Discussion Paper No. 08-101

Patent Thickets, Licensing and Innovative Performance

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First Version: November 27, 2008
This Version: October 29, 2009

Non-technical summary

In recent years, the view of patents as a policy tool to stimulate R&D has increasingly come under criticism. The theoretical literature has shown that when research is sequential and builds upon previous innovations, stronger patents may discourage follow-on inventions and a debate has emerged over the extent to which patent "thickets" may stifle innovation. Patent thickets can be defined as "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology".

While some progress has been made in empirically characterizing thickets in terms of fragmented ownership of patent rights, there is very little evidence about how effectively the market for technology can mitigate their effects, and the extent to which this affects innovative performance. In this paper, we investigate these questions using survey data on licensing activity and innovation by German manufacturing firms. We use indexes of fragmentation of patent rights based on the patent portfolios of firms operating in the respective technologies of the German companies.

We find evidence that firms facing patent thickets have a higher propensity to engage in in-licensing. Therefore markets for technology may provide an effective mitigating mechanism for the defragmentation of rights. We then analyze the relationship between fragmentation and innovative performance, considering separately firms requiring access to patented technology (in-licensors) and firms that do not require this access (non-licensors). For firms that report positive expenditures on in-licensing, we find a negative relationship between fragmentation of IP rights and innovative performance as measured by share of sales with products new to the firm. This is consistent with the hypothesis that, for firms that require licenses to commercialize new technology, the fragmentation of upstream property rights hampers innovation. The negative effect on product innovation is particularly strong for in-licensing firms with few patents, which suggests an important strategic role for building up a large patent portfolio in the context of fragmented property rights.

Das Wichtigste in Kürze

In der Vergangenheit sind Patente als Anreizmechanismus für Forschung und Entwicklung in die Kritik geraten. Die theoretische Literatur hat gezeigt, dass bei auf früheren Innovationen aufbauender sequentieller Forschung stärkere Patentrechte die nachfolgenden Innovationen behindern können. Es entstand eine Debatte darüber, in welchem Ausmaß „Patentdickichte“ Innovationen erschweren. Unter Patentdickichten versteht man „ein undurchlässiges Netz von sich überschneidenden Rechten zum Schutz von geistigem Eigentum, durch das sich ein Unternehmen den Weg bahnen muss, um neue Technologien auf den Markt bringen zu können.“

Obwohl Fortschritte in der empirischen Beschreibung von Patentdickichten gemacht wurden, gibt es wenig Evidenz dafür, ob der Markt für Technologien den Einfluss von Dickichten abschwächen kann und in welchem Ausmaß Dickichte die Innovationsleistung von Unternehmen behindern. In dieser Arbeit gehen wir diesen Fragen anhand von Daten über Lizenzaktivitäten und Innovationen von deutschen Unternehmen im verarbeitenden Gewerbe nach. Das verwendete Fragmentierungsmaß baut auf Patentportfolios von Unternehmen auf, die in den gleichen Technologien tätig sind, wie die beobachteten deutschen Unternehmen.

Wir finden einen positiven Zusammenhang zwischen dem Ausmaß von Patentdickichten und der Wahrscheinlichkeit Patente einzulizenzieren. Märkte für Technologien sind also ein möglicher Mechanismus, um mit der Defragmentierung von Patentrechten umzugehen. Anschließend analysieren wir die Beziehung zwischen Fragmentierung und Innovationserfolg separat für Unternehmen die einen Zugang zu patentierten Technologien benötigen (lizenzierende Unternehmen) und für Unternehmen, welche keinen Zugang benötigen (nicht lizenzierende Unternehmen). Für lizenzierende Unternehmen finden wir einen negativen Zusammenhang zwischen der Fragmentierung von Patentrechten und dem Innovationserfolg gemessen als Umsatzanteil mit neuen Produkten. Dies ist konsistent mit der Hypothese, dass Fragmentierung für Unternehmen die Lizenzen benötigen die Kommerzialisierung von neuen Produkten erschwert. Negative Auswirkungen auf Produktinnovationen sind bei lizenzierenden Unternehmen mit einer geringen Anzahl Patente besonders stark. Daraus ergibt sich eine strategische Bedeutung des Aufbaus eines großen Patentportfolios im Zusammenhang mit fragmentierten Eigentumsrechten.

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This version: October 29, 2009

- FORTHCOMING: INDUSTRIAL AND CORPORATE CHANGE -

Abstract

We examine the relationship between fragmented intellectual property (IP) rights and the innovative performance of firms, taking into consideration the role played by in-licensing of IP. We find that firms facing more fragmented IP landscapes have a higher probability of in-licensing. For firms with small patent portfolios we also find a positive association between fragmentation and licensing costs as a share of sales. We observe a negative relationship between IP fragmentation and innovative performance, but only for firms that engage in in-licensing. In contrast, greater IP fragmentation is associated with higher innovative performance for firms that do not in-license. Furthermore, the effects of fragmentation on innovation also appear to depend on the size of a firm's patent portfolio. These results suggest that the effects of fragmentation of upstream IP rights are not uniform, and instead vary according to the characteristics of the downstream firm.

Keywords: patent thickets, licensing, innovative performance

JEL classification: O34, O31

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Acknowledgements: We would like to thank participants of the Markets for Technology and Industry Evolution conference in Madrid (2008), the IIOC conference in Boston (2009), the SFB/TR conference in Berlin (2009) and seminar participants at ZEW Mannheim and the University of Mannheim for helpful discussions. We would like to thank Bruno Cassiman and Boris Loshkin for detailed comments. Elisabeth Müller gratefully acknowledges financial support from the German Science Foundation (DFG) under grant SFB/TR 15-04. This manuscript was prepared for the Markets for Technology and Industry Evolution Conference, Madrid, September 2008.

1. Introduction

Recent decades have seen an “explosion” in patenting (Hall, 2004), generating great interest among policymakers and researchers working on innovation. A variety of underlying causes of this phenomenon have been proposed, including: a surge of inventiveness in “new” technologies such as biopharmaceuticals and IT; institutional and legal changes that have strengthened patent rights or made it easier to obtain patents; changes in industry structure and the nature of competition; and changes in the strategic behavior of firms, which are thought to have become both more sophisticated in their use of patents as a means of protecting investments in proprietary technology, and of shaping competition with rivals. Increases in patenting also appear to have been accompanied by a concomitant increase in licensing activity (Athreye and Cantwell (2007)), suggesting that part of the explosion in patenting reflects expansion of the “market for technology.”

Patents and other forms of intellectual property are a critical “infrastructure” for markets for technology. The presence of a market for technology should in principle promote increased efficiency in innovation through the division of labor and gains from trade. By providing property rights over inventions, patents facilitate contracting and provide a mechanism for transactions in ideas. Arora et al. (2001), Gans and Stern (2003), Gans et al. (2002), and others have highlighted the role of patents and other formal IP rights in providing an avenue for new entrants to realize value from innovation by licensing, entering into collaboration agreements, or selling themselves to incumbents. At the same time, as markets for technology expand, incentives to obtain patents also increase, and this positive feedback loop may be an important determinant of the startling increase in patent applications and grants.

However, it has been argued that the patent system, classically thought to promote innovation by creating incentives to innovate, may now be at risk of stifling innovation (Federal Trade Commission (2003), Bessen and Meurer (2008), Jaffe and Lerner (2004), and Merrill et al. (2004)). A theoretical literature has shown that when research is sequential and cumulative, with each invention building upon previous inventions, stronger patents can in fact discourage follow-on innovation (Merges and Nelson (1990), Scotchmer (1991), Green and Scotchmer (1995), Bessen and Maskin (2007) etc.). A debate has also emerged over the extent to which patent "thickets" may stifle innovation. Defined by Shapiro (2001) as "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology", patent thickets may raise transactions costs associated with contracting around existing patents to the point at which the costs associated with patents may outweigh any positive impact on R&D incentives.

The potential for patent thickets to stifle innovation depends on the extent to which they raise the costs of innovators. In general, patents held by one firm are likely to impose some costs on other innovators, such as incremental R&D expenditures to design around patents, or licensing fees paid for rights to use patented technology. Where there is a patent "thicket" these costs may be large enough to materially impact incentives to innovate, and in the extreme case, an "impenetrable" patent thicket may completely block inventors from accessing some technologies, or make it prohibitively costly to bring improvements to market. These situations are thought to be most likely to occur where innovation is strongly cumulative, or products are highly complex (in the sense of containing many different independently patented components), so that there are potentially multiple blocking patents that an innovator would have to work around or gain access to.

In principle, the ability to negotiate licensing contracts with patent holders should allow firms to use patented inventions. Gallini (2002) notes that the stifling effects of stronger patents may be mitigated by in-licensing or other arrangements to use patented technology in downstream research projects. However, there may be circumstances under which licensing does not alleviate the thicket problem. With imperfect and asymmetric information about the value of a technology, limited resources and experience, "thin markets" and other problems in conducting negotations, licensors and licensees may not be able to agree on terms.[1] It is also possible that the total cost of obtaining all of the necessary licenses (the "royalty stack") reduces remaining profits to the innovator to an unacceptable level. In these circumstances, downstream innovation may be impeded in spite of attempts to gain access to upstream patented technology through licensing.

This paper contributes to the relatively under-developed literature on the determinants of firms' in-licensing activities by providing evidence on how the density of the patent thicket – measured here as the fragmentation of ownership of patents – affects firms' participation in markets for technology. It also presents evidence on the relationship between fragmentation and firms' propensity to introduce new products to the market. It provides what is to our knowledge the first direct evidence of a negative relationship between the fragmentation of upstream IP rights and the innovative performance of in-licensing firms. However, it also uncovers a provocative positive relationship between fragmentation and innovative performance among firms that do not in-license. Finally, it provides suggestive evidence that the effects of patent thickets may depend on the size of a firm's own patent portfolio. We show that the positive association between fragmentation of patent ownership and higher licensing payments as a share of sales is restricted to firms with small patent portfolios, and further, that the negative effect of fragmentation on innovative performance is observed primarily among firms that hold few patents. This heterogeneity in the effects of thickets for firms of different types suggests the importance of further research on how the market structure of markets for technology promotes or hampers innovation by different types of firms.

2. Hypotheses

A number of papers have pointed out that downstream innovation can be hampered if downstream firms, having already sunk investments in developing or commercializing a product,

[1] Razgaitis (2006) reports that 50% or more of substantive licensing negotiations fail to result in an executed agreeement, with the leading cause of "deal failure" being inability to agree on financial terms.

are threatened with an injunction by a patentee. Lemley and Shapiro (2007) show that in these circumstances, a patentee may be able to negotiate royalties significantly above the economic contribution of the patent (known as "patent hold-up"). If there are a large number of potential licensors, it becomes very costly to contract with all of them, particularly if the holdup problem magnifies the royalty fees paid to each patentee. The presence of "upstream" patent holders may also create the problem of double marginalization, with the impact on the downstream firm's prices and quantities increasing with the number of patentees.

The effects of multiple upstream potential licensors have been considered by a number of papers that have focused on the "fragmentation" of IP rights. Most research in this area suggests that IP fragmentation is associated with negative externalities. Ziedonis (2004) and Von Graevenitz et al. (2008) have found that fragmented ownership of IP is associated with more aggressive defensive patenting. Clark and Konrad (2008) obtain evidence of decreased R&D effort in patent races in a theoretical model. Noel and Schankerman (2006) show that higher fragmentation of patent ownership is associated with lower market values (in other words, increased costs) for publicly traded software firms. Cockburn and MacGarvie (2009) show that increases in the number of patents in software markets are associated with reductions in the hazard of acquiring initial funding by software start-ups.

The analysis of Shapiro (2001) and Lemley and Shapiro (2007) implies that licensing costs will be increasing in the number of upstream patentees, through the royalty stacking effect. These higher licensing costs will reduce the net returns from downstream innovation (conditional on licensing) and can therefore be expected to be associated with lower rates of innovation. It also implies that, for firms that are required to in-license, more fragmented upstream property rights will be associated with higher prices and lower quantities produced of the downstream product as a result of double marginalization. This analysis suggests the following hypotheses:

H1: The more fragmented the ownership of patents that read on a firm's product, the higher are the licensing costs associated with commercializing that product.

H2: Greater IP fragmentation will be associated with lower rates of downstream innovation by firms requiring access to the fragmented IP.

It should be noted that, when firms entering into cross-licensing agreements have asymmetric patent holdings, they may use balancing payments proportional to the size of the firm's net contribution of patents. Teece (2002) points out that "Balancing royalty payments, i.e. agreements with net cash transfers, are part of most cross-licenses, even when the main purpose is freedom to operate."[2] We would thus expect that the firms operating in fragmented markets with larger patent portfolios will incur lower costs of licensing than firms with few patents, due to the effects of balancing payments. In turn, the negative effect of fragmentation on innovative performance should be concentrated among the firms with few patents. This suggests another testable hypothesis:

H3: The effects of fragmentation on licensing costs and innovative performance will be exacerbated for firms with small patent portfolios.

The theoretical basis for these hypotheses is not unambiguous. Lichtman (2006) has presented a counter-argument to the idea that fragmentation of patent ownership raises transactions costs, suggesting that when upstream patent holders have to divide the rents extracted from a downstream producer, incentives to seek injunctions or incur other costs associated with enforcing patent rights or negotiating license agreements are weakened. With many upstream patentees, the incentive for any individual patentee to seek an injunction may be severely

[2] Teece (2002), p. 139-140

reduced. For example, Lichtman suggests, "If fifteen patent holders can credibly threaten to shut an infringer for six months while that firm redesigns its products and services, the value associated with avoiding six months of disruption must be split fifteen ways."[3] Lichtman refers to this effect as "safety in numbers".

Galasso and Schankerman (2008) have modeled the relationship between upstream IP fragmentation and downstream bargaining, and show that settlements will be reached more quickly when upstream IP is distributed among a larger number of patentees, or when upstream patents are less strongly complementary to the downstream innovation. This argument would seem to suggest that, if firms have not obtained licenses, an increase in upstream fragmentation is associated with a reduction in the probability of litigation and therefore an increase in the expected profits from innovation.

A third argument in the literature is that patent thickets are not, as a factual matter, particularly important. If patent thickets are rarely present, or impose only small additional transactions costs, then it is reasonable to expect that markets for technology operate efficiently and that firms are generally able to obtain access to patented upstream technology on terms that do not deter them from innovating. Citing examples of specific technologies, Denicolò et al. (2008), for example, critique the Lemley-Shapiro model and argue that "despite Lemley and Shapiro's insistence to the contrary, there is little evidence of the existence of the holdup and royalty stacking problems that concern them."[4] The effect of fragmentation of patent ownership on innovative activity thus remains an open empirical question.

3. Literature review and Contribution

Our paper builds upon and contributes to the literature which investigates the determinants of licensing. Gans et al. (2002) argue that stronger IP rights increase both the absolute returns to

[3] Lichtman (2006), p. 10

[4] P. 718. See also Geradin and Rato (2006), Lin (2009) and Sidak (2008).

innovation as well as the returns to cooperation (i.e. selling an innovation to an incumbent) relative to competition. Anand and Khanna (2000) use data on licensing announcements from the SDC database to show that variations in the strength of IPRs across industries affect the amount and nature of the licensing contracts entered into. It is likely that the pure *strength* of IP rights may not be the only factor affecting the participation of firms in the market for technology, but that the fragmentation of IP rights may also play a role.

Relatively few empirical papers model the determinants of firms' expenditures on licenses. Link and Scott (2003) show that firms are more likely to license when their patents cite the patents of potential licensors. Cassiman and Veugelers (2000) relate licensing versus in-house development of technology to the external environment of the firm using CIS survey data for Belgium. Cassiman and Veugelers (2006) establish a complementary relationship between the absorptive capacity of the firm and acquisitions of external technology. Czarnitzki and Kraft (2005) study licensing expenditures by incumbents and entrants using the same innovation survey data we consider in the present paper. They find that incumbents spend more on licenses than do potential entrants.[5] Czarnitzki and Kraft (2005) also find that exporters spend more on licenses than do importers and non-trading firms. Larger firms spend more on licenses, both in absolute terms and as a percentage of sales or as a percentage of innovation expenditures. Grimpe and Hussinger (2008) investigate a different possibility of participating in the market for technology, namely buying access to a technology through acquisition of the companies holding the patents. The authors find that companies whose patent portfolio has a higher blocking potential achieve higher prices when taken over by other companies.

In our analysis, we build upon the aforementioned literature on in-licensing and also examine the relationship between IP fragmentation and licensing. A priori, markets in which the

[5] Czarnitzki and Kraft (2005) identify entrants as the firms that rate as very important (choosing 5 on a 5-point Likert scale) as a motive for innovation "the enlargement of the product portfolio outside of the main markets you are operating in." Incumbents are classified as firms that use innovation for the purposes of "securing and increasing the current market share."

requisite IP is distributed across a larger number of patentees would seem more likely to be markets with more specialization and division of innovative labor. In such markets, firms need a means of assembling the specialized inputs in order to commercialize their products. Entering into licensing agreements is a means by which firms can gain access to the necessary IP inputs held by other firms. Thus, we would expect to see more licensing when firms operate in areas characterized by more fragmented IP.[6] Support for this hypothesis can be found in Nagaoka's (2008) survey of Japanese inventors, which shows that the propensity of firms to engage in licensing increases as the number of patents required to commercialize a technology increases.

A contrasting view of the relationship between licensing and fragmentation is taken by Siebert and von Gravenitz's (2006) study of the semiconductor industry. The paper examines pairs of firms and models the probability that a given pair enters into a licensing contract. It finds that on average, fragmentation is greater for firm pairs that engage in licensing. However, in a bivariate probit model that also controls for the extent to which two firms' patents "block" each other (i.e. are technological rivals with the potential for hold-up), they estimate a negative relationship between fragmentation and the probability of ex ante licensing (with no significant effect on ex post licensing). Blocking is estimated to have a positive and significant effect on the probability of both types of licensing. This result is interpreted as evidence that the threat of hold-up increases the propensity to license, and conditional on the level of hold-up threat, an increase in the fragmentation of relevant patent holdings makes licensing less likely. It is important to note that the sample analyzed in this paper is quite different from the one we consider here, in that it

[6] Gambardella and Giarratana (2008) model the relationship between the "fragmentation" of the product market (i.e., the extent to which firms are specialized in one product class and do not have generalized complementary assets that could be profitably deployed across other classes) and licensing. They argue that, if fragmentation in the product market increases the wedge between the licensee's profits and the effect of competition from the licensee on the profits of the licensor, we can expect increases in fragmentation to be associated with increases in the propensity to license. Indeed, Gambardella and Giarratana (2008) examine a sample of 87 software security firms and find a positive relationship between fragmentation and licensing activity. It should be noted that the product-market fragmentation considered by Gambardella and Giarratana is measured quite differently from the IP fragmentation discussed here. Instead, it is "the annual share of all products released in the market sold by the firms that sell products in only one of the six [software security] product submarkets" in their sample (p. 16).

focuses in detail on one industry, models the probability that a given *pair* of firms enters into a contract, employs information on ex ante licensing which includes cross-licensing, and separately controls for the potential for hold-up. We are unable to control for the latter factor in a similar way, due to data constraints (we do not observe the universe of firms in an industry and cannot therefore construct pairs of patentees in a similar fashion).

In summary, we look for evidence on the one hand of a relationship between a) fragmentation and licensing activity, and b) fragmentation and innovation in a sample of German firms. First, we ask whether firms facing more fragmented IP landscapes are more or less likely to engage in in-licensing. If markets for technology help firms cope with patent thickets, we should expect to see markets for technology used to reassemble fragmented property rights so that firms will be more likely to in-license when they operate in fields characterized by fragmented property rights. We also expect licensing costs to be higher in fragmented markets due to the effects of royalty stacking. Secondly, we expect that any negative effect of fragmentation on innovative performance (via royalty stacking) will be most evident in the population of firms that clearly make use of upstream technologies, that is, firms reporting positive in-licensing expenditures. Among these firms, the "safety in numbers" effect may less important than the "royalty stacking" effect, because they have already signed licenses and thus are presumably at lower risk of litigation from upstream patentees. In contrast, the group of firms that report no in-licensing expenditures will obviously not be affected by the increasing costs associated with royalty stacking (because they pay no royalties). However, these firms may still be at risk of infringing the upstream patents that they have not licensed. For this group (the non-licensees), "safety in numbers" may dominate "royalty stacking", and increases in upstream fragmentation may benefit firms.

4. Data Sources and Variable Definition

4.1 Data Sources

The analysis is based on the Mannheim Innovation Panel (MIP), an annual survey which focuses on the innovative activities of German companies. The survey is conducted annually by the Centre for European Economic Research (ZEW) on behalf of the German Federal Ministry of Education and Research since 1992. Every fourth year the survey is part of the Community Innovation Survey (CIS) conducted by Eurostat. The questionnaire follows the guidelines of the Oslo Manual for collecting innovation data (OECD and Eurostat, 1997). The target population of the MIP covers legally independent firms in Germany with at least five employees and covers both the manufacturing and the service sector.[7] Patent information from the European Patent Office (EPO) is merged at the company level to the MIP.[8]

For our analysis we are restricted to information from the years 1993, 1995, 1996, 2000 and 2004, since the other years do not include all the required variables. The information has been collected in the years 1994, 1996, 1997, 2001 and 2005 respectively. We focus on the manufacturing sector, since it has a high patenting activity and our control variable for competition in the product market is not available for the service industries.

Our estimation sample is mainly formed by small to medium-sized manufacturing companies active in patenting. The five years of MIP information that we can use contain together 20,383 observations. After eliminating observations with missing information for basic company characteristics and licensing information, we are left with 8,513 observations. We further need to restrict the sample to companies with at least one patent application, since we rely on information from patent applications to determine in which technology class the company is mainly active in. The sample reduces to 1,932 observations due to this restriction. Furthermore,

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[7] This survey has been used for many previous publications, see, for example, Czarnitzki and Kraft (2004), Kaiser (2002) and Griffith et al. (2006).

[8] Since the MIP is conducted by ZEW, where one of the authors is based, we know the names and addresses of the companies and can therefore match patent applicants according to these criteria.

we restrict the sample to companies with less than 1,500 employees. Larger companies are often active in several technology classes. The fragmentation of ownership rights in one technology class would be an imprecise indicator for the possibly different situations the companies face when introducing new products.[9] This restriction reduces the sample by 302 observations so that we arrive at 1,630 observations.[10] A handful of firms in our data are clearly outliers, reporting licensing expenditures as high as more than 155% of sales. While interesting in their own right, these firms are clearly engaged in distinct activities (for example, "brokering" technology), and we exclude them from this analysis. Specifically, we drop observations where licensing/sales is in the highest percentile (> 2.27%) and we also drop some observations with very large absolute amounts of licensing expenditure, which are likely data mistakes.[11] We also drop observations with R&D/sales ratios and innovation expenditures/sales ratios of above the 99th percentile (85% and 105%, respectively). These are generally the same firms that report exceptionally high licensing/sales ratios. Our final dataset contains 1,616 observations for 1,053 companies for the licensing equation. For the innovative performance equation, our dataset consists of 1,325 observations on 912 firms when the dependent variable is the share of sales new to the market companies, and 1,690 observations for 1,086 firms when we look at the share of sales new to the firm.

For the companies it is not mandatory to answer to the survey questionnaire. Since many companies do not answer every year, our final sample is an unbalanced panel. Because so many companies are only observed once (e.g. out of the 912 companies in the first innovative performance equation 642 are observed only once), we cannot use panel estimators without

[9] We decided to use a size restriction to cover only companies that are active in a limited number of technology classes, since a direct measurement of technology classes would not be more precise. Based on the technology classes of the patent applications we would probably underestimate the number of classes in which a company is active in, since many companies apply for only one or two patents.

[10] The cut-off value of 1,500 employees is arbitrary. However, the size of the effects and the significance levels of our main results remain almost unchanged if we use 1,200 or 1,800 employees as a maximum.

[11] We obtain a similar precision of our results but partly a smaller size of the economic effect if we use no restriction on the variable licensing/sales or if we drop the two highest percentiles of this variable.

sharply decreasing the sample size. The average number of observations for non-licensees is 1.4, whereas we observe licensees only 1.2 times.

There are differences between the companies that we include in the analysis and the surveyed companies from the manufacturing sector. Compared to the full sample, the restriction to companies with at least one patent leads to the selection of larger companies and of companies with more innovative activities. For example, the probability for in-licensing is 12.8% overall but 21.9% with the restriction to patentees. The further restriction to companies with a maximum size of 1,500 employees and the exclusion of outliers leads to a decrease in the median size of the companies but does not change our main variables relating to innovative activity (i.e. R&D/sales, probability of in-licensing and share of sales from products new to the market or new to the firm).

With the use of sample weights the responses of the MIP companies can be made representative for German companies with at least five employees in the covered industries. Due to our sample selection criteria, a weighted regression would not provide results representative for German companies. Still we are able to identify the influence of fragmentation of IP rights, since we control for the company characteristics that were used in the stratification of the sample.

Due to the unbalanced nature of our data and our sample selection criteria we need to be concerned with several biases. Non-response bias can result if the companies' decision to answer is related to the question studied. Since it is unlikely that the degree of fragmentation of technology markets is related to the response behaviour, we do not expect a serious problem here. Survivorship bias could influence our results if companies go out of business because they cannot obtain licenses for the products that they would like to commercialize. Our results would then constitute a lower bound for potential problems due to fragmentation of intellectual property rights. A further potential bias derives from the fact that companies without any patents are excluded from our sample. Non-patenters may also face problems due to fragmentation of IP rights and, indeed, these companies may face even more severe problems, given that these companies cannot strengthen their position in licensing negotiations by offering to license their own patents. Thus our findings may be viewed as an underestimate of the influence of fragmentation for these firms.

4.2 Variable Definitions

Our main interest is the influence of fragmentation on in-licensing and on the innovative performance of companies. Our measure of fragmentation follows the definition of Ziedonis (2004) with the difference that we measure fragmentation at the technology level and not at the company level. This fragmentation measure gives an indication whether the IP rights of one technology are concentrated in the hands of only a few companies or dispersed among many. We use the measure of fragmentation as a proxy for patent thickets.[12]

The formula below gives the exact definition of the fragmentation measure. The calculation is based on the information in the references (backward citations) in a company's patent portfolio. $Fragmentation_j$ refers to fragmentation in technology j in year t, whereby the time index t is omitted to increase clarity. $References_{ijk}$ is the number of references in company i's subportfolio of patent applications in technology j that refer to patents hold by company k. $References_{ij}$ is the total number of references in company i's subportfolio of patent applications in technology j. For a given company i we then calculate one minus the sum of the squared shares of references to other companies k, which is the fragmentation measure at the company level. We multiply the fragmentation at the company level by a correction factor to adjust for the total number of references as suggested by Hall (2002). In a second step we average over all companies i that have patent applications in technology j.

$$Fragmentation_j = \frac{1}{N}\sum_{i=1}^{N}\left\{\left(1-\sum_{k=1}^{K}\left(\frac{references_{ijk}}{references_{ij}}\right)^2\right)\left(\frac{references_{ij}}{references_{ij}-1}\right)\right\}$$

[12] We thank Georg von Graevenitz, Dietmar Harhoff and Stefan Wagner for making the information on the fragmentation index available to us.

The calculation of the fragmentation index is based on all large EPO applicants without restriction to certain applicant countries. The calculation of the index is therefore not only based on the MIP companies included in our estimation sample. Only companies that meet a minimum size requirement are included in the calculation of the fragmentation index. Companies need to have filed at least 100 patents in the time period 1987-2002 and need to have at least three years of positive applications in a given technology area. This minimum size requirement is necessary to obtain a meaningful fragmentation measure, since with very small numbers of patents in each technology, spuriously high or low values of fragmentation are likely to be obtained. In part this is due to the fact that at the EPO patent documents contain fewer references than at the USPTO (for our sample we find on average 4.3 references per application).[13] For each year the current applications of the companies are divided into 30 technologies, i.e. for each company up to 30 subportfolios are defined.[14] We take the classification into 30 technology classes from the update of OECD (1994) and provide the full list of the technology classes in Table A1 in the Appendix.

References to patents that are expired and references to company i's own patents are excluded for the calculation of the fragmentation index. This is important since licensees only need to be obtained for patents of other companies which are still in force. We also only include references of type X and Y. At the EPO references are classified into different categories. The X and Y references are those references that are detrimental to the novelty of the patent. An X-type reference means that a claimed aspect of the invention cannot be considered novel and thus may not deserve patent protection. The combination of at least two Y-type references has also the power to invalidate a claimed aspect of an invention. These references define the prior art that is most critical for the commercialization activities of company i. References that are only included

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[13] This is also a reason why we prefer to use the fragmentation measure computed at the technology level as opposed to the company level. The median number of patent applications in our sample is only four and 28% of the companies have only one application, leading to a very noisy calculation of fragmentation at the company level. We tested the company level fragmentation measure in exploratory regressions but found mostly no relationship with the variables of interest.

[14] Data from the database PATSTAT ("EPO Worldwide Patent Statistical Database") is used for the calculation of the fragmentation index.

to describe the technological background of the invention are omitted (A-type references) as well as references that were included by the applicant but not used by the patent examiner (D-type references).

We are first interested in testing whether fragmentation leads to royalty stacking. As dependent variable we use the *Dummy licensing* which is equal to one if the company reports positive expenditure for in-licensing. Alternatively we use the licensing intensity defined as licensing expenditure divided by sales as dependent variable (*Licensing/sales*). Our main explanatory variable of interest is *Fragmentation* as defined above. We include the fragmentation index with a time lag of one period into the regression specification to allow companies to respond to a given level of fragmentation. As control for the innovative activities of the company we include the expenditure for internal R&D normalized by sales (*R&D/sales*). Expenditures for internal R&D and for licensing are two distinct, non-overlapping sub categories of innovation expenditure. We also control for the stock of patent applications normalized by the number of employees (*Patent stock of firm/employees*). We use the sum of all patent applications to calculate the stock without a depreciation factor. To control for general company characteristics we include the natural logarithm of the number of employees (*Log employees*), the natural logarithm of the company age measured in years (*Log age*), a dummy which is equal to one if the company belongs to a national or a multinational group (*Dummy group*) and a regional dummy which is equal to one if the company is based in Eastern Germany (*Dummy Eastern Germany*).

We also control for industry and technology characteristics. From the 1992 wave of the Mannheim Innovation Panel we calculate the *Index patent protection* as industry-average at the 3-digit level of the reported effectiveness of patents "to obtain or improve competitive strength". Companies indicated on a 5-point Likert scale how effective patent protection is for them. This control is included since the literature has shown that more effective patent protection facilitates licensing (Gans et al., 2008). We include the *Herfindahl index* on sales concentration defined at the 3-digit industry level to control for the competitive situation in the product market. Note that this calculation is based only the sales of German companies within Germany. This index is calculated and published by the German Monopoly Commission. As an indicator of how crowded a technology class is we use *Log patents at technology level* which is the natural logarithm of the number of patent applications at the European Patent Office in a given technology class in a given year measured in thousands of applications. In addition we include a set of *Industry dummies* which are defined at the 2-digit SIC level to control for industry effects and *Year dummies* to control for time effects.

Secondly, we are interested in the influence of fragmentation on the innovative performance of companies. As a measure for the success with product innovations we use the *Share of sales from products new to the market.* A product is considered to be new to the market if the surveyed company is the first company to introduce this product and if the introduction has taken place within the three-year period preceding the survey. We also alternatively measure innovative sales with the *share of sales from products new to the firm.* We control for the inputs into the innovation process by including the innovation expenditure in thousand Euro normalized by sales (*Innovation expenditure/sales*). The four subcategories of innovation expenditure are expenditure for internal R&D, expenditure for external R&D, expenditure for machinery and equipment for innovative activities and expenditure for in-licensing. We use only R&D expenditure in the in-licensing regression to avoid to double-counting of licensing expenditures. However, in the innovative performance regressions we want to control for a comprehensive measure of innovative expenditure. We also include the square of this variable to allow for decreasing returns to scale in the innovation process. As in the previous regression, we control for the stock of patent applications of the firm per employee (*Patent stock of firm/employees*). We include the same controls for general company characteristics as well as for industry and technology characteristics as in the licensing specification. Industry and year dummies are also included.

5. Results

Table 1 provides descriptive statistics for the variables used in our analysis. As Table 1 shows, the mean firm in our data had 346 employees, 62.4 million Euro in sales, and spent 1.16 million Euro on R&D. 56% were innovators, in the sense of realizing sales from a product that was new to the market. Overall the share of sales with products new to the market amounts to 9%. Of greatest interest for this paper, 22% reported spending money on licensing technology. The amounts spent on licensing are quite small relative to sales: in the entire sample, the average amount spent on licensing as a percentage of sales was 0.054%. However, among those firms that spent anything on licensing, the ratio was 0.26%.

By contrast to the licensing data, many more firms in the sample report nonzero R&D expenditure: 78% perform R&D, (76% spent at least 100,000 euros), and the average R&D sales ratio was 3.21%. Conditional on reporting positive R&D spending the R&D sales ratio was 4.1%.

The fragmentation index ranges from 0.607 to 0.794 across the 30 technology classes in this sample. Weighted by the number of firms in each technology represented in our sample, the average value is 0.725.

Table 2 gives simple correlations between all variables used in the regression analysis. As can be seen from the table, the raw correlation between licensing/sales and R&D/sales is 0.11, consistent with the idea that innovative firms are more likely to be participants in the "market for technology." The raw correlation between licensing/sales and the fragmentation index is very small, though positive, which on its face suggests only very limited use of licensing as a solution to deal with fragmentation of IP rights. However this is clearly a problem with both confounding with other effects, and the skewness of the licensing/sales variable.

Turning to the regression results, we begin by examining the relationship between licensing expenditures as a percentage of sales and IP fragmentation. Since the dependent variable is truncated at 0, we use a Tobit model. Tobit allows both for the possibility that there are unobserved “negative in-licensing payments” (i.e. positive licensing revenues) but censored at zero by the data reporting processes, or for the possibility zero licensing payments represent an optimizing corner solution.[15] The results in column 1 of Table 3 show that fragmentation is positively and significantly related to licensing expenditures as a percentage of sales. We also estimate a probit model of the probability of licensing as well as a Tobit restricted to positive observations on licensing as a percentage of sales. In the latter specification, we observe a positive but insignificant effect of fragmentation, while the effect in the Probit model remains statistically significant at the 5% level. Using the probit specification we find that an increase in fragmentation of one standard deviation increases the probability of in-licensing by 3.0 percentage points. This is a sizable effect given that the probability of in-licensing is 22% in the sample.

Our control variables have mainly the expected sign. The R&D/sales ratio is positively and significantly associated with licensing, consistent with the hypothesis that in-licensing is positively related to the firm’s absorptive capacity. The index for patent protection is positively associated with licensing, consistent with the predictions of Gans et al. (2002) and Arora et al. (2001) that stronger IP rights should be associated with more licensing. Larger firms spend more on licensing as a percentage of sales, but age is insignificantly related to licensing expenditures.

We then turn to separately examining the effects of fragmentation on licensing costs for firms above and below the median patent portfolio size in our dataset (columns 4 and 5). The results accord with our hypothesis that fragmentation acts to increase licensing costs through royalty stacking primarily among firms that have few patents to trade in cross-licensing arrangements. A one standard-deviation increase in *Fragmentation* is associated with

[15] In all of our Tobit models, the dependent variable is censored “below” at zero. The dependent variable *Share of sales new to the market* is also censored “above” at 100%. Here the Tobit model accounts for both possibilities of a corner solution. We also estimated alternative specifications. The two-tier or “hurdle” model (Wooldridge (2002), p. 537) did not give markedly different results. The Papke-Wooldridge “fractional logit” model also gave broadly similar results, though with somewhat larger standard errors. The estimated standard errors are robust to heteroskedasticity.

approximately a 0.06 percentage-point increase in licensing expenditures as a share of sales. Given that the mean of this variable in this subsample is around 0.3%, this is a substantial increase of 19%. However, the coefficient is only marginally significant with a p-value of 0.08. There is no statistically significant relationship between fragmentation and licensing costs for licensees with patent portfolios above the median size in the sample.

We now ask whether fragmentation of IP rights affects innovative performance. We focus on firms' success with product innovations and use the firms' reported share of sales coming from new products. We use both products new to the market and those new to the firm as our measures of performance. The dependent variables *Share of products new to the market* and *Share of products new to the firm* capture the ability of firms not just to generate new products in the sense of concepts or prototypes, but to get past any patent thicket and realize sales. Column 1 of Table 4 contains results from a Tobit regression in which the dependent variable is the share of sales coming from products new to the market. The sample size is slightly smaller at 1343 observations since information on the dependent variable is missing for some companies. Overall, the estimated relationship between fragmentation and innovative performance is positive and marginally significant. When we use *Share of sales from products new to the firm* as the dependent variable in Column 2, the relationship is again positive but statistically insignificant. Importantly, however, this positive effect is driven by firms that do not license, because when we restrict attention to firms that report non-zero licensing expenditure, we observe a negative relationship between fragmentation and innovative performance (which is statistically significant at the 5% level for products new to the firm).

The positive relationship between fragmentation and innovative performance among non-licensors could reflect Lichtman's "safety in numbers" effect. It could also reflect unmodeled differences in the characteristics of licensors and non-licensors. We find that when we restrict our attention to non-licensors that more closely resemble licensors along observable dimensions, the positive effect is diminished. We do this by obtaining the predicted values of the licensing Probit model estimated in Table 3 and dropping the non-licensors with the lowest predicted probabilities of licensing (below 50th percentile of the predicted propensity to license). When this is done, the positive coefficient on *Fragmentation* falls and is no longer statistically significant at the 5% level, which suggests that the positive effect may be driven by the firms that are least likely to engage in licensing and thus may be fundamentally different from the licensors in our sample (columns 7 and 8).[16]

These results are consistent with the hypothesis that, for firms that require licenses to commercialize new technology, the fragmentation of upstream property rights hampers innovation. A one standard deviation increase in fragmentation reduces the share of sales with products new to the firm by 3.8 percentage points for licensees and increases the share by 2.2 percentage points for companies without in-licensing activity. Relative to the mean of the share of sales new to the firm in these two groups (licensees and non-licensees) this translates into a reduction of around 10% and an increase of around 9% respectively. One could also expect that firms that are experiencing high transaction costs but nevertheless manage to finalise a license contract should be more successful with their innovations. Our results show that this effect does not dominate. We find that the negative influence through "royalty stacking" is quantitatively more important.

Estimated coefficients for other explanatory variables conform to expectations: we find positive and significant concave relationship between innovative performance and innovation expenditures as a percentage of sales and stock of granted patents per employee, and a negative association between innovative performance and firm age (older firms are more likely to have a larger share of sales from previous generations of products).[17]

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[16] Other interpretations are that the non-licensors are operating in an uncrowded part of technology space, with relatively sparse coverage by existing patents, or that these are firms which have launched products "at risk" of patent infringement law suits.

[17] In regressions not reported here, we also investigated the relationship between fragmentation and strategic patenting. We regressed the firm's patent stock on the fragmentation index and a set of control

We also investigate whether fragmentation influences mainly the probability of having any sales of new products or influences mainly the size of the share of new products in total sales conditional on selling any new products (results not shown).[18] For in-licensing firms we find that fragmentation reduces the sales share of new products, conditional on positive sales of new product products, but does not reduce the probability of having positive sales. For firms that do not buy external IP we find the opposite pattern. Here fragmentation has a positive influence on the probability of having sales with new products but does not influence the size of the share.

To dig deeper into these findings, Table 5 presents results comparing the innovative performance of "insiders" (IP-intensive firms with five or more patents) and "outsiders" (firms with fewer than five patents). We chose the median number of patent applications of four to divide into the two subsamples. These regressions reveal that the negative relationship between fragmentation and innovation is strongest for licensing firms with fewer patents. This result is intriguing, as it is consistent with the hypothesis that in-licensing firms with smaller patent portfolios are more susceptible to the type of hold-up associated with patent thickets, while firms with large portfolios that do not need to license upstream technology may actually benefit from the existence of patent thickets.

6. Discussion and Conclusions

We have examined the relationship between fragmented IP rights and innovative performance, taking into consideration the role played by in-licensing of IP. When firms with small patent portfolios face more fragmented IP landscapes, they have higher licensing costs. This is consistent with a "royalty stacking" story, and/or a relationship between bargaining problems and fragmented ownership of rights. Note that this is not a reflection of a linear relationship between

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variables. However, in contrast to the work of Ziedonis (2004), we do not observe any significant relationship between the firm's patent stock and the degree of IP fragmentation.

[18] We use the simple "two-tier" model proposed by Wooldridge (2002, p. 537) to separately estimate the probability of positive sales of new products, and the share of sales of new products in total sales, conditional on positive sales of new products.

the number of licenses acquired and in-licensing expenditures: the fragmentation index captures a very different aspect of the patent landscape. We also observe a negative relationship between IP fragmentation and performance with product innovations, but only for firms that engage in in-licensing. This is consistent with the hypothesis that firms that require licenses to commercialize new technology are hampered in innovative activity by the fragmentation of upstream property rights.

The relationship between fragmentation and innovative performance also depends on the size of a firm's patent portfolio. That is, the relationship between fragmentation and licensing costs on the one hand, and fragmentation and innovative performance on the other, is most pronounced among licensing firms that have a below-median number of patents. This finding is suggestive of the strategic importance of defensive patenting in the context of fragmented property rights – firms seem to be able to reduce the impact of fragmentation on performance by building up a stock of patents. This appears to be consistent with Ziedonis (2004)'s hypotheses about the benefits of defensive patenting when facing fragmented ownership of rights to complementary technologies.

A limitation of our study is our focus on small and medium-sized companies. As our results are obtained for this size group, they do not necessarily hold for very large players. Since large companies have more negotiation power, they may be differently influenced by fragmentation. Another limitation of our data is that we cannot observe cross-licensing agreements in which no licensing fees are paid. To the extent that firms use a mixture of licensing contracts with monetary compensation and cross-licenses, our findings about the importance of patent portfolio size could reflect the use of firms' patent portfolios in cross-licensing to deal with the fragmentation problem.

Notwithstanding these limitations, we believe that this research contributes to our understanding of the complex role played by market structure in the market for technology. While businesses, economists and policy-makers arguably have a relatively clear understanding of the private benefits of patents to the firms that hold them, as well as the more general benefits of the innovative activity patents help stimulate, we still lack a complete picture of the possible negative externalities associated with patent thickets. In particular there is to date little evidence on which types of firms are most affected, and this paper helps fill this gap in our understanding. Perhaps our most salient findings are those about the effects of IP fragmentation on in-licensing firms with small patent portfolios, many of whom are young, small firms. Entrepreneurial firms are an important source of innovation and a driver of economic growth, and it is thus important from a policy perspective to know whether patent thickets are particularly pernicious for these firms. However, it is striking that we do not observe any significant negative correlation between fragmentation and innovative sales more generally, and we even estimate a *positive* correlation between fragmentation and innovative sales among firms that do not in-license. This heterogeneity in the estimated effects of fragmentation suggests that there is no straightforward, uniform relationship between patent thickets and innovation for all firms. This latter finding suggests the need for further research on the potentially varying impacts of patent thickets.

Our results have several implications for future research on the relationship between IPRs and markets for technology. One is that the decision to participate in markets for technology via in-licensing is correlated not just with the overall *strength* of IPRs but also with the *distribution* of property rights across potential licensors. Another is that terms of licensing agreements (measured here by the size of in-licensing payments relative to total sales) depend on the distribution of IP rights across potential licensors, but that this only matters for firms with small patent portfolios that may find it more difficult to offset licensing costs via cross-licensing. Our results suggest that future research in this area should take into consideration the role of the concentration of IP rights in determining equilibrium outcomes for different types of firms in markets for technology.

While licensing transactions offer a means of accessing technology and product markets in the face of thickets of blocking patents, the economic efficiency of this mechanism is poorly understood, and it may have important limits. In particular, there may be important non-linearities in the relationship between fragmentation of IP rights, incentives to license, and costs of innovating. For example, in the extreme case of very highly fragmented patent landscapes, the presence of too many licensors and too many patents may led to insuperable bargaining problems that render licensing impractical or irrelevant, bringing about a complete breakdown of the price mechanism in the market for technology. Here we may expect to see quite different solutions emerge, with very different IP strategies used by market participants.

Table 1: Summary statistics

Variable	Mean	Median	Std. dev	Min	Max
Employees	346.4	260	302.9	2	1500
Age (years)	20.9	14	22.8	0	175
Sales (in million EUR)	62.43	38.45	92.71	0.19	1240
R&D (in million EUR)	1.16	0.35	2.10	0	26.04
Fragmentation	0.725	0.729	0.028	0.607	0.794
Dummy licensing	0.219	0	0.413	0	1
Licensing/sales (in %)	0.0542	0	0.198	0	2.12
Licensing/sales conditional on licensing>0 (in %)	0.262	0.123	0.367	0.0002	2.12
Share of sales from products new to the market (in %)	8.71	3	15.08	0	100
Share of sales from products new to the firm (in %)	26.02	20	26.01	0	100
R&D/sales (in %)	3.21	1.31	5.91	0	63.6
R&D/sales conditional on R&D>0 (in %)	4.10	2.11	6.40	0.001	63.6
Patent stock of firm	10.36	4	20.25	1	236
Patent stock of firm/employees	0.053	0.020	0.135	0.001	3
Innovation expenditures/sales	5.83	3.21	9.77	0	101.4
Dummy Eastern Germany	0.132	0	0.338	0	1
Dummy group	0.430	0	0.495	0	1
Index patent protection	2.67	2.62	0.464	1	5
Herfindahl index	45.3	14.67	66.7	0.88	416.1
Patents at technology level (in '000)	3.05	2.77	1.48	0.275	12.28

Table 2: Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Fragmentation	1															
(2) Share of sales from products new to the market	0.065	1														
(3) Share of sales from products new to the firm	0.038	0.586	1													
(4) Dummy licensing	0.092	0.047	0.158	1												
(5) Licensing/sales	0.023	0.089	0.134	0.525	1											
(6) R&D/sales	0.030	0.389	0.348	0.001	0.095	1										
(7) Patent stock of firm/ employees	0.068	0.091	0.052	-0.001	0.032	0.106	1									
(8) Innovation expenditures/ sales	0.057	0.364	0.322	0.091	0.165	0.671	0.128	1								
(9) Log patent stock of firm	0.119	0.034	0.070	0.148	-0.007	-0.007	0.297	0.046	1							
(10) Log employees	-0.019	-0.181	-0.112	0.103	-0.109	-0.257	-0.408	-0.194	0.345	1						
(11) Log age	0.097	-0.064	-0.073	0.062	-0.017	-0.081	-0.026	-0.029	0.114	0.156	1					
(12) Dummy group	0.201	-0.046	0.027	0.060	0.010	-0.060	0.019	0.014	0.252	0.229	0.051	1				
(13) Dummy Eastern Germany	-0.015	0.084	0.185	-0.066	0.032	0.248	0.048	0.142	-0.110	-0.219	-0.186	-0.021	1			
(14) Index patent protection	-0.093	0.037	0.046	0.057	0.056	0.100	0.042	0.110	0.041	-0.092	-0.082	-0.049	0.088	1		
(15) Herfindahl index	-0.097	0.065	0.078	-0.063	-0.022	0.110	0.036	0.095	-0.031	-0.083	-0.001	-0.045	-0.009	0.129	1	
(16) Log patents at technology level	0.330	0.072	0.060	0.062	-0.011	0.128	0.062	0.077	0.097	-0.061	0.038	0.128	-0.005	-0.047	0.013	1

Table 3: Licensing expenditures

	(1)	(2)	(3)	(4)	(5)
Model	Tobit	Probit	Tobit	Tobit	Tobit
Sample	All firms	All firms	Lic./sal. > 0	Lic./sal. > 0 patent stock < 5	Lic./sal. > 0 patent stock ≥ 5
Fragmentation	2.261**	1.051**	0.678	3.053*	-0.514
	(1.090)	(0.521)	(1.201)	(1.723)	(1.971)
R&D/sales	0.008**	0.002	0.017***	0.011*	0.023**
	(0.004)	(0.002)	(0.006)	(0.006)	(0.010)
Patent stock of firm/employees	0.103	0.101	0.151	3.809*	0.015
	(0.163)	(0.068)	(0.314)	(2.143)	(0.382)
Log employees	0.054**	0.063***	-0.143***	-0.098*	-0.147***
	(0.022)	(0.011)	(0.026)	(0.059)	(0.041)
Log age	0.005	0.004	-0.012	0.004	-0.025*
	(0.016)	(0.009)	(0.011)	(0.019)	(0.014)
Dummy group	0.020	-0.012	0.074*	0.098	0.063
	(0.047)	(0.024)	(0.042)	(0.071)	(0.056)
Dummy Eastern Germany	-0.089	-0.050*	0.097	0.123	0.067
	(0.074)	(0.029)	(0.099)	(0.129)	(0.163)
Index patent protection	0.126**	0.077**	-0.062	-0.130*	-0.086
	(0.062)	(0.034)	(0.056)	(0.079)	(0.073)
Herfindahl index	-0.000	-0.000*	0.000	0.001***	-0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log patents at technology level	-0.044	-0.009	-0.074*	-0.005	-0.131**
	(0.048)	(0.022)	(0.042)	(0.050)	(0.061)
No of observations	1616	1616	334	154	180
No of firms	1053	1053	283	132	156
Log likelihood	-713.84	-784.17	-79.27	-32.87	-22.63
Pseudo R squared	0.057	0.077	0.428	0.567	0.611

Note: Robust standard errors in parentheses. The dependent variable in columns 1 and 3-5 is licensing expenditures/sales. The dependent variable in column 2 is a dummy for positive licensing expenditures. Column 2 shows marginal effects. Year and industry dummies included. Standard errors in parentheses. In the Tobit regressions, the lower limit for left-censoring is zero. In columns 3-5 the regression is the MLE with no censoring. * significant at 10 %, ** significant at 5%, *** significant at 1%.

Table 4: Tobit estimation: product innovation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	New to the market	New to the firm	New to the market	New to the firm	New to the market	New to the firm	New to the market	New to the firm
Sample	All firms		Licensees		Non-licensees		Restricted sample of non-licensees	
Fragmentation	78.726**	50.114	-97.341	-120.727**	116.311***	78.598**	90.105*	31.551
	(33.629)	(33.747)	(84.085)	(60.543)	(37.848)	(39.541)	(54.140)	(51.967)
Innovation expenditures/	1.272***	1.955***	0.683	0.870***	1.331***	2.202***	1.125***	1.769***
sales	(0.196)	(0.188)	(0.433)	(0.296)	(0.201)	(0.238)	(0.263)	(0.270)
Square of innovation	-0.005*	-0.015***	-0.002	-0.006	-0.005*	-0.018***	-0.002	-0.012***
expenditures/sales	(0.003)	(0.003)	(0.006)	(0.004)	(0.003)	(0.005)	(0.003)	(0.004)
Patent stock of firm/	4.325	5.104	-7.439	14.147	6.202	3.361	8.617	4.401
employees	(5.716)	(7.796)	(13.684)	(14.528)	(6.468)	(8.633)	(7.984)	(9.654)
Log employees	-0.046	2.071***	-3.467**	-0.683	0.487	2.287***	1.396	2.401**
	(0.659)	(0.711)	(1.502)	(1.334)	(0.755)	(0.827)	(1.148)	(1.098)
Log age	-0.022	-1.040**	0.587	-0.601	-0.060	-1.273**	0.401	-0.990
	(0.506)	(0.518)	(1.021)	(0.958)	(0.598)	(0.620)	(0.752)	(0.736)
Dummy group	1.603	0.058	6.213**	1.779	-0.046	0.016	0.112	0.467
	(1.508)	(1.668)	(2.785)	(3.100)	(1.731)	(1.941)	(2.055)	(2.263)
Dummy E. Germany	-5.534**	4.971*	-4.237	7.584	-4.881**	5.215*	-2.493	4.957
	(2.243)	(2.547)	(5.826)	(4.869)	(2.411)	(2.862)	(3.901)	(4.307)
Index patent protection	2.121	-0.921	10.337**	-0.961	-0.818	-2.055	-1.208	-2.348
	(2.235)	(2.394)	(5.153)	(5.211)	(2.593)	(2.676)	(3.832)	(3.379)
Herfindahl index	-0.000	0.027**	0.042*	0.062***	-0.008	0.024*	-0.025	-0.007
	(0.012)	(0.012)	(0.022)	(0.023)	(0.013)	(0.014)	(0.017)	(0.016)
Log patents at tech. level	-0.102	0.209	4.562	3.667	-1.647	-1.081	-0.696	-0.021
	(1.456)	(1.379)	(3.773)	(2.833)	(1.508)	(1.589)	(2.093)	(1.856)
No of observations	1325	1690	281	372	1044	1318	588	800
No of firms	912	1086	243	309	750	895	474	623
Log likelihood	-3624.58	-6580.51	-930.14	-1596.94	-2666.27	-4942.83	-1496.39	-3100.49
Pseudo R squared	0.0390	0.0439	0.0354	0.0524	0.0459	0.0443	0.0534	0.0455

Note: The dependent variable is share of sales from products new to the market/new to the firm. Year and industry dummies included. Robust Standard errors in parentheses. In the Tobit regressions, the lower limit is zero and the upper limit is 100%. * significant at 10 %, ** significant at 5%, *** significant at 1%. Restricted sample includes Non-licensees above 50th pctile of predicted probability of licensing.

Table 5: Tobit estimation: product innovation – size differences

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Share of sales new to the market				Share of sales new to the firm			
Sample	Licensees patent stock < 5	Licensees patent stock ≥ 5	Non-licensees patent stock < 5	Non-licensees patent stock ≥ 5	Licensees patent stock < 5	Licensees patent stock ≥ 5	Non-licensees patent stock < 5	Non-licensees patent stock ≥ 5
Fragmentation	-112.518	-98.809	92.698	132.043***	-278.813***	-81.445	177.283***	-29.008
	(139.235)	(88.202)	(56.989)	(48.237)	(84.096)	(89.671)	(53.358)	(61.426)
Innovation expenditures/	1.056	0.204	1.284***	1.766***	0.734*	0.333	2.004***	2.984***
sales	(0.639)	(0.573)	(0.255)	(0.403)	(0.394)	(0.472)	(0.260)	(0.503)
Square of innovation	-0.005	-0.001	-0.004	-0.022**	-0.008*	0.009	-0.015***	-0.043***
expenditures/sales	(0.007)	(0.007)	(0.003)	(0.010)	(0.004)	(0.007)	(0.004)	(0.016)
Patent stock of firm/	44.585	-1.350	6.893	2.117	76.530	6.036	0.732	1.386
employees	(79.651)	(11.503)	(21.481)	(6.376)	(73.895)	(16.734)	(27.907)	(9.410)
Log employees	-3.712	-1.499	-1.183	1.625	1.025	-1.308	1.019	2.839*
	(3.029)	(1.661)	(1.184)	(1.296)	(2.466)	(2.359)	(1.328)	(1.481)
Log age	1.027	0.850	0.357	-1.577*	-0.651	0.267	-1.526*	-2.043**
	(2.231)	(0.968)	(0.884)	(0.835)	(1.569)	(1.305)	(0.865)	(0.856)
Dummy group	10.666**	1.774	-1.018	0.463	1.632	2.977	-0.258	0.092
	(5.249)	(2.645)	(2.479)	(2.402)	(3.936)	(4.544)	(2.600)	(2.767)
Dummy Eastern Germany	-2.849	-5.635	-3.980	-3.240	18.324***	0.754	8.048**	-1.048
	(8.232)	(4.866)	(3.214)	(3.318)	(6.780)	(5.040)	(3.618)	(4.715)
Index patent protection	13.031	12.298***	-4.061	0.667	4.851	-3.161	-4.226	1.700
	(11.459)	(4.419)	(3.467)	(4.323)	(7.324)	(6.603)	(3.039)	(5.262)
Herfindahl index	0.066**	0.043	-0.009	-0.004	0.057**	0.079***	0.012	0.055**
	(0.032)	(0.033)	(0.015)	(0.023)	(0.029)	(0.029)	(0.016)	(0.022)
Log patents at techn. level	7.214	2.231	-2.507	-1.077	3.564	2.693	-1.122	0.127
	(6.781)	(2.339)	(2.190)	(2.170)	(3.704)	(3.281)	(2.364)	(2.275)
No of observations	131	150	598	446	156	210	770	548
No of firms	117	131	447	316	132	176	553	370
Log likelihood	-413.7160	-481.077	-1376.25	-1257.12	-654.85	-891.79	-2735.71	-2174.09
Pseudo R squared	0.0597	0.0340	0.0673	0.0413	0.0801	0.0547	0.0564	0.0407

Note: The dependent variable is share of sales from products new to the market/new to the firm. Year and industry dummies included. Standard errors in parentheses. In the Tobit regressions, the lower limit is zero and the upper limit is 100%. * significant at 10 %, ** significant at 5%, *** significant at 1%

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Appendix

Table A1: Technology classes

Area	Description	Area	Description
1	Electric machinery, energy	16	Chemical engineering
2	Audiovisual technology	17	Surface technology, coating
3	Telecommunications	18	Materials, metallurgy
4	Information technology	19	Materials processing, textiles, paper
5	Semiconductors	20	Handling, printing
6	Optics	21	Agric. and food processing, machines
7	Analysis, measurement tech.	22	Environmental technology
8	Medical technology	23	Machine tools
9	Nuclear engineering	24	Engines, pumps and turbines
10	Organic fine chemistry	25	Thermal processes and apparatus
11	Macromolecular chemistry	26	Mechanical elements
12	Pharmaceuticals, cosmetics	27	Transport
13	Biotechnology	28	Space technology, weapons
14	Agriculture, food chemistry	29	Consumer goods and equipment
15	Petrol industry, basic materials	30	Civil engineering, building, mining

Note: The technology classes are taken from an update of the patent manual ”Using Patent Data as Science and Technological Indicators” published in 1994 by the OECD.