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The patenting activity of German Universities

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Abstract Patents serve as indicators of a university's knowledge base; consequently, information on the patent volumes and patenting activity of universities is crucial for scientific and industrial organizations and policy makers. By matching secondary patent data from PATSTAT with secondary data on German universities from the CHE research ranking, we provided a broad overview of the patenting activity of German universities. Specifically, we first introduced a patent ranking. Second, we analyzed a broad spectrum of different indicators of the patenting behavior of German universities. Third, we analyzed potential determinants of their patent output. Our data revealed that patenting activity varied not only among the 25 universities that had the highest overall number of patent applications between 2002 and 2011 but also among the 156 universities that filed at least one patent. Using a Heckman sample selection model for our regression analyses, we analyzed (1) the influence of university size, university type, technical university, and faculty profile on the probability that a German university was active in patenting ($N = 328$) and (2) the relationships between patenting experience, research breadth, and research quality and the patent output of German universities ($N = 156$). Our findings suggest that patent output at least partly depends on these determinants, thereby shedding light on the substantial performance differences in patenting activities that existed in our sample.

Keywords Patenting · University patent · Academic performance · Knowledge-based view

JEL Classification O32 · O34 · I20

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1 Introduction

Investigating the patenting activity of universities[1] is crucial for the following reasons. First, university patents (i.e., "the legal right[s] of [universities] to exclude others from making or using a particular invention" (Hall 2007, p. 568) protect intellectual property and thus serve as indicators of a university's knowledge base. Given increasing competition among universities (Melo et al. 2010), such knowledge base indicators appear to be crucial, as "sustainable advantages and performance differences result when firms have unique knowledge bases" (Santoro and Bierly 2006, p. 496). Second, university patents enable knowledge transfer from universities to industry (Perkmann and Walsh 2007). Such knowledge transfer is important because university research contributes to firm knowledge and industrial innovation (Fabrizio 2006). The creation of economically useful knowledge and its effective conversion into economic activity are essential for economic growth (Carlsson et al. 2009). Therefore, elucidating the patenting activity of universities and the factors stimulating and hindering it provides scientific and industrial organizations and policy makers with the information necessary to optimize industry-science cooperation. Third, and closely related to the aforementioned argument, analyzing the patenting activity of universities, and especially its determinants, provides organizations and politicians with valuable insights into the structural changes they might wish to implement and the incentives they might wish to provide to foster patenting activities.

Previous research on university patents has primarily examined the consequences of academic patenting. For instance, previous research has focused on the effects of academic patenting (by universities or individual researchers) on academic research (e.g., Azoulay et al. 2009; Fabrizio and Di Minin 2008; Geuna and Nesta 2006). Studies investigating patenting activity as a dependent variable rather than as a predictor variable have primarily analyzed the effects of changes in the legal framework on university patenting activity (e.g., Frietsch et al. 2010; Mowery et al. 2001; Von Ledebur et al. 2009) or the individual determinants (e.g., scientific productivity) of academic patenting (e.g., Azoulay et al. 2007). However, research has thus far largely failed to analyze the institutional determinants of academic patenting (Van Looy et al. 2011). A notable exception is the study of Van Looy et al. (2011), which reported a positive relationship between scientific productivity and patenting activity in a sample of European universities and stated that patenting activity is influenced by, among other factors, the size of a university. A further gap in the literature is that most previous research on academic patenting activity has focused on the US (cf. Acosta et al. 2009; Czarnitzki et al. 2009) and the few other studies have focused on Europe rather than on individual countries such as Germany. Few studies have analyzed the patenting activity of German universities (e.g., Fritsch and Slavtchev 2006; Von Ledebur et al. 2009). Studies investigating the patenting activity of German universities address, for instance, the ownership structure (Schoen and Buenstorf 2013) or geographical nature of patents (Blind and

[1] In the following, we use the term university as collective term for traditional universities, universities of applied sciences, and colleges of art and music.

Grupp 1999). However, a descriptive overview of the patenting activity of German universities and an analysis of the determinants of such patenting activity is lacking. Thus, despite the substantial importance of understanding the university patenting activity, our knowledge in this research field is limited in the following ways: (1) studies on the institutional determinants of patenting behavior, in general, are scarce; and (2) research on the patenting activity of German universities remains in its infancy—in particular, a descriptive overview of the current state of the patenting activity of German universities and information on the determinants of patenting activity are absent.

This is an important oversight because the university patenting activity differs considerably across European countries (Geuna and Rossi 2011) due to legislative differences, such that findings can become blurred if they are based on a sample of universities from different countries (Geuna and Rossi 2011), and generalizing empirical findings from one country to another is not necessarily possible. Moreover, knowledge on the patenting activity of German universities is urgently needed as a basis for policy recommendations: research on the patenting activity of German universities and especially on its determinants is essential for politicians to understand the potential effects of measures designed to foster the patenting activity of German universities and, in turn, the knowledge transfer from universities to industry. Thus, providing a broad overview of the patenting activity of German universities and analyzing potential determinants of the patent output of German universities is long overdue.

In our study, we seek to address these gaps in the literature by providing an extensive overview of the patenting activity of German universities. First, we present a university ranking based on the patenting activity of German universities, thereby revealing information on which higher education institutions perform especially well with respect to the number of patent applications and the extent to which even the 25 best universities differ regarding their patenting activity. Second, to probe deeper into the patenting activity of German universities, we analyze the different patenting behaviors of universities and predict substantial differences in the strategies used by various universities to protect their intellectual property. Third, we analyze potential determinants of patent output, by investigating the influence of patenting experience, and the breadth and quality of research on the patent output of German universities. Thus, we shed light on factors that might contribute to the differences among German universities in patent output, thereby providing politicians with essential knowledge concerning what needs to be fostered in the higher education system to promote the patenting activity of German universities.

This paper is organized as follows: first, in Sect. 2, we present differences between universities and firms and the knowledge-based view as a theoretical basis of our study before we provide theoretical foundations on patent rankings and patenting behavior and on the determinants of patenting activity. Second, in Sect. 3, we describe our sample, the data sources and operationalization of the variables used in this study, as well as our data analyses. Third, in Sect. 4, we report the patent ranking of German universities, our observations regarding the patenting behavior of German universities, and our findings regarding the determinants of

German universities' patent output. In Sect. 5, we finally discuss our findings and the theoretical and practical contributions of our study and provide suggestions for future research.

2 Theory

2.1 Universities and the knowledge-based view

2.1.1 Differences between universities and firms

Universities differ from firms along the following important dimensions (Minssen and Wilkesmann 2003; Osterloh 2010; Ringelhan et al. 2013). First, competition among universities differs from competition among firms. Although there was previously no meaningful competition among German universities, recently, competition among universities has become an issue in Germany. Specifically, at present, universities compete fiercely to raise money from third party agencies, attract high-quality students and faculty members, and achieve high-ranking positions.[2] Thus, although, in the literal sense, the "research mission of academia […] is to add to the stock of public knowledge by conducting basic research, i.e., research resulting in fundamental insights" (Sauermann and Stephan 2012, p. 3), similar to firms, universities face a competitive environment. However, in contrast to firms, universities compete in a highly specific environment, namely in the market for higher education and research. Second, universities are "expert organizations" (Pellert 1999) that heavily rely on the knowledge stored in individual scholars. Although knowledge-intensive organizations (e.g., consultancies) also depend on highly qualified employees and their knowledge, there are many firms that are less knowledge intensive. Thus, one might argue that the average dependency on knowledge resources and individuals is much higher in a university context. Third and closely related, most firms focus on standardized production processes (e.g., for clothes or cars) and the provision of services (Ringelhan et al. 2013). By contrast, universities rely more on the originality and creativity of their employees (Osterloh 2010) with respect to the typically desired outcomes, namely research contributions, and thus rely to a greater extent on processes that are more difficult to plan and to control. Fourth, task complexity differs (Ringelhan et al. 2013): while task complexity is generally relatively low, at least in producing firms, work tasks in universities are typically highly complex and involve multiple performance dimensions (Keller 2012; Schmoch et al. 2010). Accordingly, defining and measuring performance in firms is generally much easier than defining and measuring performance in an academic setting. Fifth, due to differences regarding the autonomy and freedom of employees in firms and universities, the types of motivation that are prevalent among employees are also assumed to differ (Ringelhan et al. 2013). For example, scholars have greater freedom to select which projects they pursue, and hence their personal interests are

[2] We thank an anonymous reviewer for highlighting this difference.

considered to a larger degree. Project choices in academia are—if at all—limited by the requirement that they should contribute to the progress of science, whereas project choices in firms are generally limited by the specific needs that are determined at higher levels (cf. Sauermann and Stephan 2012). Accordingly, in firms, employees are assumed to be often highly extrinsically motivated (i.e., motivated by extrinsic factors such as money, recognition, status, or competition; see, e.g., Amabile et al. 1994; Deci 1971). By contrast, while employees in academia are also assumed to be extrinsically motivated (e.g., by reputation or by additional rewards that they can gain from also operating a consultancy firm), empirical (Ringelhan et al. 2013) and anecdotal evidence indicate that the level of intrinsic motivation (i.e., motivation by factors such as interest, enjoyment, or an inner drive to perform a task; see, e.g., Amabile et al. 1994; Deci 1971; Minssen and Wilkesmann 2003) is also very high in this context.

Knowledge of these differences between firms and universities is important with respect to the generalizability of empirical findings on patent output in both fields. For example, on the one hand, one might argue that universities should generate a higher patent output given their drive for exploration, originality and creativity. On the other hand, one might argue that the primary focus on contributing to the progress of science, often paired with a lack of experience in patenting at universities, leads to a lower patent output. Thus, the specific environments must always be considered before transferring results from one context to the other. With respect to the transfer of research findings, one should also bear in mind that findings gained in a firm context often relate to departments that are knowledge-intensive (e.g., R&D departments) rather than to producing firms. Because the differences noted above are less pronounced when considering knowledge-intensive organizations or departments, the transfer of results bears fewer risks than when transferring results from producing firms to universities or vice versa.

2.1.2 The knowledge-based view as a theoretical basis

The knowledge-based view (e.g., Grant 1996b; Spender 1996) offers insights on performance differences between firms (Eisenhardt and Santos 2006) by examining their knowledge resources (e.g., at patents). It "can yield insights beyond the production-function and resource-based theories of the firm. It is a platform for a new view of the firm as a dynamic, evolving, quasi-autonomous system of knowledge production and application" (Spender 1996, p. 59).

In their seminal article, Kogut and Zander (1992, p. 383) argue that "what firms do better than markets is the sharing and transfer of the knowledge of individuals and groups within an organization." Because organizations efficiently structure the knowledge embedded in established individual relationships, organizational knowledge exceeds the sum of individual capabilities (Kogut and Zander 1992, 1993). This argument is supported by the literature on organizational knowledge creation and transfer, which regards knowledge as the appropriate unit of analysis for explaining firm behavior (Nonaka 1994; Nonaka and Takeuchi 1995; Nonaka et al. 1996). In general, scholars distinguish between explicit and tacit knowledge. Explicit knowledge refers to knowledge concerning facts and theories (Grant 2010)

and thus to knowledge that can be codified and easily transferred (Nonaka 1991). In contrast to explicit knowledge, tacit knowledge is implicit and highly personal. "It is hard to formalize and, therefore, difficult to communicate to others […] [and it] is also deeply rooted in action and in an individual's commitment to a specific context" (Nonaka 1991, p. 98). Knowledge creation occurs through the continuous interplay of these two knowledge types (Wahab et al. 2009), whereas knowledge transfer denotes "learning indirectly from the experience of others" (Argote and Miron-Spektor 2011, p. 1130).

Grant (1996a) summarizes four assumptions that underlie the knowledge-based view: (1) knowledge adds value, and thus knowledge should be considered strategically important and the primary productive resource of the firm; (2) due to its limited transferability, tacit knowledge is of particular importance; (3) individuals are the principal repositories of knowledge and acquire and store (especially tacit) knowledge in a highly specialized form (Grant 1996a; Wahab et al. 2009); and (4) production generally entails applying different knowledge types, and economies of scale and scope may apply to knowledge (Wahab et al. 2009). Explicit knowledge in particular can, once created, be reapplied at low marginal costs (Grant 1997). We suggest that these assumptions are not only valid in a firm context but also that these assumptions can be transferred to universities as organizations for the following reasons. First, excellence in education and research is highly dependent on a university's knowledge base. As knowledge is the key antecedent for achieving the primary goal of universities (i.e., excellence in education and research) and universities, as expert organizations (Pellert 1999), heavily rely on the knowledge stored in individuals, one might argue that knowledge is strategically important and also serves as the primary productive resource in universities. Second, one might argue that tacit knowledge is also of particular importance in a university context. Tacit knowledge plays a crucial role in knowledge creation and knowledge transfer and might thus be considered an important prerequisite for patenting. Patents represent a specific type of intellectual property rights (IPRs) and are directly related to the transfer of explicit knowledge. In recent years, a market for patents, in which knowledge is exchanged, has begun to emerge (Monk 2009). Certain scholars expect IPRs to be the "emerging currency of the global, knowledge-based economy" (Carayannis and Alexander 1999, p. 2). Patents protect inventions in technological or scientific fields, such as new products or production processes (Ramello 2005); thus, in addition to explicit knowledge, tacit knowledge is required and of major importance for developing the invention protected by the patent. Third, scholars serve as the principal repositories of knowledge in universities. Because universities are knowledge-intensive expert organizations (Pellert 1999), one might argue that the role of individual scholars who acquire and store the knowledge in a highly specialized form is even more important in universities than in typical firms. Fourth, both explicit and implicit knowledge are generally also required in a university context. While, for example, teaching or writing articles involves direct communication and thus requires scholars to be aware of the facts that they communicate and the ability to represent them in a declarative form, one might argue that the daily work of scholars is to a large extent

characterized by a tacit component of knowledge that is fostered through experience accumulation. Such tacit knowledge components are crucial for inventions; however, to be patentable, the knowledge must ultimately be explicitly coded. Overall, the fundamental assumption of the knowledge-based view stating that the "primary role of the firm [is] integrating the specialist knowledge resident in individuals into goods and services" (Grant 1996b, p. 120) appears to be transferable to universities. Universities seek to integrate the knowledge of individual scholars employed at their institutions to be able to provide excellent education and produce research results that might contribute to the progress of science and be manifest in publications and/or patents.

For successful knowledge transfer to occur, organizations require certain capabilities (Schulze et al. 2014). Specifically, the disseminating organization must be able to "efficiently, effectively, and convincingly frame knowledge in a way that other people can understand accurately and put their learning into practice" (Tang et al. 2010, p 1587) (i.e., it has to dispose of a disseminative capacity, cf. Tang et al. 2010). Therefore, first, performance differences in universities' patent outputs might be explained by differences in their efficiency at integrating and creating new knowledge. Second, performance differences might result from differences in the resources and capabilities necessary to disseminate knowledge via patents. Specifically, universities with the following resources and capabilities can be expected to patent more inventions: first, universities that have appropriate research capabilities presumably have a high patent output because research capabilities enable universities to integrate knowledge efficiently and create more valuable, patentable inventions (Grant 1996a; Vinig and van Rijsbergen 2009). Second, the financial resources that can be used to cover the costs of patent applications and conduct research influence research excellence (e.g., Azoulay et al. 2007; Czarnitzki et al. 2009; Fabrizio and Di Minin 2008; Van Looy et al. 2011), and thus, patent output and licensing (Coupé 2003; Wayne 2010). Third, scientific, business, and legal capabilities are important because they are required for coding the tacit and explicit knowledge generated by research in patents. Fourth, administrative structures, such as technology transfer offices, represent a crucial resource for university patenting (Baldini 2009; Siegel et al. 2003). Fifth, the ability to assess the needs and capabilities of firms that might be interested in the generated knowledge is important because patents are only useful if firms are able to recognize that the related invention is valuable and know how to apply the disseminated knowledge appropriately (Huggins et al. 2008).

In summary, the knowledge-based view represents a valuable approach for explaining performance differences between firms and universities with respect to their patent volume and activity. Given the importance of knowledge transfer for innovation and thus for society, shedding greater light on patenting activities in academia and thus universities' efficiency in knowledge integration can reveal important policy implications. It may reveal insights regarding performance requirements in academic patenting. Such insights might serve as a valuable starting point for deciding, for example, which universities and academic disciplines German ministries should foster.

2.2 Patent ranking and the patenting behavior of German universities

Over the past few decades, increased attention has been devoted to academic patents. Academic patents encompass patents by universities (referred to as university patents), by individual academic researchers or by companies that involve academic researchers in their research process (Geuna and Rossi 2011). The increased attention to academic patents primarily emerged as a consequence of changes in the legal framework of patenting activities. In the US, academic patenting has advanced significantly since the passage of the Bayh-Dole Act in 1980 (Mowery and Shane 2002), which gave universities the right to own patents on inventions arising from federally funded research. To respond to perceptions that public research was excessively distant from industry, the Bayh-Dole Act increased incentives for the commercialization of public research (Cohen et al. 2002). Underlying this legislation was the assumption that companies would only undertake investments to transform an invention into a commercial product if they were legally protected against imitation by competitors (Verspagen 2006). For similar reasons, legislation was subsequently changed in numerous European countries (Geuna and Rossi 2011).

In 2002, Germany abolished the so-called professors' privilege through changes to the law on employee inventions (*Arbeitnehmer-Erfindungsgesetz*) (Frietsch et al. 2010). Professors' privilege means that professors and academic staff were allowed to retain patents on their inventions arising from publicly funded research in exchange for the related costs (e.g., application fees, potential infringement costs) (Czarnitzki et al. 2009). Since the abolition of professors' privilege in 2002, universities have had the right to claim ownership of inventions but must bear the financial risks and necessary administrative efforts involved in the patent application process (Frietsch et al. 2010). Revenues from the exploitation of inventions are then shared among universities and inventors (Czarnitzki et al. 2009). This change in legislation was expected to reduce legal obstacles to patenting academic inventions and foster university patenting activity (Brockhoff 1998).

The abolition of professors' privilege (likely in conjunction with other influencing factors, cf. Cuntz et al. 2012; Geuna and Rossi 2011) has generally led to an increase in university-owned patents in Germany, but the overall number of patent applications with academic involvement has decreased since 2002 (Frietsch et al. 2010; Von Ledebur et al. 2009). Thus, despite the increase in the number of university-owned patents, applications that are either filed privately by professors (as owners) or list professors (as inventors) but are owned by companies have declined in number (Von Ledebur et al. 2009). This decline might, on the one hand, indicate less knowledge transfer from universities to industry; on the other hand, it might indicate more selective patenting due to increased attention to the actual economic potential of inventions (Frietsch et al. 2010).

Despite the crucial importance of academic patenting activities for economic growth (Carlsson et al. 2009) and in explaining performance differences between organizations, our knowledge on the patenting activities and patenting behavior of German universities remains limited. Thus far, the literature has not provided an overview of the patenting activity of German universities. Such an overview can be

created by employing a ranking that sorts the observed entities on the basis of certain criteria (Dilger 2010). In the university sector, rankings are commonly employed to evaluate the research performance of universities and individual researchers (Dilger and Müller 2012). Similarly, the number of patent applications during a specific period of time can be used as a sorting criterion in rankings. Until 2006, the *Center for Higher Education* (*CHE*) provided such a patent ranking in their annually published research ranking for a limited number of universities and in particular research fields (e.g., engineering, biology, chemistry). Since 2007, these rather objective but nonetheless limited patent rankings have been replaced by an aggregate overview that lists the number of inventions reported to the respective responsible university office. Thus, a detailed overview of the patenting activity of all German universities is lacking.

Given the substantial heterogeneity in the German university system (e.g., different types of universities, different funding bodies, different sizes of universities, different research profiles), one might expect that the patenting activity of German universities differs significantly, for example, regarding the number of national and international patent applications, the number of patent families (i.e., inventions), and the value of their patent families. A considerable heterogeneity with respect to patent output might also be expected due to differences in universities' knowledge bases and their capabilities to accumulate, recombine and create knowledge. As German universities currently compete fiercely to raise money from third-party agencies and attract high-quality students and faculty members, they differ in the amount of financial resources available and in the skills of their staff. With respect to patent output, these differences appear to be important because financial resources are crucial for bearing the risks and costs of patenting and because highly skilled staff may allow for a more efficient combination of tacit and explicit knowledge and thus for the creation of patentable invention. Another reason that might lead one to expect differences in the patenting activities of German universities is that universities differ in the support structure for knowledge dissemination via patents (e.g., with respect to the existence of a technology transfer office) or in patenting strategies (e.g., with respect to protecting inventions nationally vs. internationally). In summary, we therefore assume that a ranking concerning various aspects of the patenting activities of German universities will reveal notable differences and, thus, interesting insights.

2.3 Determinants of patent output

Research on academic patenting tends to consider patenting activity a predictor rather than an explanatory variable. The few studies that focus on the determinants of academic patenting often examine general conditions such as changes in the legal framework (e.g., Frietsch et al. 2010; Henderson et al. 1998; Von Ledebur et al. 2009). However, research on the institutional determinants of academic patenting is sparse (Van Looy et al. 2011). Below, we summarize the existing research and develop our hypotheses regarding the influence of potential determinants on the patenting activity of universities.

A potential determinant that appears to be of particular importance with respect to the knowledge-based view is patenting experience. Foltz et al. (2003, p. 195) found "strong evidence of a correlated dynamic effect in which patenting experience helps to produce more patents". Similarly, Von Ledebur et al. (2009) and Huelsbeck/Menno (2007) observed a positive impact of universities' patenting experience on their patent output. Because a patent application follows a certain process, one might argue that the development of operating routines is inevitable if a university wishes to master the patent application process. Zollo and Winter (2002, p. 341) highlight that "effective operating routines are always a necessity, and superior operating routines are always a source of advantage." The accumulation of experience is crucial to improving of operating routines (Zollo and Winter 2002). Experience accumulation is accompanied by an increase in tacit knowledge. According to the knowledge-based view, tacit knowledge is of particular importance, as it is difficult to transfer; however, both explicit and tacit knowledge are needed for production (Grant 1996a). Specifically, experience in patenting may allow universities to improve the identification of patentable ideas in their knowledge base and improve the integration and recombination of knowledge in a manner that enables explicit coding and thus the patenting of inventions. Previous research indicates that such experience accumulation effects are important in a university context (O'Shea et al. 2005). In line with previous research, we assume that this logic also applies to patenting activities and therefore posit a positive relationship between universities' patenting experience and their patent output.

H_1: Patenting experience is positively related to the patent output of German universities.

Additionally, the breadth of research might represent a potential determinant of university patenting activity. Geuna and Nesta (2006) observed differences across disciplines regarding patent output in academia. Van Looy et al. (2011) found that the patent output of universities is influenced by the universities' disciplinary scope. Specifically, they observed that the presence of an engineering department positively affects the patenting activity of European universities. Further studies support a positive impact of an engineering faculty (e.g., Coupé 2003; O'Shea et al. 2005; Sine et al. 2003) or a biological and medical department (e.g., Coupé 2003; Lach and Schankerman 2004; Sine et al. 2003) on patent output, and in general, patents are regarded as more appropriate for the protection of intellectual property in technology, medical and chemical science than, for example, in art-related research fields (Frietsch et al. 2010, p. 28). Thus, the disciplinary scope or, in other words, the breadth of research appears to be crucial to analyzing the patenting activity of universities. The more disciplines a university has, the more likely it is that patenting-intensive disciplines are present. In addition to the number of disciplines, the type of research discipline might be important in this context because technological progress differs across disciplines (Brockhoff 1998). To achieve technological progress, i.e., to create new knowledge, in certain disciplines, it is necessary to use previously gained knowledge (cumulative progress), whereas in other disciplines, systematically accumulating a knowledge base is not required (empirical progress) (Brockhoff 1998). Whether technological

progress is achieved in a cumulative or in an empirical manner affects whether patenting results in payoffs for researchers that exceed the benefits from not patenting (e.g., the free use of the created knowledge for subsequent research) (Brockhoff 1998).

Regarding the knowledge-based view, on the one hand, one might argue that the specialized knowledge that is most likely available in patenting-intensive disciplines (i.e., from the individuals working in patenting-intensive disciplines) is crucial for creating patentable inventions. A wide breadth of research enables interdisciplinary exchange between highly specialized individual researchers and departments, thus fostering creativity and, in turn, knowledge creation as a basis for patenting (because patents represent one alternative for how organizations might integrate the knowledge of specialized individuals into outputs (Grant 1996b). The broader the disciplinary scope, the greater the potential for integrating knowledge from different fields and achieving economies of scale and scope in patenting. On the other hand, operational activities, such as the formulation of legal parts or the search for licensing partners, might also benefit from interdisciplinarity. Interdisciplinarity might facilitate filing patents that are valuable in more industries. Additionally, interdisciplinarity might fuel interdisciplinary patents for commercialization in different industries. This appears to be beneficial because innovations increasingly involve different industries (Hargadon and Sutton 1997; Joshi et al. 2007; Schulze et al. 2014). Because the synergies accompanying broad scope of research are likely to reinforce both an efficient integration of new knowledge and capabilities for exploiting resulting invention, we assume that breadth of universities' research efforts is positively related to their patent output. Therefore, we suggest the following hypothesis:

H_2: Research breadth is positively related to the patent output of German universities.

Finally, the quality of research appears relevant to the potential determinants of university patent output. Hewitt-Dundas (2012) investigated how the research quality of universities in the UK is reflected in their knowledge transfer strategies and activities. Overall, they observed notable differences in transfer strategies and activities, which indicates that high research quality is positively associated with patent output. Such a positive relationship between research quality and patent output has been observed in several previous studies focusing on the level of the individual researcher (e.g., Azoulay et al. 2007; Czarnitzki et al. 2009; Fabrizio and Di Minin 2008) or on the laboratory or university level (e.g., Carayol and Matt 2004; Van Looy et al. 2011).

Regarding the knowledge-based view, one might argue that research quality is a prerequisite of efficient knowledge creation and expanding a university's knowledge base. It appears reasonable to assume that high research quality has beneficial effects on patent outcome because it contributes to the expansion of the knowledge base and might attract high-performing scholars who dispose of both explicit and tacit knowledge. Previous research demonstrated that a large knowledge base and knowledge creation and recombination are beneficial to patent output (Vinig and

van Rijsbergen 2009) and suggested that high-performing scholars produce inventions of high commercial value (Sapsalis et al. 2006).

As patent protection is costly and requires an inordinate amount of effort, one might argue that universities are highly selective with respect to patenting and only patent those inventions that definitely require protection or promise high revenues from commercialization. Because academic and industry patents were observed to have similar value distributions (Sapsalis et al. 2006), it appears likely that universities devote as much attention to the commercial value of patented inventions as companies do. Inventions of high commercial value are more likely to occur if the quality of research and knowledge creation is above average. Therefore, it appears reasonable to assume that the patent output of universities is positively influenced by the quality of research. Against this background, we suggest the following hypothesis:

H_3: Research quality is positively related to the patent output of German universities.

3 Data and method

3.1 Sample

To construct our sample, in mid-May 2012, we obtained a list of all German higher education institutions from the *Higher Education Compass* (*Hochschulkompass*), which is provided by the German Rector's Conference. According to the German Rector's Conference, this database is updated daily and offers the most reliable data on higher education institutions in Germany. Including universities, universities of applied sciences, and colleges of art and music, in mid-May 2012, the list contained 387 institutions in total. These institutions were either funded by the state or privately. Because we were investigating patenting activity between 2002 and 2011, we excluded institutions from our sample that were founded in 2003 or later ($n = 59$). Thus, our final sample consisted of $N = 328$ German higher education institutions.

3.2 Data collection and operationalization of variables

The collection of data on patenting activities and specific characteristics of the universities under investigation required a combination of different data sources. Specifically, we obtained patent data from the worldwide patent database PATSTAT[3] and data on German universities from the 2008 research ranking published by the CHE (Berghoff et al. 2008).

[3] The PATSTAT database is the EPO Worldwide Patent Statistical Database licensed by the OECD-EPO Task Force on Patent Statistics. We employed the April 2012 version for our analyses.

3.2.1 Data on patenting activity

The PATSTAT database was queried for patent applications that the universities in our sample filed between 2002 and 2011.[4] We generally relied on patent applications rather than on patent grants because there is typically a delay of three to 5 years between a patent application and the grant of the patent, and hence patent grants reflect innovation activity with considerable delay.[5] Nevertheless, in our analysis of universities' patenting behavior, we also report the grant rate. The PATSTAT database includes all worldwide patent applications that have been published. Naturally, this database (as in all other patent databases) cannot contain the most recent patent applications because, according to patent law, patent applications remain confidential until 18 months after their filing date.

The reason that we did not include patent applications from the years prior to 2002 in our analyses was that professors' privilege was abolished in Germany in January 2002. The abolition of professors' privilege led to significant changes in the legal conditions for academic patenting. We limited our observations to the year 2011 because we sought to create a proxy for patent value through patent citations. Restricting the dataset to a year earlier than 2011 would allow patents to accumulate more citations, but we sought to include the most recent patent applications in the portfolios and thus deemed the year 2011 as the best possible compromise.

To ensure that all patent applications from a single university were included in our sample, we performed several iterations of the process of matching patent applicants with universities. Patents filed under the name of an entity belonging to a respective university, such as university hospitals or institutes, were counted as patents filed by the university. However, to ensure high data quality, we made such matching decisions very conservatively and only assigned patents to universities that were unambiguously filed by the respective university.

In total, we identified 21,110 patent applications filed by 156 different German universities for the period from 2002 to 2011. For the remaining 172 universities, there were no entries in the patent database, and hence we coded the respective variables as zero for our analyses.

To produce an extensive overview of the patenting activity of German universities, we defined the following patent-related variables for our patent ranking and describing the patenting behavior in our sample.

We assessed the *number of patent applications* between 2002 and 2011. This variable contains all patents filed by an organization (Hall et al. 2005). For cases in which a university sought protection for one invention in Europe and in the US, for example, this would induce two patent applications. The reason for this is that patents are rights for specific territories and are bound to the jurisdictions in which they are filed. To achieve worldwide protection, a university needs to file multiple applications in various jurisdictions.

[4] Please note that patent output was significantly lower in 1992-2001 relative to the period that we consider here (e.g., in our sample of 156 universities: number of patent families: $M = 10{,}987$, $SD = 2.54$ in 1992-2001 compared to $M = 52{,}686$, $SD = 6.94$ in 2002-2011; number of patent applications: $M = 29{,}474$, $SD = 6.16$ in 1992-2001 compared to $M = 135{,}321$, $SD = 17.87$ in 2002–2011).

[5] In the following, we use the terms patent and patent application interchangeably.

We also measured the *number of patent families*. A patent family refers to a group of patent applications that are filed for a single invention. The size of the patent family is an indicator of patent value (Putnam 1996). Thus, patents within one family are connected and correspond to the same priority application, which is the first patent application of a family submitted to a patent office. Patent families therefore reflect the number of inventions for which a university seeks protection.

The *grant rate* (*DPMA, EPO*) measures the share of those patents filed with the DPMA (German Patent and Trademark Office) and the EPO (European Patent Office). As noted above, patent offices require several years before they decide whether a patent application will be granted. Because we used 2011 as the last year of patent filing, this variable is downward biased because the respective patent office could not have yet decided whether to grant patents filed in this year.

Additionally, we assessed the *number of forward citations* of the patent families. This variable also reflects the value of a patent (Bloom and Van Reenen 2002; Hall et al. 2005; Harhoff et al. 1999). Specifically, we counted the frequency with which patents in a given family were referenced by subsequent patents belonging to another patent family. We only considered forward citations at the family level that arrived within 3 years of the publication of a patent family's so-called earliest priority application (i.e., the first member of the patent family). The reason for this restriction is that (1) patents receive a significant share of their lifetime citations within the first 3 years following the publication of the search report (Marco 2007) and (2) absent such a restriction, forward patent citations filed at different points in time would not be comparable. It is important to note that we measured "family-to-family" citations because only when using this criterion is the number of citations not inflated by large patent families with members that might be cited multiple times in separate jurisdictions.

Accordingly, the variable *citations per patent family* measures the average citation intensity in a university's patent portfolio. The higher the value of the variable is, the more valuable are the patents that are included in the patent portfolios. In other words, citation intensity reflects the quality of the patent portfolio (Hall et al. 2005).

Furthermore, we assessed the *patent applications per patent office* to analyze universities' patenting behavior with respect to the geographical scope of their patent applications. Specifically, similar to Hall (2007), we segmented the patent portfolios according to their filings with the DPMA, the EPO, the United States Patent and Trademark Office (USPTO) and with other patent offices.

Additionally, we measured the *share of patent applications per patent office* to account for the variation in the size of university portfolios. Specifically, we assessed the share of patent applications with the DPMA, the EPO, the USPTO, and with other patent offices.

Furthermore, we measured *PCT patent applications* and the *share of PCT patent applications*. If universities decide to obtain global protection for a patent, they can file patents trough the so-called PCT route with the World Intellectual Property Organization (WIPO). The Patent Cooperation Treaty (PCT) provides residents or nationals of its 145 contracting states with the opportunity to file a single international patent application under the PCT, which has the same effect as

multiple national applications. These variables can also serve as indicators of patent quality because, due to the high costs, only potentially valuable patents are filed through the PCT route.

To further scrutinize universities' patenting behaviors, we measured several variables that are based on the bibliographic characteristics of the patents. *IPC classes* reflect the number of classes the patents are assigned to according to the International Patent Classification (IPC). This variable indicates the average breadth of each patent in a university's portfolio (Lerner 1994). *IPC4 breadth* measures the cumulative technological breadth of the universities' patent outputs. Regarding technological classification, each patent application is assigned to one or more IPC classes. We used the first four characters of each IPC class (i.e., IPC4) listed on the patent applications to compute *IPC4 breadth*. In total, approximately 800 of these so-called subclasses exist. *IPC4 breadth* reflects the cumulative subclasses covered by a university with each covered subclass counting only once.

The *average number of patent claims* represents an approximate estimate of the scope of protection and is obtained from the number of claims that the patent document includes. The patent claims are the core of each patent, as they describe which specific aspects of an invention are protected. Patents covering a broader invention generally hold more patent claims to protect more facets of the underlying invention.

As described above, a patent can be cited by future patents. Conversely, a patent application also includes references to older documents (either patents or the scientific literature). These backward references indicate the breadth of the underlying—but previously existing—technology. Because both patents and the scientific literature define the state of the art, we computed the *average number of patent literature references* and the *average number of non-patent literature references*. Depending on the year when these documents were published, we also measured the *average year of patent literature references* and the *average year of non-patent literature references*. These variables reflect how old the underlying technology is on average.

Finally, using the algorithm provided by Hinze et al. (1997) that maps the approximately 70,000 existing IPC classes to six broad technological areas, we created the following technological profile variables for each university: *electrical engineering, instruments, chemistry, process engineering, mechanical engineering, consumer goods* and *construction*. These variables are displayed in percentages. The reason that the figures do not sum to, but rather exceed, one hundred percent is that patent applications can be assigned to multiple technological areas.

3.2.2 Data on German universities

Concerning the institutional characteristics of the universities, we primarily employed the data provided by the German Rector's Conference and the CHE research ranking (Berghoff et al. 2008). This approach allowed us to construct a profile of the universities involving various measures.

First, we assessed *patenting experience* by calculating the number of years since a university had filed a patent for the first time based on the patent metrics.

Second, we further collected information on the breadth and quality of research using the CHE research ranking for the year 2008 (Berghoff et al. 2008). The CHE research ranking encompasses 16 research fields: (1) English/American studies (2) business studies, (3) biology, (4) chemistry, (5) engineering and information technology, (6) educational sciences, (7) history, (8) mechanical engineering, (9) mathematics, (10) medical sciences, (11) pharmacy, (12) physics, (13) psychology, (14) social sciences, (15) economics, and (16) dentistry. The number of these research fields covered indicates the university's *research breadth.* For these fields, the CHE research ranking indicates which university employs faculty in the respective field and which university belongs to the top group with respect to research quality. Based on the latter information, we defined our variable *research quality*. In the CHE ranking, a university belongs to the top group if it is listed under the best possible group that accounts for at least 50 percent of the overall sum of an aggregated variable or is among the best quartile when per person variables are used. The CHE research ranking assesses research quality with five different indicators. First, it considers expenditures of third-party funds; second, the number of publications; third, the number of inventions; fourth, it measures doctorates awarded; and finally, it uses a university's reputation as the fifth indicator of research quality. Using numerous indicators to approximate research quality rather than a single one delivers a broader picture of research quality and allows for deeper insights into research quality at different universities. CHE undertakes several steps to ensure high quality of the data reported, such as assessing the data for plausibility, quality and manipulation, involving scientific experts, or striving for transparency in methods ("Qualitätssicherung im CHE Hochschulranking" 2014). Therefore, using the CHE research ranking appears appropriate.

In this vein, we sought to identify which universities appeared in the CHE research ranking and thus derived the dichotomous variable *CHE ranking*.

Additionally, we distinguished between traditional universities and universities of applied sciences. In our study, traditional universities encompass universities that have the right to award doctorate degrees, whereas universities of applied sciences include universities of applied sciences and colleges of art and music. The distinction between traditional universities and universities of applied sciences is reflected by the dichotomous variable *university type* (0 = universities of applied sciences, 1 = traditional universities). To allow for more fine-grained interpretations, we additionally included two dummy variables: one dummy variable measures whether an institution has been awarded the status of an *excellence university* in the second round by the German government (0 = not an excellence university, 1 = excellence university); the other dummy variable indicates whether the university is a *technical university* or not (0 = not a technical university, 1 = technical university).

Moreover, we measured *university size* (which we included in our regression analyses as a control variable) by the number of students. We argue that the regular financial budget and the number of professors and research staff are closely related to the number of students at most universities, and hence the number of students is a reasonable proxy for measuring university size. This assumption is supported by Fritsch and Slavtchev (2006), who obtained similar results when investigating the

patent output of regions, regardless of whether the size of a university was approximated by the number of students, the number of professors, or by the regular financial budget. This variable is also drawn from the data published by the German Rector's Conference.

As a further characteristic of the universities, we assessed the *founding year*. Because certain universities were established many decades ago (occasionally even hundreds of years ago) and others have only been established recently, this variable provides valuable information and might also serve as an indicator of a university's reputation in society (note that older institutions generally have had more time to develop a reputation and influence public opinion or "bargain" with ministries on new funds to grow into new areas).

Additionally, we assessed the *faculty profile* of the universities included in our sample, as the research disciplines represent a crucial factor influencing researchers' decisions of whether to patent (Brockhoff 1998); namely, depending on the type of technological progress in the respective discipline (i.e., cumulative vs. empirical), and thus depending on the use of previously obtained knowledge, researchers' payoffs from patenting might vary (Brockhoff 1998). Specifically, we included dummy variables that indicate whether a university has a faculty in *electronics or machinery, mathematics or physics, medicine* (including dentistry)*, life sciences* (biology, chemistry, pharmacy), *social sciences,* and *humanities* (0 = has no faculty in this field; 1 = has a faculty in this field).[6]

Finally, we defined the variable *arts, music, pedagogy* as a dichotomous variable (0 = the university does not focus on one of these three fields; 1 = the university focuses on one of these three fields). Although we acknowledge that these universities are not prone to file patents, we included them in our analysis for the following two reasons: first, we sought to deliver an overview of all German universities and were naturally only able to decide whether a university filed patents *after* we searched for their activity as patent applicants. Second, we specifically considered this fact by employing a Heckman sample selection model with patenting activity (i.e., having filed at least one patent) as the selection variable.

3.3 Data analyses and method

We begin our analyses by presenting a patent ranking of the 25 German universities with the highest overall number of patent applications, followed by a descriptive analysis of the patenting behavior of the universities in our sample. Thereafter, we examine potential determinants of the patent output of German universities. To determine whether patenting experience and the breadth and quality of research relate to patent output, we use Heckman sample selection models for our regression analyses. The analyses are conducted at the university level; the dependent variable is patent output.

Specifically, we employ four different regression models with the following four dependent variables to analyze potential determinants of the patent output of German universities: (1) the number of patent families, (2) the number of patent

[6] We thank an anonymous reviewer for advising us to include the faculty profiles in our model.

applications, (3) the number of PCT applications, and (4) IPC4 breadth. We use patent families because they correspond to inventions, in contrast to patent applications for which the counts can be inflated simply by extending the geographical scope of protection to other countries. That is, patent families approximate the real number of patented inventions more precisely than individual patent applications, and hence using patent families rather than the number of patent applications helps to avoid an overestimation of inventive activity.

For our regression analyses, we use Heckman sample selection models to account for the fact that certain universities do not exhibit any patenting activity. Thus, as a selection variable, we analyze whether the universities in our sample exhibit any patenting activity. In other words, we define the variable *patenting activity* as 1 if the university had at least one (PCT) patent application or at least one patent family and 0 otherwise. Specifically, in the selection equation, we argue that the following variables should influence *patenting activity*: *university type, technical university, university size*, and *faculty profile* (including *arts, music, pedagogy*). In the outcome equation, in which we estimate the effect of the institutional determinants on patent output, we include our key variables, supplemented by four control variables, to test our hypotheses.

4 Results

4.1 Patent ranking and patenting behavior of German universities

Table 1 reports the overall number of patent applications (i.e., national plus PCT patent applications), the number of PCT patent applications, the share of PCT applications, the number of patent families and the number of forward citations for the 25 German universities with the highest overall number of patent applications between 2002 and 2011.[7]

All 25 universities included in the ranking of the 25 best institutions measured using the overall number of patent applications between 2002 and 2011 are traditional universities with permission to award doctorates. Technische Universität Dresden outperformed all other German universities with respect to the overall number of patent applications between 2002 and 2011. Specifically, within this time frame, Technische Universität Dresden applied for 1,266 patents. Because only two universities in total applied for more than 1,000 patents during this period, while the universities in rankings ten through twelve applied for only approximately half of this number of patents, the distribution of the number of patent applications appears to be highly skewed. Considering the PCT applications and thus focusing on the international patenting activities of German universities, one observes that the universities that rank highest in overall patenting activity are not necessarily ranked highest with respect to different patenting indicators. With 217 PCT applications, Universität Freiburg ranked second, but filed the highest number of PCT applications. The share of PCT patent applications does not vary substantially

[7] A patent ranking of all 328 universities is available upon request.

Table 1 Patent ranking of German universities

Rank	Name of university	Overall patent appl.	PCT patent appl.	Share of PCT appl. (%)	Patent families	Forward citations	Average citations	IPC4 breadth
1	Technische Universität Dresden	1,266	208	16.4	656	379	0.578	372
2	Universität Freiburg	1,109	217	19.6	351	288	0.821	145
3	Friedrich-Alexander-Universität Erl.-Nürnberg	847	176	20.8	273	241	0.883	163
4	Humboldt-Universität zu Berlin	846	204	24.1	281	180	0.641	170
5	Freie Universität Berlin	825	203	24.6	268	161	0.601	88
6	Technische Universität München	766	155	20.2	275	193	0.702	187
7	Eberhard Karls Universität Tübingen	745	167	22.4	239	156	0.653	93
8	Universität München	666	146	21.9	184	161	0.875	91
9	Universität Heidelberg	545	133	24.4	175	156	0.891	78
10	RWTH Aachen	520	127	24.4	247	116	0.470	192
11	Universität Stuttgart	515	83	16.1	197	207	1.051	173
12	Technische Universität Berlin	512	106	20.7	239	120	0.502	136
13	Friedrich-Schiller-Universität Jena	498	80	16.1	256	136	0.531	158
14	Georg-August-Universität Göttingen	474	113	23.8	142	90	0.634	82
15	Universität Hamburg	470	114	24.3	127	48	0.378	56
16	Johannes Gutenberg-Universität Mainz	454	95	20.9	110	66	0.600	59
17	Technische Universität Braunschweig	354	77	21.8	138	78	0.565	111
18	Technische Universität Ilmenau	346	63	18.2	162	93	0.574	127
19	Universität Rostock	336	86	25.6	147	49	0.333	160
20	Universität Hannover	335	78	23.3	165	78	0.473	135
21	Philipps-Universität Marburg	325	75	23.1	85	49	0.576	72
22	Julius-Maximilians-Universität Würzburg	318	81	25.5	107	74	0.692	59

Table 1 continued

Rank	Name of university	Overall patent appl.	PCT patent appl.	Share of PCT appl. (%)	Patent families	Forward citations	Average citations	IPC4 breadth
23	Westfälische Wilhelms-Universität Münster	314	80	25.5	107	41	0.383	64
24	Universität Kassel	303	62	20.5	132	83	0.629	127
25	Rhein. Friedrich-Wilhelms-Universität Bonn	279	73	26.2	98	43	0.439	56

among the 25 universities that rank highest regarding the overall number of patent applications between 2002 and 2011. The ranked universities filed between 16.1 and 26.2 % of their overall patent applications under the PCT. It is remarkable that Technische Universität Dresden, which applied for the most patents, filed a rather small share of its patent applications under the PCT (16.4 %).

Additionally, it is striking that filing a larger number of patent applications does not necessarily entail a larger number of patent families. Thus, the patent families of certain universities appear to comprise fewer patents than those of other universities. Moreover, there appears to be no clear linear relationship between the number of patent families and the number of forward citations. For instance, Universität Stuttgart has a citation intensity of 1.05, indicating that, on average, each patent family was cited approximately once. In comparison to other universities (e.g., the citation intensity of the RWTH Aachen of only 0.47), this is a very high value.

With regard to IPC4 breadth, it is particularly interesting that this variable does not appear to be associated with the size of a patent portfolio. Additionally, it is striking that there are universities that exhibit a broad technological profile (e.g., Technische Universität Dresden, RWTH Aachen), whereas other universities are more focused with respect to their technological breadth (e.g., Freie Universität Berlin, Universität Heidelberg).

In summary, in line with our assumption, the ranking reveals that patenting behavior varies considerably even among the 25 universities filing the highest overall number of patent applications between 2002 and 2011. To investigate the patenting activity of German universities in greater depth, we further analyzed the descriptive statistics for those 156 universities that filed at least one patent between 2002 and 2011 (see Table 2).

Because the share of universities having filed at least one patent between 2002 and 2011 ($N = 156$) is high relative to the share of universities that have not filed any patents within this time frame ($N = 172$), it appears reasonable to begin by analyzing the characteristics of the universities that were active in patenting. These universities have 19.8 years of patenting experience on average. The 156 universities encompass an average of 4.4 research fields (research breadth), again approximately twice as many as in the overall sample ($M = 2.1$), and have 1.0 research fields among the top group (research quality), relative to 0.5 research fields among the top group in the overall sample. Of the 156 universities, 46.2 % are included in the CHE research ranking (overall sample: 25 %), and 48.7 % are traditional universities (overall sample: 32.3 %). 5.8 % of the universities have been awarded the excellence status (overall sample: 2.7 %), and 9 % of the universities that were active in patenting are technical universities (overall sample: 4.3 %). The universities educate 12,435 students on average, twice as many as the universities in the full sample ($N = 328$; $M = 6{,}814$). However, the standard deviation for the number of students is higher in the subsample of universities that are active in patenting ($SD = 11.39$) than in the full sample ($SD = 9.67$). The mean founding year is 1887, which is significantly earlier than the founding year in the full sample ($M = 1916$). Thus, the patenting universities appear to be older and more established than the non-patenting universities. With regard to the

Table 2 Descriptive statistics for universities having filed at least one patent

Variables	Mean	SD	Median	Min	Max
University characteristics					
Patenting experience (years)	19.769	18.27	12	2	102
Research breadth	4.365	5.503	0	0	15
Research quality	1.026	2.051	0	0	10
In CHE ranking (dummy)	0.462		0	0	1
University type (dummy)	0.487		0	0	1
Excellence university (dummy)	0.058		0	0	1
Technical university (dummy)	0.090		0	0	1
Number of students (in 1,000 s)	12.435	11.387	7.828	0.587	69.5
Founding year	1886.72	153.814	1961	1386	2002
Electronics and machinery (dummy)	0.628		1	0	1
Mathematics and physics (dummy)	0.462		0	0	1
Medicine (dummy)	0.231		0	0	1
Life sciences (dummy)	0.462		0	0	1
Social sciences (dummy)	0.846		1	0	1
Humanities (dummy)	0.526		1	0	1
Patenting activity					
Patent applications	135.321	223.177	29.5	1	1266.00
Patent families	52.686	86.622	13	1	656
Grant rate (DPMA, EPO)	0.268	0.241	0.233	0	1
Citations (family to family)	30.513	57.324	5.5	0	379
Citations per patent family	0.475	0.542	0.376	0	4
Patent applications per patent office					
DPMA	51.026	86.941	14	0	764
EPO	46.365	80.657	8.5	0	428
USPTO	12.795	24.907	1	0	130
Other	25.135	48.203	3	0	247
Share of patent applications per patent office					
DPMA	0.495	0.231	0.5	0	1
EPO	0.324	0.171	0.333	0	1
USPTO	0.062	0.067	0.05	0	0.5
Other	0.119	0.105	0.115	0	0.5
International patent applications under the PCT					
PCT patent applications	29.34	47.126	5	0	217
Share of PCT patent applications	0.214	0.122	0.221	0	1
Further characteristics of the patent portfolio					
Average number of IPC classes	2.705	1.962	2	1	15
IPC4 breadth	45.058	55.045	23	1	373
Average filing year	2007.12	1.607	2007	2002	2010
Average number of claims	1.671	1.839	1.513	1	15.75
Average number of PL references	7.422	2.655	7.203	1	18.25
Average year of PL references	1995.93	2.992	1996	1984	2003

Table 2 continued

Variables	Mean	SD	Median	Min	Max
Average number of NPL references	8.292	8.582	5.301	1	61.599
Average year of NPL references	1998.32	7.624	2000	1949	2009
Technological profile (*in %*)					
Electrical engineering	0.222	0.252	0.144	0	1
Instruments	0.314	0.229	0.285	0	1
Chemistry	0.293	0.285	0.213	0	1
Process engineering	0.149	0.184	0.093	0	1
Mechanical engineering	0.182	0.241	0.099	0	1
Consumer goods and construction	0.064	0.136	0.008	0	0.938

$N = 156$ universities having filed at least one patent. The technological profile of each university usually exceeds 100 % since patent applications can be assigned to more than one technological area

DPMA German Patent and Trademark Office, *EPO* European Patent Office, *IPC* International Patent Classification, *PCT* Patent Cooperation Treaty, *PL* patent literature, *NPL* non-patent literature, *SD* standard deviation, *USPTO* United States Patent and Trademark Office

faculty profile, we found that 62.8 % of the 156 universities educate students in electronics or machinery (overall sample: 33.8 %); 46.2 % have a faculty in mathematics or physics (overall sample: 22.3 %); 23.1 % have a medical faculty (including dentistry) (overall sample: 11.3 %); 46.2 % have a life sciences faculty (overall sample: 23.5 %); 84.6 % educate students in social sciences (overall sample: 47.9 %); and 52.6 % educate students in humanities (overall sample: 31.7 %).

Analyzing direct indicators of patenting activity reveals that, on average, each of the 159 universities applied for approximately 135 patents and 53 patent families between 2002 and 2011. The grant rate of their German and European patent applications was 26.8 %. On average, universities obtained nearly 31 forward citations at the family level and 0.48 forward citations per individual patent family. These variables again indicate that patenting activity varies widely. Approximately half of the universities have applied for fewer than 30 patents and 13 patent families during the period of investigation. Regarding maximum values, one university applied for 1,266 patents and 656 patent families (Technische Universität Dresden, see the patent ranking of German universities above). A university's patent family portfolio was cited a maximum of 379 times.

Regarding the patent application submission strategy, we observe that, naturally, German universities filed patents with the German Patent and Trademark Office (DPMA) most frequently, and each university applied for an average of 51 patents. On average, universities filed 49.5 % of their total number of applications with the DPMA, 32.4 % with the European Patent Office (EPO), and 6.2 % with the United States Patent and Trademark Office (USPTO). The remaining 11.9 % were filed with other patent offices around the world.

The 159 universities filed 29 PCT applications on average—i.e., 21.4 % of their overall patent applications were filed internationally. Most universities, however,

filed fewer than five applications under the PCT, whereas one institution filed 217 PCT applications.

Concerning the technological breadth of the patents filed by the universities, we observe a mean of 2.7 IPC classes covered ($Min = 1$, $Max = 15$ IPC classes). On average, universities cover 45.1 IPC subclasses (IPC4 breadth); however, IPC4 breadth varies substantially within the sample ($SD = 55.045$). The mean filing year in universities' patent portfolios is 2007. Typically the patents in universities' portfolios appear to cover specific subject matter. The mean of the number of patent claims is 1.7; certain universities with smaller patent portfolios seek to file rather complex patents with an average of 15.8 patent claims.

Furthermore, we observe a mean of 7.4 references to the patent literature per patent. Recall that the fewer references a patent has, the more basic its research is in nature. Yet, the maximum value of this variable is 18.3. These references to previous patents refer (on average) to patent documents published in 1996, but this variable also has a broad range: certain university portfolios reference literature from 1984 on average, whereas others have an average literature reference from 2003. Similarly, patents also contain references to non-patent literature. Of this type of reference, the average in universities' portfolios is 8.3 references, again exhibiting a broad range from 1 to 61.6. The average year of these non-patent references was 1998, with an even broader range from 1949 to 2009. Both the average year of patent literature and non-patent literature citations in universities' patents are significantly earlier than the average of the filing year in the patent portfolios, which indicates that the universities conduct basic research.

Concerning universities' technological profiles, we observe that most patent applications are filed in the areas of chemistry and instruments, followed by electrical engineering. Fewer patents are, however, filed in the areas of process engineering, mechanical engineering, and consumer goods.

In summary, these descriptive statistics reveal important information on the patenting behavior of German universities. The standard deviations of the presented variables confirm the overall finding that patenting behavior varies considerably among German universities, thus supporting our assumption.

4.2 Determinants of patent output

4.2.1 Correlation table

Table 3 presents correlation coefficients among variables for the 156 universities in our sample that filed at least one patent. Please note that this sample corresponds to the sample entering the estimation of the outcome equation in the Heckman sample selection model that is reported below.

To compute the variance inflation factors, we estimated a simple OLS regression with patent families as the dependent variable. In general, with certain exceptions, we observe that the correlation coefficients are of moderate size. As expected, the type of university and the number of students are highly correlated. Additionally, the number of students, research breadth, and research quality are highly related. This finding is unsurprising, as universities with faculty members in more research

Table 3 Correlations for the universities having filed at least one patent

Variables	1	2	3	4	5	6	7	8	VIF
1. Patent families									n.a.
2. Patenting experience	0.469*								1.478
3. Research breadth	0.669*	0.407*							5.909
4. Research quality	0.681*	0.441*	0.685*						3.866
5. University type (dummy)	0.527*	0.327*	0.816*	0.515*					3.241
6. Excellence university (dummy)	0.407*	0.337*	0.319*	0.656*	0.254*				1.963
7. Technical university (dummy)	0.386*	0.109	0.204*	0.150	0.277*	0.115			1.111
8. University size	0.572*	0.448*	0.757*	0.711*	0.590*	0.347*	0.147		2.925
9. Founding year	−0.434*	−0.448*	−0.558*	−0.481*	−0.376*	−0.229*	0.008	−0.418*	1.670

$N = 156$ observations. No VIF is available for patent families because the VIFs were estimated using this variable as the dependent variable in an OLS regression format. Significance levels *$0.01 < p \leq 0.05$

VIF variance inflation factors, *SD* standard deviation

fields can clearly educate more students, and the more research fields a university has, the more likely it is that at least some of them are in the top group.

4.2.2 Regression analyses

To ensure that multicollinearity among the predictors does not affect our regression results, we computed variance inflation factors (VIFs). Table 3 indicates that VIF values range from 1.11 to 5.91. Therefore, the critical value of ten is not reached (Kennedy 1992), and all criteria to ensure that the analysis is not affected by multicollinearity are satisfied. Nevertheless, as some correlation coefficients are comparably high, our results should be interpreted with caution.

Because many universities in our sample did not file any patents between 2002 and 2011, we chose to estimate our regression models using a Heckman sample selection model. As the selection variable, we use patenting activity—namely, the occurrence of at least one patent family, patent application, or PCT patent application. The selection equation contains those variables that we assume primarily affect whether a university devotes efforts to patent inventions: university type (i.e., a traditional university vs. a university of applied sciences), technical university, university size in terms of the number of students, and faculty profile (including arts, music, pedagogy). The outcome equation contains the variables of our hypotheses and selected control variables. Table 4 displays the results of four regression models using the dependent variables of patent families, patent applications, PCT applications, and IPC4 breadth. In the following, we describe models M1–M4.

Concerning the selection equation of our estimation model, in models M1–M4, we find that university type is not related to patenting inventions. The technical university variable, however, is positively related to patent families and IPC4 breadth. Additionally, in three of the four models, those universities that educate more students are more prone to file patents. With respect to the faculty profile, we observed that if a university educates students in electronics, machinery, medicine, social sciences or humanities, this has a significant effect on the probability that the university files patents in most of the models. The significant effects of social sciences or humanities—which are lower than the effects of the technical faculties—might be explained by the fact that social sciences or humanities faculties can be regarded as adjacent to the technical faculties. Having a mathematics or physics faculty, a life sciences faculty or educating students in arts, music, or pedagogy is generally not related to patenting activity (there is one exception: educating students in arts, music, or pedagogy is negatively related to IPC4 breadth).

Concerning the outcome equation, in models M1–M3, we find that the coefficient of patenting experience is not significant, indicating that the experience universities have in filing patents does not affect their patent output. Thus, while the coefficient of patenting experience is significant in model M4, indicating that more experienced universities exhibit a technologically broader patent portfolio, our first hypothesis is not confirmed. For research breadth, we observe a significantly positive coefficient in models M1, M2 and M4, indicating that the breadth of research is positively

Table 4 Regression results regarding the determinants of patent output

	Model			
	M1 Patent families	M2 Patent applications	M3 PCT applications	M4 IPC4 breadth
Outcome equation ($N = 156$)				
Patenting experience	0.385 (0.233)	−0.037 (0.019)	0.436 (0.503)	0.285*** (0.006)
Research breadth	3.644**	3.914*	0.025	2.962**
Research quality	17.126*** (3.931)	54.479*** (8.750)	8.779*** (1.912)	3.186 (2.355)
University type (dummy)	15.171 (11.799)	45.533 (27.069)	9.651 (5.793)	13.657 (7.031)
Excellence university (dummy)	−20.679 (24.322)	−14.712 (54.823)	11.535 (11.673)	−10.244 (14.675)
Technical university (dummy)	75.149*** (15.707)	117.622** (35.852)	22.911** (7.649)	53.297*** (9.639)
University size	0.022 (0.622)	0.696 (1.302)	0.615* (0.313)	−0.371 (0.360)
Founding year	−0.038*** (0.004)	−0.088*** (0.011)	−0.021*** (0.002)	−0.025*** (0.003)
Electronics and machinery (dummy)	56.100*** (9.502)	122.705*** (21.684)	22.861*** (4.882)	44.596*** (5.849)
Mathematics and physics (dummy)	4.207 (12.898)	10.249 (30.101)	2.971 (6.842)	10.209 (7.855)
Medicine (dummy)	64.885*** (14.214)	172.984*** (32.851)	41.177*** (7.007)	33.367*** (8.562)
Life sciences (dummy)	2.806 (10.787)	9.364 (24.754)	6.424 (5.787)	3.684 (6.612)
Social sciences (dummy)	14.757 (9.804)	37.877 (22.222)	7.980 (4.972)	8.513 (6.018)
Humanities (dummy)	14.199 (9.169)	22.312 (21.088)	3.204 (4.563)	15.248** (5.601)
Selection equation ($N = 328$)				
University type (dummy)	0.194 (0.247)	0.242 (0.238)	0.453 (0.246)	0.305 (0.228)
Technical university (dummy)	1.072** (0.366)	0.594 (0.319)	0.549 (0.320)	1.220*** (0.350)
University size	0.058* (0.023)	0.067*** (0.016)	0.012 (0.013)	0.033* (0.014)
Electronics and machinery (dummy)	1.023*** (0.191)	0.973*** (0.195)	0.940*** (0.200)	1.273*** (0.192)
Mathematics and physics (dummy)	−0.002 (0.258)	0.069 (0.482)	0.203 (0.588)	0.193 (0.258)
Medicine (dummy)	1.571*** (0.337)	1.847*** (0.425)	2.070*** (0.400)	1.063** (0.339)

Table 4 continued

	Model			
	M1 Patent families	M2 Patent applications	M3 PCT applications	M4 IPC4 breadth
Life sciences (dummy)	0.026 (0.215)	0.045 (0.217)	0.524 (0.483)	−0.037 (0.215)
Social sciences (dummy)	0.401 (0.208)	0.458* (0.203)	0.505* (0.209)	0.404* (0.199)
Humanities (dummy)	0.718* (0.320)	0.832* (0.328)	0.676* (0.302)	0.898*** (0.241)
Arts, music, pedagogy (dummy)	−0.399 (0.319)	−0.527 (0.331)	−0.238 (0.308)	−0.483* (0.230)
Diagnostics				
Wald Chi^2 (degrees of freedom)	594.76 (14)***	618.27 (14)***	609.45 (14)***	601.83 (14)***
Log likelihood	−871.35	−999.45	−685.43	−796.22
ρ	0.737	0.720	0.706	0.773
Chi^2 of log likelihood-ratio test of independent equations	20.23***	17.41***	16.22***	24.06***

Estimation method: Heckman sample selection model with "patenting activity" as selection variable. Standard errors in parentheses. Constants not reported. Significance levels: * $0.01 < p \leq 0.05$; ** $0.001 < p \leq 0.01$; and *** $p \leq 0.001$

related to patent output. This effect is insignificant in model M3. Thus, we can partly confirm our second hypothesis. Research quality is—in models M1 to M3—significantly and positively related to patent output. These positive relationships indicate that those universities excelling relative to others in the quality of their research appear to have a higher patent output in terms of patent families, patent applications, and PCT applications. This relationship is, however, insignificant when IPC4 breadth is used as the dependent variable, meaning that our third hypothesis is partly confirmed.

The university type is not significantly related to patent output in any of the four models, indicating that the patent output of traditional universities does not differ from the patent output of universities of applied sciences. Similarly, being a university of excellence does not increase patent output in any of the four models. However, we observed that technical universities have a significantly higher patent output than non-technical universities in models M1 to M4. In models M1 and M2, university size and patent output are not positively related, indicating that the number of students does not affect patent output. However, in models M3 and M4, the coefficient is significant, indicating that the number of students is positively related to PCT applications and IPC4 breadth. Concerning the founding year of the universities, our observations are consistent across the models. The coefficient of founding year is significantly negative. In other words, those universities founded more recently exhibit lower patent output and a technologically broader patent portfolio. Concerning the faculty profile, we observed that having an electronics, machinery or medicine faculty is positively related to patent output. This finding is consistent throughout all models. Conversely, educating students in mathematics, physics, life sciences, social sciences and humanities is (with one exception) not significantly related to patent output in models M1–M4.

5 Discussion

5.1 Discussion of the main findings

This study sought to provide an extensive overview of the patenting activity of German universities for the period from 2002 to 2011. Specifically, we (1) presented a university ranking based on the patenting activity of German universities, (2) analyzed the different patenting behaviors based on descriptive statistics and (3) investigated potential determinants of the patenting activity of German universities.

We observed that German universities differ considerably in patenting activity and patenting behavior. Our ranking, based on the overall number of patent applications for the period from 2002 to 2011, revealed that the universities that perform best with respect to this dependent variable are all traditional universities. In contrast to universities of applied sciences, traditional universities are allowed to award doctoral degrees and tend to be more focused on research; this finding accorded with our assumption. Additionally, the patent ranking illustrated that the distribution of the overall number of patent applications is highly skewed, supporting our assumption that there are considerable differences in patent output,

even among the 25 universities that filed the most patent applications overall in the period from 2002 to 2011. This assumption was not confirmed for the share of PCT patent applications, which did not vary considerably among the 25 universities.

The observed differences in patent output are in line with earlier research that reports a highly skewed geographical concentration of university patents in Europe (Acosta et al. 2009) and considerable differences among universities with respect to commercial success in licensing (Geuna and Nesta 2006). Our ranking complements these findings by revealing the extent to which and in what patent characteristics the patent output of German universities differs. Comparing the patent output of German universities on an international basis, it appears remarkable that the University of Oxford filed 2,632 patents in the period from 2002 to 2011; this figure is clearly higher than the figure for the overall number of patents filed by the highest ranked German university with respect to this criterion. Such discrepancies between foreign and German universities can also be observed for other universities, albeit partly to a lesser extent (e.g., ETH Zürich, University of California, Tsinghua University). Thus, although substantial performance differences can be observed regarding the patenting activity of German universities, one should consider that universities abroad, in general, are much more active in patenting than German universities, and hence patenting activities could be substantially increased even at the best German universities. However, one should bear in mind that there are numerous potential reasons that foreign universities are more active in patenting than German universities, such as differences in the strategies applied, the legal environment, or pressure to exploit new funding sources.[8]

Analyzing the descriptive statistics regarding patenting activities for all universities in our sample that filed at least one patent between 2002 and 2011, we found additional support for our assumption that there are notable differences in the patenting activities of German universities. Although a few universities were highly active in patenting, most universities were either completely inactive or applied for many fewer patents during the period from 2002 to 2011. Comparing the universities that filed at least one patent within the investigated time frame, we observed that universities that are active in patenting had, on average, approximately twice as many students as universities in the full sample, operated in approximately twice as many research fields and were significantly older and more established.

To gain a better understanding of the determinants of the patenting activities of German universities, we investigated patenting experience, research breadth, and research quality as potential determinants. Our findings suggest that the observed performance differences regarding patent output are at least partly due to university-specific characteristics. Using a Heckman sample selection model, we first analyzed the influence of the university type, being a technical university, university size and the faculty profile on the probability that universities have at least one patent family, patent application or PCT patent application or that the universities cover at least one IPC class. Regarding university type, we observed that traditional universities and universities of applied sciences did not significantly differ in the probability that

[8] We thank an anonymous reviewer for this valuable comment.

a university is active in patenting. This finding is surprising because one might intuitively expect that the research intensity of a university (which can be assumed to be higher in traditional universities than in universities of applied sciences) is generally reflected in the propensity to file patents. We found that being a technical university was significantly related to patent output in terms of patent families and IPC4 breadth. This finding indicates that technical universities file patents to protect their inventions and increase their technological breadth, but they do not necessarily have more patent applications (neither applications in various legislations nor PCT applications). Regarding the faculty profiles, we observed that possessing specific faculties (i.e., electronics, machinery, and medicine) was positively related to patent output.

Second, to gain a deeper understanding of the potential determinants of the patent output of German universities, we analyzed patenting experience, research breadth, and research quality using the outcome equation of our Heckman sample selection model. Contrary to our assumption, overall, patenting experience was not related to patent output. Patenting experience only significantly influenced the technological breadth of the universities' patent portfolios. Our finding that patenting experience is generally not related to patent output partly contradicts the findings of prior research: using the year of the first patent application as proxy for patenting experience, Von Ledebur et al. (2009) observed that professors employed at universities with a longer experience in patenting are more likely to have university-owned patents. This contradictory finding might be explained by the fact that, according to Huelsbeck and Menno (2007), the influence of the year of the first patent application on the patent output of German universities has changed over time: while patenting experience positively influenced the patent output of universities before 2002, patenting experience lost its impact on patent output after the legal reform in 2002. Thus, our results might differ from the results of Von Ledebur et al. (2009), as we only considered data from 2002 onwards whereas Von Ledebur et al. (2009) considered data from 1991 to 2006.[9] One might argue that in our sample certain universities might have begun to file patents a very long time ago but did not continue to do so regularly, whereas other universities might have begun to file patents recently but are currently very active in patenting. Although, intuitively, one might imagine that universities that began to file patents a very long time ago are more experienced, it also appears reasonable to assume that universities that began to file patents at a later date caught up in the learning process because they now file more patents than the other universities, thereby accumulating comparably more experience and thus knowledge. Given our finding that patenting experience is generally not related to patent output, it is surprising that patenting experience influences the technological breadth of patents. This finding indicates that universities conducting research in more technological areas began to file patents earlier. Thus, it might have been more attractive for universities conducting research in various fields to file patents prior to the legal reform in 2002.

[9] Note that a post hoc analysis based on data from 1992 to 2001 revealed that this explanation for the contradictory finding concerning patenting experience is valid for patent applications; however, for the other dependent variables (i.e., for patent families, PCT applications, and IPC4 breadth), our results were robust, indicating that there might be other reasons for the conflicting results.

Additionally, we observed that, regarding the number of patent families, the overall number of patent applications, and with regard to IPC4 breadth, research breadth was positively related to the patent output of German universities. This relationship was not, however, observed when PCT patent applications were used as the dependent variable. Regarding the specific faculty types, we found that universities educating students in electronics, machinery, and medicine have a significantly higher patent output. Additionally, as one might have expected, we observed that having faculties in social sciences and humanities did not influence patent output. However, surprisingly, mathematics, physics or life sciences faculties were not associated with a higher patent output. As life sciences provide technologies for the future, and because Germany has a strong history in chemistry, it is astonishing that, in our study, these faculties did not increase patent output. Overall, our results on research breadth and faculty profiles generally confirm prior research that observed a positive impact of an engineering faculty (e.g., Coupé 2003; O'Shea et al. 2005; Sine et al. 2003) or of a life sciences and medical department (e.g., Coupé 2003; Lach and Schankerman 2004; Sine et al. 2003) on patent output. In general, patents are more appropriate for the protection of intellectual property in technology, medical and chemical science than, for example, in art-related subjects (Frietsch et al. 2010, p. 28). As the likelihood of being active in one such patenting-intensive research field increases with research breadth, the positive influence of research breadth that we observed on the number of patent families and the overall number of patent applications was not surprising. Similarly, our finding that the research breadth and technological breadth of patents are positively related was not surprising. Yet, we did not expect the non-significant finding when PCT patent applications were used as the dependent variable. We assumed that research breadth allows for benefits from interdisciplinary research, namely in the form of synergies for operational activities and benefits from the cross-fertilization of patents. There are several reasons that these benefits did not have the expected impact: first, interdisciplinarity might be of minor relevance for university patenting except for its influence on the technological breadth of patents. Second, one might argue that research breadth does not necessarily mean that different departments interact intensively and interdisciplinary projects are frequently conducted.

Finally, in line with our assumption, we observed that research quality was generally positively related to the patent output of German universities but did not affect the technological breadth of patents. This finding confirms prior research (e.g., Fritsch and Slavtchev 2006; Perkmann et al. 2011; Van Looy et al. 2011) and supports our assumption that scientific productivity and patenting build on similar organizational resources and capabilities: it appears reasonable to assume that research excellence enables the expansion of the knowledge base and thus the creation of valuable patents. The more valuable an invention is, the more likely that a university might be willing to bear the costs of patenting related inventions. In addition, both research excellence and valuable patents might attract further high-performing scholars, which in turn, might further increase research quality and thus patent output. Regarding the non-significant relationship between research quality and IPC4 breadth, one might argue that research quality does not necessarily result

in a broad technological scope but rather allows universities to focus on few technological areas if this appears more appropriate to them.

5.2 Theoretical and practical implications

The findings of our research contribute to science and practice in the following ways: first, our study provides an extensive overview of how patenting activity is spread across German universities using a patent ranking. Our patent ranking represents an important step toward facilitating the comparison of patenting activity among German universities and with higher education institutions abroad. Prior studies in Germany focused on describing the development over time and ownership structures of university patents (e.g., Cuntz et al. 2012; Frietsch et al. 2010; Schoen and Buenstorf 2013; Von Ledebur et al. 2009). Our overview thus contributes to the current state of knowledge by enabling a comparison between universities. This approach creates transparency for political and university decision-makers and for investors and firms seeking research partners. For example, venture capital funds invest in high-tech startups, partly based on the patents these startups have filed, thereby relying on the signaling effects of patents (i.e., they associate patenting activity with expertise, knowledge and value) (Häussler et al. 2012). From a research perspective, our patent ranking appears to be a valuable starting point in explaining performance differences between universities. The reasoning behind this argument is that patents are directly related to the transfer of explicit knowledge and knowledge appears to be a (or maybe even *the*) resource that is associated with competitive advantage (e.g., Kogut and Zander 1992; Spender 1996).

Second, by investigating potential determinants of the patent output of German universities, our study complements research using the knowledge-based view as its theoretical underpinnings. We argue that differences in knowledge-related resources and capabilities to disseminate knowledge could explain performance differences in knowledge transfer from universities via patents. Our findings support the assumption that appropriate research capabilities are an important prerequisite for patenting. On the one hand, confirming previous research (e.g., Coupé 2003; O'Shea et al. 2005; Sine et al. 2003), we found that research breadth, and thus research capabilities related to patenting in various disciplines, are positively related to patent output. On the other hand, we observed that research quality was positively related to patent output, and hence it appears to be an important resource for successful patenting. This finding supports the assumption that scientific productivity and patenting build on similar organizational resources and capabilities (Van Looy et al. 2011). Both scientific productivity and patenting are intended to enhance explicit and tacit knowledge, and from an economical perspective, one might argue that high patenting activity results in knowledge accumulation and thus an improved knowledge base. As advocates of the knowledge-based view postulate that knowledge is a strong predictor of competitive advantage (e.g., Spender 1996), knowledge on underlying variables that might influence the knowledge base should be of crucial importance, especially for governments and universities but also for university departments and research groups.

Third, in addition to our university ranking, our findings on the determinants of patent output might be used as a basis for determining policy. For example, our findings regarding the determinants of patent output suggest that research breadth and research quality are positively related to the patent applications and patent families of German universities. Thus, when seeking to foster patenting activities, politicians might promote research breadth by introducing new, patent-intensive research fields to universities or promote research quality by introducing incentives for improving their rankings in the best research fields. However, the substantial differences in patenting activities indicate that any measures or incentives for fostering patenting activities should be tailored to suit the respective needs of specific universities. For instance, different measures might be introduced for traditional universities vs. universities of applied sciences.

Fourth, our regression analyses also contribute to the patent literature because we use a Heckman sample selection model, which allows us to analyze the probability that universities are active in patenting and investigate the degree to which specific variables influence patenting output in a single model. This approach is highly recommended, particularly for analyses based on samples such as ours that include numerous universities or firms that have not filed any patents.

5.3 Limitations

Our study suffers from several limitations that one should consider regarding the generalizability of our findings. First, our results on the determinants of the patent output of German universities are based on regression analyses and therefore cannot be interpreted causally. However, conceptually, it is reasonable to argue that patent output is influenced by institutional determinants and that the effect does not operate the opposite direction. Given financial constraints in the university system, one might argue that universities in general cannot necessarily expand in terms of research breadth, even when patent output increases. Moreover, analyzing the institutional determinants of patenting activities using experimental designs is not feasible. Although there are possibilities for conducting field experiments, mapping the university system to a laboratory setting appears impossible.

Second, our study is limited because we focused on university patents and did not consider patents that were based on university research but were nevertheless filed by individuals or companies. Therefore, we only investigated one of the three types of university-invented patents (Schmoch 2000), thereby neglecting two other types that might be interesting and might be influenced by the institutional determinants investigated in our study in a different manner.

Third, a potential limitation is that we generally restricted our analyses to patent output measured by the number of patent applications or patent families and thus do not consider the costs of and revenues from patenting activities. Although the inclusion of the number of PCT patent applications in all aspects of our analyses and the inclusion of forward citations in our patent ranking allow for tentative conclusions regarding patent quality, we cannot draw any conclusions regarding the financial effectiveness of the patenting activities of German universities.

Fourth, our study might be considered limited because we focused on specific potential determinants of universities' patent output in our study. There might be further aspects that could explain the patent output of universities and simultaneously might be more managerially relevant (e.g., leadership styles, team diversity). Further research could conduct surveys focusing on such aspects, thereby shedding light on further potential determinants of patent output.

5.4 Further research

To address the aforementioned limitations, future research should investigate the influence of potential determinants on patent output using patents that are based on university research but are either privately filed or filed by firms. Furthermore, future research should perform event studies using the 2002 legal reform as the event. Using event studies, one could explicitly analyze the effect that the legal reform had on patenting, thereby distinguishing this effect from other potential determinants of patenting output. Additionally, the financial effectiveness of patenting activities should be considered. In particular, it would be highly valuable to study knowledge transfer through patent sales and licensing income. Such data are, however, not yet available. Additionally, productivity measures such as the ratio between patent output and researchers' head count are potential avenues for future research. Moreover, as the conditions for academic patenting differ considerably among European countries (Geuna and Rossi 2011), it might be highly interesting to replicate our study based on a European (or even a global) sample, as such a replication study could contribute to our understanding of academic patenting in Europe (Geuna and Rossi 2011) (or globally) and deliver important insights into the comparability of university patenting and knowledge transfer in different countries. Similarly, one could select a narrower (rather than a broader, European or global) focus. Specifically, focusing on specific research fields and comparing them might reveal important insights into the role that the determinants investigated in our study play in determining the patenting activities of German universities. Additionally, conducting case studies to obtain deeper insights into differences between individual universities (e.g., Universität Freiburg vs. Technische Universität München) with respect to patenting activities appears highly promising. Finally, investigating and comparing the influence of individual-level variables (e.g., age, gender) and organizational-level variables (e.g., university type, the funding body) on patenting activities might be a fruitful avenue for future research.

6 Conclusion

In conclusion, our study serves as an important step toward a more profound understanding of how German universities differ in their patent output and their patenting behavior and in the potential determinants of such differences. Our findings indicate that research quality and research breadth are particularly relevant to patent output. Patenting experience, however, only appears to be relevant with

respect to the technological scope of university patents. Future research should build on our results and extend the generalizability of our findings thereby contributing to an advanced understanding of this important research field.

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