiations are successful. The setup allows us to construct counterfactuals to estimate the importance of the two hypothesized roles of patents. In addition, it enables us to obtain estimates of patent effects that do not suffer from the sample bias in existing studies that only consider patented technologies. The analysis relies on a sample of 860 immature technology transactions—sale, license, cross-license, contract research, etc.—negotiated in Australia around the 2010s. A first noteworthy finding is that 20.3 per cent of technology transaction negotiations in the sample do not involve a patent. Second, we find that the positive patent effect comes mostly from limiting expropriation of the technology (and more so in technology fields where patents are effective). The evidence in support of the disclosure effect is less apparent.

2. Literature review and hypotheses

2.1 Existing studies

A first set of studies that are relevant to the focus of this paper offers indirect evidence of the importance of patents in markets for technology. Lamoreaux and Sokoloff (2001) argue that the changes in the US patent law in the nineteenth century were instrumental in the development of a market for technology. Burhop (2010) documents a well-developed market for patents in Imperial Germany. Using more recent data, Branstetter, Fisman, and Foley (2006) show that technology transfer within US multinational firms increases in response to a strengthening of intellectual property (IP) rights in host countries. Arora and Ceccagnoli (2006) find that an increase in the effectiveness of patent protection can increase licensing propensity. Another stream of research has surveyed the motives to patent and provides additional evidence on the importance of patents in technology transactions (Cohen, Nelson, and Walsh 2000; Blind et al. 2006; de Rassenfosse 2012; Jensen, Palangkaraya and Webster 2015). These surveys of patenting firms typically report that between 20 and 30 per cent of respondents take patents in order to generate licensing revenues.

More direct evidence on the role of patents in technology transactions is scarcer. Drawing on data on 1,397 patents assigned to Massachusetts Institute of Technology, Shane (2002) studies among other questions, the determinants of patent licensing. He finds that inventions are more likely to be licensed when patents are an effective mechanism for appropriating the returns to innovation. Using a sample of technologies invented by faculty at Harvard University, Elfenbein (2007) studies the factors that affect the likelihood of an invention being licensed. He finds that, although a majority of technologies are licensed prior to the receipt of a patent, a patent more than doubles the likelihood of finding a license partner. Gans, Hsu, and Stern (2008) study how the IP system impacts the timing of cooperation between start-up technology entrepreneurs and established firms during commercialization. Based on a sample of 200 technology-licensing deals announced in 1990–1999 they find that patent allowance speeds up licensing. The grant event is associated with a 70 per cent increase in the hazard rate of licensing. Other authors have recently produced additional evidence on the effect of patents on the *timing* of licensing agreements. Hegde and Luo (2013) and Drivas, Zhen and Wright (2013) use the enactment of the American Inventors Protection Act of 1999, which requires patent applications to be published 18 months after the priority filing date, to show that patent disclosure accelerates the licensing of technologies. Hegde and Luo (2013) take this result as evidence that patents reduce search cost in the market for ideas.

2.2 Hypotheses

Although the above studies provide evidence of the impact of patents, they were not designed to explain the reason(s) for the effect. This is because their samples had a different focus: some samples focus on patented technologies only, while others focus only on technologies that will ultimately become licensed. As a result these studies provide limited insight on the extent to which, and the reason(s) why, patents increase the success rate of technology transactions. In a nutshell, this paper empirically investigates how patents facilitate technology trade: by insulating the idea against expropriation (appropriation effect); and by increasing the sharing of information during the negotiation phase by disclosing technical details of the idea (disclosure effect). The first effect arises because a granted patent gives its owner the right to exclude others from using the ideas embodied in the patent document. The second effect occurs because, by law, patent applications are made public 18 months after application. Thus, there is no reason for the seller to withhold any relevant technical information that would have become public anyway.

2.2.1 Appropriation Effect

HYPOTHESIS 1: *Patents facilitate technology trade by strengthening the appropriability of the invention.*

Because inventions are typically non-excludable (or at least weakly excludable), buyers may rely on patent protection to ensure exclusive use of their inventions. Traditionally, the patent system ensures excludability by granting the owner of an invention the temporary monopoly right over its invention.

However, in practice, the effectiveness of patents in enhancing appropriation varies significantly across technology fields (Mansfield 1986; Levin et al. 1987; Cohen, Nelson, and Walsh 2000). In particular, patent protection is more critical in technologies based on more codified knowledge, which are easier to imitate and are more exposed to third-party expropriation (Teece 1986). These include the chemical and drug-related technologies in which patent validity is easier to assess and infringement is easier to detect (Levin et al. 1987). Hence, we may expect the appropriation effect to be stronger in such fields of technology. By contrast, patent effectiveness is lower in complex technologies, which rely more on hard-to-articulate tacit knowledge beyond the codified description of technology in the patent document. Summarizing existing studies, Troy and Werle (2008) argue that patent documents do not provide tacit knowledge on the context of the technology creation, relevant technical data and complicated formulas, and complementary know-how of the patentee. In addition, patents in these technologies have more fuzzy boundaries and are easier to circumvent without detection (Bessen and Meurer, 2008). [1]

2.2.2 Disclosure Effect

HYPOTHESIS 2: *Patents facilitate technology trade by enabling information disclosure during negotiations*.

Mowery (1983) and Pisano (1990) argue that an exchange can fail to occur when the quality of the product traded is opaque, which happens for example if trade is infrequent or quality is only revealed through use. We may surmise that this problem is especially great in frontier technologies due to the novelty of the idea and the absence of working examples and established nomenclature. Furthermore, where the nature of the good traded is a mere idea, this problem is even more acute. As first articulated by Arrow (1962), knowledge markets are different from traditional markets. The value of a piece of knowledge is unknown to the buyer until it is disclosed to him or her, but once disclosed the buyer has no need to buy it. Assuming that the buyer is not prepared to buy blind, the market will collapse if the seller is reluctant to share valuable information for fear of second party expropriation.

[1] By contrast, the chemical and drug-related technologies are harder to invent around: adding an extra atom to a molecule can change the properties of the compound significantly.

The much-celebrated Kearns' case of an intermittent windscreen wiper is the archetypical example of second-party expropriation. The inventor, Robert Kearns, disclosed technical details of the idea to Ford Motor Company and Chrysler Corporation in a bid to license the technology. Although the offer was rejected, Kearns found out afterward that Ford and Chrysler had installed intermittent wipers in their cars (Seabrook 2008). Clearly, Kearns had disclosed too much information during the negotiation.

This disclosure dilemma, which has been well accepted among IP professional circles for some time, is also raised within the academic literature. Scholars argue that patents can solve this market failure (Ordover 1991; Arora 1995; Lamoreaux and Sokoloff 2001; Anton and Yao 2003; Gans and Stern 2003; Gans, Hsu, and Stern 2008; OECD 2008; and Kani and Motohashi 2012). Patent holders can knowingly share the patent application information with the prospective buyer with the confidence that they are legally protected from second-party expropriation. We expect that the more fulsome provision of information, under the cover of the patent, will increase the chance that the negotiation will succeed.[2] However, parties who seek to negotiate before the patent has been successfully examined do not have the legal protection yet have disclosed considerable information about their technology in the patent application process. As discussed later, we exploit this distinction between technologies with patent pending and those that had never filed for a patent to identify the disclosure effect of patents.

3. Data and methodology

We perform a matching analysis to novel data on 860 negotiations to sell or license (simply, to trade) immature technology in Australia. A specific feature of this study is that the unit of analysis is a technology transaction *negotiation* where not all negotiations were successful and not all negotiations involved a granted (or pending) patent. This allows for a richer analysis on the effect of patent on negotiation outcome than can be done with data limited to patented technologies only. Immature technologies, in this study, refer to ideas that need further work in order to be useful or deliver final products in contrast to mature technologies that are ready-to-use. The distinction between mature and immature technologies is seldom made explicit in the literature, even though the issues at stake are quite peculiar to the degree of maturity of technologies. Most studies of markets for technology consider the trading of immature technologies (or 'embryonic' technologies, see Jensen and Thursby 2001) because it is the area where transaction frictions are the most stringent. By contrast, the market for mature (*i.e.,* proven) technologies, at the far end of the innovation process, raises issues such as price competition, which are well studied in the broader economics literature (see *e.g.* Katz and Shapiro 1986).

[2] Note that our hypothesis concerns the effect of patents on success via the disclosure effect—we are not testing whether or not disclosure matters *per se*.

3.1 Data source and sample descriptive

We collected the data by conducting a survey of Australian technology traders. For the scoping phase, we conducted 66 semi-structured interviews around Australia during 2010. This preparatory work allowed us to identify the types of individuals and organizations that may participate in the Australian technology market and to identify key variables to collect from the survey. The final list of potential traders, which comprised both in-house business development managers and independent go-betweens, was surveyed in early 2011 by mail. The sample includes 1,427 people who we believed had a hands-on role in technology transactions (we excluded managers with only supervisory or policy roles). The overall response rate was 47.0 per cent, which is high for a company-level, mail-based survey and perhaps reflects the provision of an incentive in the first mail-out (a A$50 gift voucher).[3] The response rates vary from 31.6 per cent for business angels to 65.0 per cent for public sector research organizations. While 670 people responded to the survey, 214 indicated that they had not been involved in a technology transaction with their current employer, leaving 456 people providing useable information.

In the survey, we defined a technology transaction as: "A non-commercial ready technology that is exchanged between organizations for further development. Exclude transactions between parents and subsidiaries. Exclude material transfer agreements". A successful negotiation is one where the respondent described the transaction as completed, whereas an unsuccessful transaction is one that was abandoned (that is, not completed or concluded after 12 months). To ensure a balanced dataset between successful and unsuccessful negotiations, we asked each survey participant about the last completed and the last abandoned negotiation. Importantly, asking about the last transaction (as opposed to letting the respondents choose which transactions to report) ensures that the transactions in the sample are not systematically correlated with their size or with their importance to respondent's organizations. Furthermore, all negotiations contained in the dataset have been the subject of serious negotiations: the average time spent in a successful negotiation was nine months. Thus, cold calls to potential buyers that ended in the response 'we are not interested' are not sampled.

The final data set consists of 467 successful (completed) and 393 unsuccessful (abandoned) transactions of which 68 per cent occurred between 2009 and 2011 (and 27 per cent occurred between 2005 and 2009). Table 1 provides a summary of univariate statistics according to whether *at the time of negotiations* the seller held a granted patent (33 per cent of observations); a pending patent but no granted patent (39 per cent); or had never filed for a patent (27 per cent). Respondents that reported both a granted and pending patent were coded as 'granted' (these may comprise instances where the application was granted part-way through negotiations). An asterisk in the last column indicates that

[3] For the purpose of comparison, Berneman et al. (2009) web-based licensing survey achieved a response rate of about 15 per cent (with 947 responses received from 6000+ participants contacted).

we are unable to (statistically) reject, at the 5 per cent level of significance, the null hypothesis that the means for the three groups are equal. For example, data suggest that the negotiations involving a granted patent were about 10 percentage points more likely to be successful than transactions with a patent pending or no filed patent. Transactions involving licenses, bio-chemical technologies and the more valuable technologies are also more likely to involve a patent. However, as revealed by the surveys of Mansfield (1986) and Arundel and Kabla (1998), not all pharmaceutical and chemical inventions are the subject of a patent application. The average approximated value of the transacted technology is in the AU$500,000–1,000,000 range.

Table 1 Sample Means (N=860 technology transaction negotiations)

Characteristics	Definition	Granted patent[1]	Pending patent[1]	Not filed[1]	Equal means
Successful	1 if transaction was successful; 0 if abandoned	0.597	0.490	0.481	
Respondent seller	1 if survey respondent was acting on behalf of the technology seller; 0 if otherwise	0.682	0.772	0.551	
Type of transaction					
Sale	1 if the reported transaction is a sale of IP; 0 otherwise	0.219	0.172	0.171	*
License	1 if the transaction is a license/cross-license of IP; 0 otherwise	0.703	0.724	0.367	
Other	1 if transaction is a contract research/sale of technical knowhow/company acquisition/R&D partnership/other; 0 otherwise.	0.148	0.157	0.494	
Technology area					
Bio-chem-drug	1 if biotech, chemical, or drug & medical; 0 otherwise	0.661	0.623	0.487	
Software	1 if software; 0 otherwise	0.131	0.145	0.215	*
Other	1 if electronic/mechanical/other	0.240	0.267	0.310	*
How buyer and seller met					
Cold-called, conference, seminar, 3rd party	1 if buyer and seller met via a cold call; conference or professional seminar; third party introduction; 0 otherwise	0.375	0.386	0.335	*
Industry network	1 if buyer and seller met via industry network; 0 otherwise	0.385	0.362	0.424	*
Repeat business and other	1 if buyer and seller met from repeat business or other connection; 0 otherwise.	0.276	0.240	0.247	*
Has copyright also	1 if the transacted technology also has copyright protection; 0 otherwise	0.131	0.077	0.000	
Technical feasibility[a]	A Likert scale of 1 (certain) to 7 (very uncertain) of the technical feasibility of the transacted technology	3.387	4.015	3.533	
Commercial readiness					
Basic/applied science	1 if the transacted technology is at the stage of basic/applied science; 0 otherwise	0.233	0.303	0.310	*
Proof of concept	1 if the transacted technology is at the stage of proof of concept; 0 otherwise	0.336	0.392	0.241	
Prototype	1 if the transacted technology is at the stage of prototype; 0 otherwise	0.187	0.214	0.241	*
Other	1 if the transacted technology is at the manufacturing pilot or other stage; 0 otherwise	0.265	0.101	0.241	
Market-orientated parties	1 if the buyer or seller was from the private sector; 0 otherwise	0.929	0.881	0.949	
Distribution of sample		36.4%	43.3%	20.3%	100%

[a]N=847;[b]N=846;[c]N=748. Equal mean tests based on the Wilks' lambda, Pillai's trace, Lawley-Hotelling trace and Roy's largest root tests. The symbol '*' indicates that we cannot reject the null hypothesis that the sample means are the same between the three patent groups. 1. The exact question was 'At the time of negotiations, what type of formal intellectual property (IP) protection did the technology have?' (circle all that apply). Patent pending; registered patent, copyright, none of the above.

3.2 Identification strategy

The gist of the identification strategy is to compare the probability of sealing a deal across groups of negotiations in which either the extent of legal protection differs (appropriation effect) or the extent of information disclosure differs (disclosure effect) but not both.

To estimate the *appropriation* effect we compare negotiations over technologies that held a granted patent to those that held only a pending patent at the time of negotiation. Since, in both cases, all relevant features of the technologies are already disclosed by the corresponding patent applications, the main difference between the two groups is the degree of legal certainty over the negotiated technology. The patent-grant group has been granted legal protection, while the patent-pending group has not.[4] We refer to the group of negotiations involving technologies with granted patents as the treatment group and to the group of negotiations involving technologies with pending patents as the control group. Thus, the treatment is whether the patent is granted at any time during negotiations. The outcome to be compared is whether or not the negotiating parties succeeded in reaching a deal. We identify the appropriation effect as the difference between the conditional probability of successful negotiation for the treatment group and the counterfactual conditional probability of successful negotiation of the same group had it not received the treatment. We use the control group's outcome to construct an estimate of this counterfactual after accounting for endogenous selection into treatment by matching the control and treatment groups on observed characteristics.

To estimate the *disclosure* effect we compare negotiations involving technologies that had a patent pending at the time of negotiations, and had thus committed to a significant amount of disclosure, to those involving technologies that had never been applied for patent. Regardless of the reasons why a patent has not been sought (early-stage research, not patentable subject matter, cost, or desire for secrecy), the owners of the not-filed technologies have a choice of how much to reveal during negotiations. It is plausible that, on average, how much they reveal is no more, but rather less, than what has been revealed by the pending-patent group. We refer to the group of negotiations for technologies subject to a pending patent as the treatment group and to the group of negotiations for technologies that had never been the subject of a patent application as the control group. Thus, the treatment is whether the technology was associated with a pending patent and the outcome of interest is whether or not the negotiations ended with a transaction. We identify the disclosure effect using the same approach as above, that is, we construct the counterfactual outcome of the treatment group based on the matched control group's outcome.

[4] While the possibility exists that granted patents become later revoked, post-grant challenges to validity are very rare. Lemley and Shapiro (2005) estimate that 0.1 percent of US patents are litigated to trial.

The logic behind this identification strategy is that while neither the pending-patent group nor the never-filed group have assured protection from expropriation of their future profits, the patent-pending group has already committed to a significant amount of disclosure. Parties who seek to negotiate before the patent has been successfully examined do not have the legal protection yet have disclosed considerable information on their technology. Indeed the Australian IP office estimates that considerably less than one percent of applications are withdrawn before publication.[5] A patent document provides valuable technical information about the invention. For it to be valid, it must give enough information to enable a person 'skilled in the art' to reproduce the invention. Long (2002), for example, argues that in some circumstances the information in patents may be more valuable than the substance of the rights protected by the patent. Also, Hedge and Luo (2013) find that some inventors are more likely to license their inventions immediately after publication of their patent application, suggesting that the information disclosed in the pending application matters.

To obtain unbiased estimates of the appropriation and disclosure effects we need to control for factors that affect both patent status (*i.e.*, the decision to file for a patent or enter negotiations with only a pending patent) *and* negotiation success. Inventions or new forms of know-how are by definition unique and it is therefore not possible to control for all differences between the treatment and control groups. However, we expect to find some systematic factors at play.

First let us consider the decision to file for a patent. Besides the fact that some technologies may not be patentable subject matter, some inventions may embody an inventive step that is too small, and some may be too early stage to have *prima facie* utility. The cost of application may also deter many would-be sellers with limited funds. Costs, largely in patent attorney fees, can exceed $100,000 but are commonly thought to be in the tens of thousands. Secrecy may be a preferred way to protect ideas, especially process inventions, as it does not involve application costs and can potentially last forever. Finally, the modus operandi of the sellers' organisation with respect to invention disclosures can dictate the decision to patent or not.

The second consideration is the decision to enter negotiations after filing but before grant. There is evidence that sellers may want to license their technology before a patent is granted for speed-to-market reason (Gans, Hsu and Stern 2008). It is not uncommon for the examination process to take four to five years and sometimes longer. In addition, the thinness of the market means that a seller would be unwise to refuse to negotiate if a potential buyer presented himself or herself, regardless of patent status.

The semi-structured interviews threw up several systematic factors that would lead to successful negotiations. By definition, negotiations will only succeed if there is an overlap between

[5] Oral communication from IP Australia.

the seller's reservation price and the maximum the buyer is willing to pay. How large this overlap is will depend on seller's and buyer's uncertainty around their views on the invention's technical feasibility and the market for the final product. It may also depend on the degree of trust between the parties and the seller's fear that the buyer will expropriate their idea. At first glance, one could think that the overall value of the idea affects negotiation success. However, conditioning on the value being high enough to open discussions, higher value does not imply that there is a greater overlap between the seller's and buyer's valuations. Instead, what matters is the assessed commercialisability of the invention.[6]

This discussion shows that there is a limited set of factors that will systematically affect both patent status and negotiation success. The main confounding factors associated with the *appropriation effect* are those reflecting the speed-to-market imperative and the gap between seller's and buyer's valuations. The main confounding factors associated with the *disclosure effect* are those reflecting the uncertainty of the technology's patentability and its commercialisability. However, the difference in the patent filing status suggests that the difference in the underlying characteristics between the treatment and control groups for the disclosure effect is potentially larger than the difference for the appropriation effect groups. In section 3.2.2 below, we discuss how we account empirically for these confounding factors by matching on observables. Furthermore, failure to account for any unobservable source of confoundedness will lead to biased estimates. In order to assess the sensitivity of the results to unobserved heterogeneity, we complement the matching analysis with the bounding test proposed by Rosenbaum (2002), see section 3.2.3.

3.2.1 Average treatment effect on the treated

We seek to estimate the effects of patents on the probability of concluding a deal. We ask: (i) what would have been the outcome of deals involving a registered patent if they had involved only a pending patent; and (ii) what would have been the outcome of deals involving a pending patent if they had involved technologies for which no patent was filed?

Formally, we seek to estimate the average treatment effect on the treated (ATT). If Y^1 is the set of completed negotiations with either type of treatment (*REG* or *PEND*) and Y^0 is the set of completed negotiations of the same group if they did not have this treatment, then:

$$\begin{aligned} ATT &= E\left[Y_i^1 - Y_i^0 \mid REG_i \text{ or } PEND_i = 1\right] \\ &= E\left[Y_i^1 \mid REG_i \text{ or } PEND_i = 1\right] - E\left[Y_i^0 \mid REG_i \text{ or } PEND_i = 1\right] \end{aligned} \quad (1)$$

where *i* is the unit of observation (a technology transaction negotiation), *REG* denotes the treatment of whether the patent is registered at the time of negotiations (to estimate the appropriation effect), and

[6] This is not the same as the value of the patent. Simple ideas, such as the 'one-click' patent or the potato peeler, can be more easily commercialised than large and costly ideas.

PEND denotes the treatment of whether a pending patent was filed (to estimate the disclosure effect). If the appropriation and disclosure effects are important, then the probability for the negotiation to be completed increases with treatment, that is, ATT > 0.

Whereas the factual outcome $E\left[Y_i^1 \mid REG_i \text{ or } PEND_i = 1\right]$ is directly observed, the counterfactual outcome $E\left[Y_i^0 \mid REG_i \text{ or } PEND_i = 1\right]$ is not. Rather, we observe: $E\left[Y_i^0 \mid REG_i \text{ or } PEND_i = 0\right]$. As discussed in the identification strategy above we cannot be sure that the data are random with respect to selection into the treatment, such that we cannot simply assume that $E\left[Y_i^0 \mid REG_i \text{ or } PEND_i = 1\right] = E\left[Y_i^0 \mid REG_i \text{ or } PEND_i = 0\right]$ and compare the probability of completion across observed groups. If factors that cause selection into treatment also influence the outcome, then the estimate of the treatment effect will be biased. The solution adopted involves identifying a group of untreated units that match the treated units on a set of observable covariates, *X*, and that constitute valid counterfactuals. This technique, known as matched sampling (Cochran 1968; Rubin 1973), leads to an unbiased estimate of the ATT if all the confounding factors are captured in *X* (Rosenbaum and Rubin 1983). Once a set of counterfactuals is identified, the empirical counterpart of equation (1) is given by:

$$\widehat{ATT} = \frac{1}{N^T} \sum_{i:REG_i \text{ or } PEND_i=1} \left[Y_i^{obs} - \hat{Y}_i^0\right] \tag{2}$$

where N^T is the number of treated units.

The analysis uses a matching method known as coarsened exact matching (CEM) introduced by Iacus, King and Porro (2011a, 2011b). The basic idea behind CEM is to coarsen each continuous variable so that substantively indistinguishable values are grouped and assigned the same numerical value; then, exact-matching algorithm is applied to each strata within the coarsened data to identify the control group; finally, the coarsened data are discarded and the original (uncoarsened) values of the matched data are retained.[7] Iacus, King and Porro (2011a, 2011b) and Blackwell et al. (2009) discuss the various desirable properties of CEM as a matching method. For the study, the method is particularly attractive given the nature of the data in which all observed matching covariates are discrete as described below.[8]

3.2.2 Matching covariates

The relevant matching covariates are those that determine both treatment assignment and outcome but are not affected by treatment assignment. The latter condition is straightforward to satisfy because we

[7] We use a user written Stata's package "cem" to implement the matching (Blackwell et al. 2009).
[8] In fact, since most matching covariates are dummies and there is no grouping of the dummy values, the CEM matching method we use is essentially an exact matching method. This means that once the matching are done and balance is achieved, equation (2) can be used directly to estimate the ATT of interest without any further regression analysis required (Blackwell et al. 2009).

observe technological characteristics that do not change easily such as commercial-readiness, technological area, and technical feasibility *inter alia*. For the former condition, we observe characteristics of the transacted technology that we expect to be correlated with the decision to apply for patent and/or the grant of the application and the outcome of the negotiation.

In our set up for estimating the *appropriation* effect, sellers in both groups took the decision to file for a patent. We need to control for factors that might cause parties to want to enter negotiations earlier rather than later (that is, before a patent is issued) and that also affect negotiation outcome. Some parties may seek to negotiate before the patent has been granted while others wait until the legal uncertainty has been resolved. Some groups may be more candid about the content of the technology than others.

Together with the elements raised at the beginning of section 3.2, this discussion suggests that the first covariate that could affect both negotiation outcome and patent status is the degree of feasibility of the technology (one dimension of the quality of a technology). Table 1 presents *prima facie* evidence that sellers with more technically risky ideas chose to negotiate early in the patent lifecycle. It may also be harder to find an overlap in the seller-buyer valuation space for inventions that are technically more uncertain. To control for this possibility, we include a measure of the uncertainty of the technical feasibility as a matching covariate. It is also plausible that this feasibility variable captures the extent of tacit knowledge of the technology that is not communicated by the patent application thus making negotiations more fraught.

A second covariate is the degree of commercial readiness of the technology. Because of the utility and patentable subject matter rules, late-stage technologies may have had a quicker chance of receiving a patent examination decision than early-stage technologies. It is reasonable to assume that commercial readiness might affect negotiation outcome (*e.g.,* because technologies far from market may be more complex to trade and negotiations more prone to failure). Commercial readiness is captured using the basic/applied science dummy variable.

Thirdly, we include technology area as a matching covariate (one indicator variable for biotech, chemicals, drugs and medical combined and a second indicator for software) because it is plausible that both how early negotiations commence in the patent application process and the probability of reaching successful negotiations are influenced by the invention's technology area. For example, people working in faster moving technologies may prefer to enter negotiations well before examination, and these technologies may also have systematically higher (or lower) negotiation success rates.

Finally, we include the market orientation of the organizations involved. The modus operandi of private-sector firms, compared to universities, public research organizations and government agencies, is likely to differ with respect to when to start negotiations and how open they are to disclosing information about the technology. The latter should affect the seller-buyer valuation gap. It is plausible that more market-oriented organizations are more secretive about the content of their ideas than those from a public institution. These private sector organizations may also have different, arguably more difficult, negotiation styles. Each of these matching covariates is defined and summarized in Table 1 presented earlier.

To assess the robustness of the estimated *appropriation* effect, we limit the sample in two ways: only those contracts with an exclusivity clause; and only technologies in the codified areas of biotech, chemicals, drugs and medical (keeping the matching covariates the same). We expect that the appropriation effect will be larger for these sub-samples because either the need to legally exclude all others has been reported by the buyer as being highly important or because of the highly codified nature of the technology.

With respect to the *disclosure* effect, we need to control for covariates that could affect both negotiation outcome and decision to go to a negotiation with a pending patent as opposed to without filing any patent application. One such covariate is the degree of commercial readiness of the technology. Some early-stage technologies may be too early stage to be sure about its patentability and this early stage may also affect negotiation success. It is also reasonable to assume that commercial readiness might affect negotiation outcome (*e.g.,* because technologies far from market may be more complex to trade and negotiations more prone to failure). Commercial readiness is captured using a dummy variable for the basic/applied science stage.

Secondly, we include technology area as a matching covariate (one indicator variable for biotech, chemicals, drugs and medical combined and a second indicator for software) because the propensity to patent varies across technology fields (Arundel and Kabla 1998; Cohen, Nelson and Walsh 2000), and these technologies may also have systematically higher (or lower) negotiation success rates.

Thirdly, we include whether or not the technology was protected by copyright. It is plausible that the knowledge that automatic copyright protection exists, say in the form of data protection, could reduce the desire to file for a patent but also be associated with easier to negotiate technologies.

Fourthly, we include a variable that captures specific reasons the invention owner felt cautious about patenting. It includes whether the technology was not considered patentable subject matter, whether it was thought to be early stage technology, or whether the owner simply did not want to disclose. All these factors may also affect the overlap between seller's and buyer's valuations and thus the chance of negotiation success.

Finally, we include the market orientation of the organizations involved. As above, the modus operandi of private-sector firms, compared to universities, public research organizations and government agencies, is likely to differ with respect to the decision to apply for a patent and how open they are to disclose information. It is plausible that more market-oriented organizations are more secretive about the content of their ideas than those from a public institution. These private sector organizations may also have different, arguably more difficult, negotiation styles. Each of the matching covariates is defined and summarized in Table 1 presented earlier.

We do not have measures of the technology-specific cost of filing a patent. Insofar as this cost is related both to the decision to seek patent protection and the probability of negotiation success, it comprises an unobserved confounding factor. In general, the treatment (patent pending) and control (not filed) groups involved in the disclosure effect estimation are likely to differ more systematically due to unobserved factors than the respective groups for the appropriation effect.

After presenting the headline results, we test the robustness of the disclosure hypothesis by limiting the sample in two ways. First, we exclude negotiations that did not include any on-going inventor participation as these negotiations should be affected more by the *ex-ante* disclosure effect. Secondly, we exclude technologies that are not patentable subject matter, or are very early-stage or are only protected by copyright, since these features may affect both the decision to file for a patent and negotiation success.

3.2.3 Limitation of the methodology

A limitation of the matching method is its implied assumption that all relevant confounding factors are measured in the dataset (Heckman and Navarro-Lozano 2004). Although one cannot test for the presence of non-random selection into treatment, one can conduct tests for the sensitivity of results to differing levels of unobserved heterogeneity. For example, in the case of the disclosure effect, the possibility remains that the successes of the negotiations were affected by other unmeasured factors such as the net cost of the patent application process (after taking out the costs saved during the negotiating phase on account of the patent) and any other information that buyers may glean from the decision not to file for a patent.

To test the robustness of our results to unobservable factors, we conduct the bounding test first proposed by Rosenbaum (2002) and codified by Becker and Caliendo (2007)—see the Appendix for details. The test asks how much hidden bias can be present before the qualitative conclusions of the study begin to change. This test does not 'prove' the unconfoundedness assumption inherent in the matching method but rather determines how biased an unobserved variable must be to render the treatment effect insignificant.

4. Results

4.1 Estimating the appropriation effect

Table 2 summarizes the matching results and the estimated appropriation effect. In this case, the treatment group consists of negotiations for technologies protected by a registered patent and the control group consists of negotiations for technologies that have only a pending patent. The exact matching pre-processing produces a 'perfectly' matched sample of treatment and control groups. Based on the matched sample, the estimated appropriation effect (ATT) is 9.4 percentage points and is statistically significant. The grant effect rises to 16.6 percentage points with the strata-by-strata estimate. When the sample is restricted either to negotiations requiring an exclusivity clause or to technology areas in which patent is considered as more effective (biotech, chemicals, drugs & medical), the appropriation effect is larger than the full sample estimate (13.5 and 14.2 percentage points respectively).

Table 2 Estimates of the appropriation effect

	(1)	(2)	(3)	(4)	(5)
	No Correction	CEM			
	Full sample	Full sample	Strata by strata	Exclusivity clause only	Codified technologies only
N Strata	-	79	79	57	40
N Matched Strata	-	38	38	27	22
N Discarded Observations	-	68	68	43	31
Mean Standardized Bias	-	0.0	0.0	0.0	0.0
N Treated	283	267	267	121	180
N Control	337	285	285	142	186
Coefficient Treated (holding a granted patent)	0.592	0.592	-	0.612	0.600
Coefficient Control (holding a pending patent)	0.478	0.498	-	0.476	0.458
ATT (= Difference)	0.115***	0.094**	0.166**	0.135*	0.142***
	(0.042)	*(0.045)*	*(0.074)*	*(0.070)*	*(0.056)*

Note. Dependent variable is whether a contract was signed (Yes/No). 'CEM': Coarsened Exact Matching; ATT: 'Average Treatment effect on the Treated'. Standard errors in parentheses. Standard error for the strata-by-strata estimate obtained using equal weight for each strata. *,**,***: $p < .10, .05, .01$ (two-tailed).

Furthermore, respondents were asked to state their patent status during the term of negotiations. We found that 25 per cent of the situations involving a granted patent also involved a pending patent. It is probable in these instances that the patent was granted during the course of negotiations. In the matching estimations above, these instances have been classified as holding a granted patent. To the extent that the patent grant caused sellers to disclose more information than was given in the patent application, we will have overestimated the appropriation effect. On the other hand, to the extent that buyers believe there is a good chance that the pending patent will be granted, we have underestimated the appropriation effect.

The Q_{MH}^{+} test statistics of overestimation due to hidden bias (reported in the Appendix) suggests that the appropriation effect is positive and statistically significant up to a gamma value of 1.2. In other words, the conclusion that the appropriation effect is positive and statistically significant is robust to unobserved factors that would positively affect both treatment assignment and outcome such that successful negotiations are 20 per cent more likely to be in the treatment group. Given that the treatment and control groups are already matched on observables, a change in the two groups' odds ratio of more than 20 per cent would require a relatively large hidden bias.

4.2 Estimating the disclosure effect

The estimation of the disclosure effect of patent involves computing the average difference between completion rate of negotiations of technology with pending patent (the treatment group) and completion rate of negotiations of technology involving no patent (the control group). Table 3 presents the matching results and the estimated disclosure effect. The Mean Standardized Bias (MSB) is zero in all specifications. This result indicates that exact matching on observable covariates has been achieved.

The headline ATT result for the various scenarios shows that in no instance is disclosure statistically significant. Accordingly, there is no empirical evidence to support the hypothesis that patent facilitates trade by increasing information sharing during the negotiation phase through publication of technical details contained in the patent document.[9] The Q_{MH}^{-} test statistics to detect underestimation due to hidden bias (reported in the Appendix) suggests that holding a pending patent will only show a positive effect if there are unobserved factors that positively impact on selection into patent pending status but negatively affect negotiation success if gamma exceeds 1.4 (at the 10% probability threshold). This figure means that the conclusion of no disclosure effect would not be altered if the matching of both groups had failed to control for an unobserved characteristic strongly negatively related to negotiation success and positively related to selection into the treatment group such that the odds ratio into treatment is 40 per cent higher than when there is no hidden bias. Again, given that the treatment and control groups are already matched on observables, this result suggests that a large amount of hidden bias is required to change our conclusion.

[9] We have also restricted the sample to negotiations in the areas of biotech, chemicals, drugs & medical (results are not shown on Table 3). The ATT is -0.088 and not significantly different from zero (p-value of 0.40).

Table 3 Estimates of the disclosure effect

	(1)	(2)	(3)	(4)	(5)
	No Correction	CEM			
	Full sample	Full sample	Strata by Strata	Excl. ongoing inventor participation	Excl. not patentable
N Strata	-	35	35	31	32
N Matched Strata	-	13	13	11	11
N Discarded Observations	-	88	88	55	73
Mean Standardized Bias	-	0.0	0.0	0.0	0.0
N Treated	337	284	284	161	281
N Control	156	121	121	85	93
Coefficient Treated (holding a pending patent)	0.454	0.454	-	0.406	0.448
Coefficient Control (never filed for a patent)	0.463	0.492	-	0.486	0.496
ATT (= Difference)	-0.009	-0.038	0.110	-0.079	-0.047
	(0.054)	*(0.078)*	*(0.097)*	*(0.089)*	*(0.079)*

Note. Dependent variable is whether a contract was signed (Yes/No). 'CEM': Coarsened Exact Matching; ATT: 'Average Treatment effect on the Treated'. Standard errors in parentheses. Standard error for the strata-by-strata estimate obtained using equal weight for each strata. ATTs are not significantly different from 0. Not patentable observations comprise those deemed not patentable subject matter, very early-stage or only protected by copyright.

One risk associated with the operationalization of the test for the disclosure effect is that the buyer may also see the technologies in the patent-pending group as more appropriable than in the no-patent group because the chance is high that patent-pending technologies will eventually be granted patent protection. Would this be the case, our approach would bias the disclosure effect upwardly, so that our conclusion of no significant effect would be stronger.[10]

4.3 Discussion

Taken together, the results presented above support the view that patents facilitate the success of technology negotiations and suggest that the reason is mostly because they ensure the appropriation of the technology. This view is consistent with the strong result for the appropriation effect obtained on the subsample of biotech, chemicals, drugs & medical technologies, for which we know that patents are effective for protecting against imitation. However, there are alternative interpretations and limitations of the methodology that warrant further discussion.

[10] It is also possible, but unlikely, that a seller filed during negotiations and the respondent claimed that this was a 'no patent filed' type of negotiation. We asked a follow up question about why sellers did not file: 39 per cent said that the technology was not patentable subject matter; 22 per cent said that the technology was too early stage; and 12 per cent said that the owner did not want to disclose. Given these sorts of responses, we believe the respondent to the questionnaire would have classified a technology as patent pending or patent grant if a patent were filed part way through the negotiation process.

With respect to the interpretation of the results, we do not know for sure whether the legal title acts by clarifying the border between ideas or the border between users. While we have couched our discussion in terms of establishing a clear demarcation about who can and cannot use the technology, it is possible that the legal title works primarily, or also, by clearing up any fuzzy idea boundaries (see Bessen and Meurer 2008). Both factors are interrelated, as without a clear delineation of idea boundaries it is difficult to prove trespass. Two factors however speak against the latter explanation. First, to the extent that the codified technologies have innately clear boundaries, the observation that a granted legal title has a larger effect in the highly codified technologies suggests that the legal title operates to establish who can and cannot use a technology, not where the boundary lies. Second, we observe from the data that inclusion of an exclusivity clause in the proposed contract has a significant effect on negotiation success. This observation implies that the right to exclude other users has value to buyers.

It is also possible that the legal title operates merely as a signal of the value of the technology. Although patent offices do not assess patentability on the basis of technological value, but rather novelty and non-obviousness, buyers could still be more willing to commit when a trusted agent such as the patent office certifies the technology they are buying. However, given that the effect is greater in fields where patent protection is known to be more effective for appropriation, we believe that a granted legal title offers more than just a signal of technological value. [11]

Finally, the results do not imply that invention disclosure through the patent document is an irrelevant dimension in markets for technology. The analysis presented in this paper considers the success of negotiations *once parties have met*. It suggests that disclosure through the patent document does not increase the chance of success during negotiation. However, previous research has shown that invention disclosure through the patent document *increases the chance that parties meet*. For example, Hedge and Luo (2013) provide evidence that patent publications are an effective form of advertising for would-be licensors (see also Hellmann 2007).

There are a number of limitations to our work. First, as with any matched sample analysis, the validity of the results rests on the relevance of the matching covariates. The matching method we have used, namely coarsened exact matching, has reduced the observable global imbalance between treatment and control groups to essentially zero. We have matched on a dimension of quality in an effort to best capture quality variation. In order to alleviate remaining concerns related to the confounding effect of quality, we should point out that we did not find evidence of a market for lemons in our semi-structured interviews. A series of robustness tests (not reported) in the form of different matching variables (splitting the codified technology groups into: biotech; chemicals; and

[11] We also note that one of the matching covariates is the degree of feasibility of the technology, which mitigates this concern to some extent.

drugs and medical; using the type of contract; using a proxy measure for trust between parties; and controlling for whether the respondent was representing the seller or buyer) do not change the initial findings.

Matching on observables does not eliminate endogenous selection due to unobservables. We are confident that differences in confounding factors between the patent granted and patent pending groups are fairly well controlled for by the matching method. However, the potentially greater ex-ante disparity in the characteristics of the patent pending and not filed group and the limited types of observed characteristics in our data make us less confident that we have fully controlled for the full set of relevant confounders. Hence, although we feel that the finding of 'no significant effect' is reasonable, it is probably not as robust evidence as the appropriation effect result.

However, in most reasonable scenarios we can think of, not being able to control for unobservables, such as the expectation that a pending patent will be granted, implies that our estimated treatment effect will overestimate the disclosure effect.[12] To complement this intuition, we have conducted some sensitivity tests of how much countervailing unobservable factors can co-exist with our findings. Specifically, we implement a bounding approach to assess the sensitivity of our estimates to 'hidden bias' arising from selection on unobservables (Aakvik 2001). As detailed in the Appendix we find our estimates to be robust to at least 20–40 per cent higher odds of selection into the treatment group due to unobservables which are negatively (positively) correlated with outcomes leading to underestimated (overestimated) treatment effects. Given that the treatment and control groups are already 'exactly' matched, only a large amount of hidden bias would change the two groups' odds ratio by more than 20–40 per cent.

Second, we are aware of no other studies that explicitly address the issues raised in this paper. A special effort was dedicated to collecting novel survey data on technology transaction negotiations. Survey design involves a trade-off between breadth (in terms of response rate) and depth (in terms of quantity of information collected per respondent). A desire to strike the right balance between these two dimensions has precluded us from collecting the publication number of the patent documents associated with the transaction. As a result, it is not possible to link our survey data to patent databases and use the patent information to control for invention specific heterogeneity.[13]

[12] If, for example, the decision to apply for patent depends on the willingness to disclose, we will only have a selection problem if not wanting to disclose makes it easier to sell or if the more secretive sellers are better negotiators.

[13] We see this concern as a minor one since this issue has been dealt with elsewhere. Indeed, the vast majority of studies on licensing has focused on patent-related deals and has analyzed patent-level characteristics. The present work deliberately moves away from this trend. In addition, it is not clear that matching negotiations on patent-level characteristics would have improved estimates since we only need to match on confounding variables. In addition, patent-level data are of no use for the test for the disclosure effect.

Third, a note regarding the generalizability of the findings. Australia is a small open economy with an English-speaking population and a common law tradition whose geographically closest (though distant) technology-trading partner is the United States. OECD data reveal that Australia is well integrated with the US technology market. Technology receipts from (and payments to) the United States account for about half Australia's OECD receipts (payments) (OECD 2013). Given this, we see no reason why results would be of a different nature in the United States.

5. Conclusion

Previous research has established that markets for technology are imperfect and has shown that patents facilitate technology transactions. The present paper explores the reasons for the effect. The results show that patent-pending and never filed inventions are transacted at a similar rate, which is lower than the rate at which patented inventions are transacted after matching on feasibility, industry and other relevant covariates. We take these results as evidence that: i) a patent grant aides the transfer of technology by strengthening appropriation; and ii) disclosure of the idea through the patent document does not increase negotiation success. Bear in mind that our hypothesis concerns the effect of patents on success via the disclosure effect; we are not testing whether or not disclosure matters *per se*.

In our opinion, the lack of a 'disclosure effect' in the data suggests that other non-patent mechanisms are being used to protect against second-party expropriation. Disclosure still matters, but patents are not superior to other means of enhancing disclosure. Alternatively, the information contained in the patent document is of such limited value that it does not greatly reduce information asymmetry between buyers and sellers. Technology brokers often claim that confidentiality agreements, to bind prospective buyers to not use the disclosed knowledge, can be an alternative to patents. It is difficult to get hard data on the extent to which confidentiality agreements are used in transacting technology. Whereas some legal practitioners report that non-disclosure agreements are systematically used (even when patents are taken), others report that prospective R&D-active buyers will not sign these agreements. In summary then, our results do not support the idea that patents are a cure for the 'paradox of disclosure.' Ironically (or maybe not), Robert Kearns, the inventor of the intermittent windscreen wiper, in fact had a patent.

This paper deepens our understanding of success factors in technology transactions. Results indicate that patents are used as legal documents to ensure appropriability of the invention and, more generally, that weak appropriability can be a deal breaker. This interpretation is consistent with the fact that the appropriation effect is greater in fields where patent protection is more effective. A practical implication of our results relates to the derived demand for patents. While protection from third-party expropriation ultimately concerns buyers, the decision to apply for a patent essentially rests on the owner (*i.e.*, seller), putting him or her at risk of myopia. When considering whether to protect the technology with a patent, the seller should also factor in that a granted patent is likely to increase the probability of negotiation success, ceteris paribus. Another implication relates to the timing of negotiation. The data show that prospective sellers significantly increase their chance of success if they come to the negotiation table with a granted patent instead of a pending patent.

Finally, many observers of the patent system report considerable backlogs and lengthy grant delays in major patent offices. The results imply that these delays will slow down the pace of—or prevent—technology transfers. This issue is particularly problematic for start-ups and SMEs that are less able to sustain regulatory delays. In this context, the recent implementation of a fast-track option at the USPTO, whereby a patent application enjoys an expedited review in exchange of an additional fee, is particularly welcome. The results also underline the importance of high-quality patent systems. Prospective buyers do care about the threat of third-party expropriation, and a high quality examination is likely to increase buyers' confidence that their future profits will be protected. Thus, a high-quality patent system helps support a proper functioning of markets for technology.

Acknowledgements

The authors are grateful to the editor, Ashish Arora, and two anonymous referees for very helpful comments. The authors have also benefited from constructive comments from Sean Applegate, William Bird, George Chondrakis, Charlie Day, Rowan Gilmore, John Haisken-DeNew, Dietmar Harhoff, Christian Helmers, Karin Hoisl, Katrin Hussinger, Paul Jensen, John Kapeleris, Bruno Lambrecht, Di Nicol, Henry Sauermann, Karen Sinclair, Kannan Srikanth, Valerio Sterzi, Russell Thomson, and Andrew Toole as well as from participants at: the 2012 EPIP conference in Leuven, Belgium; the 2013 ZEW-MaCCI Conference on the Economics of Innovation and Patenting in Mannheim, Germany; the 2013 Searle Center Sixth Conference on Entrepreneurship and Innovation at Northwestern University in Chicago; the 2013 DRUID Conference at ESADE Business School in Barcelona, Spain; and the 2013 Conference on Patent Use by the UK Intellectual Property Office in London, United Kingdom. Funding for this research comes from Intellectual Property Research Institute of Australia and the ARC LP0989343. Linkage partners were IP Australia, the Australian Institute for Commercialization, and Watermark Patent and Trademark Attorneys.

References

Aakvik, A., 2001. Bounding a matching estimator: The case of a Norwegian training program. *Oxford Bulletin of Economics and Statistics* 63 (1) 115–142.

Anton, J., D. Yao. 1994. Expropriation and inventions: Appropriable rents in the absence of property rights. *American Economic Review* 84 190–209.

Anton, J., D. Yao. 2003. Patents, invalidity, and the strategic transmission of enabling information. *Journal of Economics & Management Strategy* 12 151–178.

Arora, A. 1995.Licensing tacit knowledge: Intellectual property rights and the market for know-how. *Economics of Innovation and New Technology* 4 41–60.

Arora, A., M. Ceccagnoli. 2006. Patent protection, complementary assets, and firms' incentives for technology licensing. *Management Science* 52 293–308.

Arora, A., A. Fosfuri, A. Gambardella. 2001. Markets for Technology: The Economics of Innovation and Corporate Strategy. MIT Press, Cambridge, MA.

Arrow, K. 1962. Economic welfare and the allocation of resources for invention. In R. Nelson (Ed) The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, NJ.

Arundel, A., I. Kabla. 1998. What percentage of innovations are patented? Empirical estimates for European firms. *Research Policy* 27 127–141.

Becker, S., M. Caliendo. 2007. mhbounds - Sensitivity analysis for average treatment effects. *Stata Journal* 7(1) 71–83.

Berneman, L., I. Cockburn, A. Agrawal, S. Iyer. 2009. U.S./Canadian Licensing In 2007-08: Survey Results. *les Nouvelles*, March Issue, 1–9.

Bessen, J., M. Meurer. 2008. *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk*. Princeton University Press, Princeton, NJ.

Blackwell, M., S. Iacus, G. King, G. Porro (2009).cem: Coarsened exact matching in Stata. *The Stata Journal* 9 524–546.

Blind, K., J. Edler, R. Frietsch, U. Schmoch. 2006. Motives to patent: Empirical evidence from Germany. *Research Policy* 35 655–672.

Branstetter, L., R. Fisman, F. Foley. 2006. Do stronger intellectual property rights increase international technology transfer? Empirical evidence from U.S. firm-level data. *Quarterly Journal of Economics* 121 321–349.

Burhop, C. 2010. The transfer of patents in Imperial Germany.*Journal of Economic History* 70 921–939.

Caves, R., H. Crookell, J. Killing. 1983. The imperfect market for technology licenses. *Oxford Bulletin of Economics and Statistics* 45 249–267.

Chesbrough, H. 2003. Open Innovation: The new imperative for creating and profiting from technology. Harvard Business School Press, Boston, MA.

Cochran, W. 1968.The effectiveness of adjustment by subclassification in removing bias in observational studies. *Biometrics* 24 295–313.

Cohen, W., R. Nelson, J. Walsh. 2000. Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent or not. NBER Working Paper 7552.

de Rassenfosse, G. 2012. How SMEs exploit their intellectual property assets: evidence from survey data. *Small Business Economics* 39 437–452.

Drivas, K., L. Zhen, B. Wright. 2013. Application information versus patent office response: Which matters most in patent licensing? Mimeo University of Piraeus.

Elfenbein, D. 2007. Publications, patents and the market for university inventions.*Journal of Economic Behavior & Organization* 63 688–715.

Gans, J., S. Stern. 2003. The product market and the market for 'ideas': Commercialization strategies for technology entrepreneurs'. *Research Policy* 32 333–350.

Gans, J., S. Stern. 2010. Is there a market for ideas? *Industrial and Corporate Change* 19 805–837.

Gans, J., D. Hsu, S. Stern. 2008. The impact of uncertain intellectual property rights on the market for ideas: Evidence from patent grant delays. *Management Science* 54 982–997.

Heckman, J., S. Navarro-Lozano. 2004. Using matching, instrumental variables, and control functions to estimate economic choice models. *The Review of Economics and Statistics* 86 30–67.

Hedge, D., H. Luo. 2013. Licensing and patent disclosure. Mimeo New York University.

Hellmann, T. 2007. The role of patents for bridging the science to market gap.*Journal of Economic Behavior & Organization* 63 624–657.

Iacus, S., G. King, G. Porro. 2011a. Multivariate matching methods that are Monotonic Imbalance Bounding.*Journal of the American Statistical Association* 106 345–361.

Iacus, S., G. King, G. Porro. 2011b. Causal inference without balance checking: Coarsened Exact Matching. *Political Analysis* 20 1–24.

Jensen, P., A. Palangkaraya, E. Webster. 2015. Trust and the Market for Technology. *Research Policy* 44 340-356.

Jensen, R., M. Thursby. 2001. Proofs and prototypes for sale: The licensing of university inventions. *American Economic Review* 91 240–259.

Kani, M., K. Motohashi. 2012. Understanding the technology market for patents: New insights from a licensing survey of Japanese firms. *Research Policy* 41 226–235.

Katz, M., C. Shapiro. 1986. How to license intangible property. *Quarterly Journal of Economics* 101 567–589.

Lamoreaux, N., K. Sokoloff. 2001. Market trade in patents and the rise of a class of specialized inventors in the 19th-century United States. *American Economic Review* 91 39–44.

Lemley, M., C. Shapiro. 2005. Probabilistic Patents. *Journal of Economic Perspectives* 19 75–98.

Levin, R., A. Klevorick, R. Nelson, S. Winter. 1987. Appropriating the returns from industrial R&D. *Brookings Papers on Economic Activity* 3 783–831.

Long, C. 2002. Patent signals. *The University of Chicago Law Review* 69 625–679.

Mansfield, E. 1986.Patents and innovation: An Empirical Study *Management Science* 32 173-181.

Mantel, N., and Haenszel, W. 1959. Statistical aspects of the analysis of data from retrospective studies *Journal of the National Cancer Institute* 22 719–748.

National Science Board (NSB). 2008. Science and Engineering Indicators 2008. National Science Foundation, Arlington, VA.

OECD. 2008. Open innovation in global networks. Organisation for Economic Cooperation and Development, Paris.

OECD. 2013. Working party on the globalisation of industry review of the technological balance of payments database. DSTI/IND/WPGI(2012)3

Ordover, J. 1991. A patent system for both diffusion and exclusion. *Journal of Economic Perspectives* 5 43–60.

Rosenbaum, P., D. Rubin. 1983. Assessing sensitivity to an unobserved binary covariate in an observational study with binary outcome. *Journal of the Royal Statistical Society. Series B* 45 212–218.

Rosenbaum, P. 2002. *Observational Studies*. New York: Springer, 2nd edition.

Rubin, D. 1973. Matching to remove bias in observational studies.*Biometrics* 29 159–183.

Samuelson, W. 1984.Bargaining under asymmetric information.*Econometrica* 52 995–1005.

Seabrook, J. 2008. Flash of Genius and Other True Stories of Invention, St. Martin's Griffin, September 2008.

Shane, S. 2002. Selling university technology: Patterns from MIT. *Management Science* 48 122–137.

Spulber, D. 2008. Innovation and international trade in technology. *Journal of Economic Theory* 138 1–20.

Teece, D. 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy. *Research Policy* 15 286–305.

Troy, I. and Werle, R. 2008. Uncertainty and the market for patents, MPlfG Working paper, No. 08/2, Max Planck Institute for the Study of Societies, Cologne.

Zhang, L., A. Agrawal, I. Cockburn. 2013. Deals not done: Sources of failure in the market for ideas. Mimeo University of Toronto.

Zeckhauser, R., 1996. The challenge of contracting for technological information. *Proceedings of the National Academy of Science* 93 12743–12748.

Appendix: Sensitivity of the estimated disclosure and appropriation effects to selection on unobservables.

This appendix presents the result of applying Rosenbaum (2002)'s bounding analysis as proposed by Aakvik (2001) to assess the sensitivity of our findings to selection on unobservables. The identification of the treatment effect in matching models depends on the assumption that selection into treatment and the outcomes are independent conditional on observables. However, matching on observables may not be sufficient to account for hidden bias caused by selection on unobservables that are correlated with outcomes.

Consider, for example, the estimation of the appropriation effect based on data of negotiations of technologies with a granted patent (negotiation i) and with only a pending patent (negotiation j). Let P_i and P_j denote the corresponding probabilities that a given negotiation is over a technology that comes with a granted/pending patent. Following Aakvik (2001), these probabilities depend on observables (x) and unobservables (u) such that $P_i = F(\beta x_i + \gamma u_i)$ and $P_j = F(\beta x_j + \gamma u_j)$. Assuming that F has the logistic distribution, the odds ratio of two matched negotiations (that is, two negotiations which come from the same stratum, have a common support on, and equal distribution of, x), the relative odds that the negotiation is over a technology with granted patent as opposed to a pending patent is:

$$\frac{P_i/(1-P_i)}{P_j/(1-P_j)} = \frac{e^{\beta x_i + \gamma u_i}}{e^{\beta x_j + \gamma u_j}} = e^{\gamma(u_i - u_j)} \qquad \text{(A1)}$$

where the last equality is obtained after matching on observables. Thus, the sensitivity of our appropriation effect estimate to unobservables can be assessed by looking at how the estimate changes with changes in the values γ or $u_i - u_j$.

According to Aakvik (2001), if $u \epsilon \{0,1\}$ then equation (A1) can be rewritten as

$$\frac{1}{e^{\gamma}} \le \frac{P_i/(1-P_i)}{P_j/(1-P_j)} = \frac{e^{\beta x_i + \gamma u_i}}{e^{\beta x_j + \gamma u_j}} = e^{\gamma} \qquad \text{(A2)}$$

and, for fixed $e^{\gamma} \ge 1$, under the null of no unobserved selection effects ($\gamma = 0$) the Q_{MH} test statistics (Mantel and Haenszel 1959) is bounded by two known distributions (Rosenbaum 2002). Aakvik (2001) provides the formulas to compute Q_{MH} in order to measure the effects of hidden bias. The Q_{MH}^{+} test-statistics is the test-statistics given that we overestimate the appropriation effect due to hidden bias; the Q_{MH}^{-} test-statistics is the test-statistics given that we underestimate the disclosure effect due to hidden bias. In this paper, we use the *mhbounds* command in *Stata* (Becker and Caliendo 2007) to compute the corresponding test statistics: Q_{MH}^{+} and Q_{MH}^{-}.

The computed test statistics (Q_{MH}^{+} and Q_{MH}^{-}) are summarized in Table A1. For the appropriation effect, the second column of Table A1 shows that under no hidden bias (Gamma = 1), the estimated effect is positive and statistically significant. Furthermore, a hidden bias of a factor greater than 1.2 is required to make the estimated appropriation effect become statistically insignificant (at 10% significance level).

Our estimated disclosure effect under the assumption of no hidden bias is not statistically significantly different from zero with $Q_{MH}^{-} = 0.050$ shown in the first row of the fourth column of the Table A1. Looking down the same column and the corresponding Gamma value, we see that we require a hidden bias of a factor of at least 1.4 (Gamma = 1.4) to change our disclosure effect estimate into a statistically significant positive effect (at 10% significance level).

Note that in the above sensitivity analysis, we do not know whether the hidden bias is actually present. Furthermore, we do not know what the acceptable magnitude of such bias is (Aakvik 2001). However, if we consider that we have implemented exact matching on various observed characteristics, the required additional 20–40 per cent higher odds of selection into the treatment group caused by unobserved factors to change our inferences appears to be quite large. In other words, our estimates appear to be robust to a 'reasonable' amount of hidden bias.

Table A1: Mantel-Haenszel (1959) bounds test statistics of underestimated disclosure effects (Q_{MH}^{-}) and overestimated appropriation effects (Q_{MH}^{+}).

Gamma = e^{γ}	**Appropriation effect**		**Disclosure effect**	
	Q_{MH}^{+}	p-value	Q_{MH}^{-}	p-value
1	2.608***	0.004	0.050	0.480
1.1	2.053**	0.020	0.170	0.433
1.2	**1.545***	**0.061**	0.570	0.284
1.3	1.079	0.140	0.938	0.174
1.4	0.647	0.259	**1.279***	**0.100**
1.5	0.246	0.403	1.597*	0.055
1.6	-0.043	0.517	1.896**	0.029

Notes: */**/*** denotes statistically significant at 10/5/1% significance level.