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*Public research and the quality of
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entrepreneurial universities and
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Public research and the quality of inventions: the role and impact of entrepreneurial universities and regional network embeddedness

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Abstract:

The positive effect of public research on industrial innovations is beyond controversy: public research institutions produce knowledge that is subsequently transferred into product and process innovations by private businesses. Besides this rather passive role in commercializing inventions, public research institutions may also proactively exploit new knowledge through public sector entrepreneurship activities. Especially entrepreneurial universities are perceived as a conduit of knowledge spillovers, as they serve as central actors of innovation networks and stimulate network activities. Whereas the linkages between network embeddedness and innovation activities have been largely explored, the impact on patent quality in terms of radicalness, originality and generality remains rather unclear. Considering Germany's diverse public research infrastructure (universities, polytechnics, and non-university research institutes), our findings reveal that the type of institution and the corresponding scientific orientation (basic vs. applied research) matter for the quality of inventions. Centrality of respective institutions within innovation networks thereby reinforces the radicalness of inventions. However, we do not find support for the general assumption that an entrepreneurial orientation of public sector entities augments the quality of inventions. We conclude the paper with policy recommendations as well as with future avenues of research.

Keywords:

patent quality, radical innovation, entrepreneurial university, network embeddedness, centrality

JEL Classification:

O31, O32, O34

1. Introduction

Fostering innovation through facilitating interactions between the public and the private sector is on the agenda of policy makers since decades. The public sector is thereby often perceived as the enabler for industrial innovation: public research institutes produce knowledge that is subsequently transferred into product and process innovations by private businesses. Following the linear model of innovation that is often traced back to the work of Vannevar Bush and his report *Science – The Endless Frontier* (Bush, 1945), basic research constitutes the prerequisite of all innovations, followed by applied research and development that is oriented towards practical use and finally results in production and diffusion. An often-used argument of publicly funded basic research is the public good character of knowledge, leading to a potential underinvestment in basic research from the private sector, hence a market failure, which the government needs to compensate for (see Salter & Martin, 2001).

Public sector entrepreneurship policies try to go one step further in not only addressing existing market failures, but proactively creating fruitful environments for innovation. Leyden and Link (2015) argue that public sector entities need to be encouraged and enabled to identify and exploit entrepreneurial opportunities in the context of uncertain environments. Examples of respective policy interventions can be found manifold: the Bayh-Dole Act of 1980, the Stevenson-Wydler Act of 1980 or the Omnibus Trade and Competitiveness Act of 1988. All these public sector entrepreneurship policies aim at shifting the rather passive role of public sector research institutes in the context of commercializing inventions towards a more proactive one. Especially entrepreneurial universities are thereby perceived as a conduit of knowledge spillovers, as they serve as central actors of innovation networks and stimulate network activities. Etzkowitz et al. (2000a: 40) describe entrepreneurial universities as a driver of the transition towards a knowledge-based society as they constitute a key mechanism in the commercialization of knowledge: “The diminishing gap between investigation and utilization,

as well as increasing recognition of dual theoretical and practical impetuses to scientific research, has made it plain that advancement and capitalization of knowledge are inextricably intertwined”. Hence, also public sector entities may decisively affect regional innovation performance as well as enhance regional competitiveness and regional economic growth.

Much research has been devoted to the economic impact of entrepreneurial universities (Cunningham & Menter, 2020; Fayolle & Redford, 2014; Guerrero et al., 2015; Trequattrini et al., 2018) and their role within innovation networks (Brown, 2016; Guerrero et al., 2016). Whereas the linkages between network embeddedness and innovation activities have been largely explored, the impact on patent quality remains rather unclear. Further, existing studies contextualize the public research body as a homogeneous entity, which is inadequate, as it restricts from deriving meaningful recommendations for the plurality of public sector actors and neglects the specific attributes of respective institutions. Our paper tries to address these shortcomings. Considering Germany’s diverse public research infrastructure (universities, polytechnics, and non-university research institutes), the purpose of this study is to explore how the type and scientific orientation (basic vs. applied research) of public research institutions affect the quality of inventions, taking into account the respective regional network embeddedness as well as their entrepreneurial orientation.

Our empirical study is based on patent applications at the European Patent Office (EPO) filed between 1998 and 2016 retrieved from the OECD databases. To assess the quality of inventions, we employ standard patent indicators that characterize the novelty of the invention (radicalness and originality) as well as the breadth of its applications (generality) (Squicciarini et al., 2013). Following Graf (2017), we reconstruct regional innovator networks to measure network embeddedness of applicants. Patent applicants are categorized according to their function within the innovation system as being focused on basic or applied research. The entrepreneurial orientation of public research is based on a ranking developed by Schmude and

co-authors (e.g. Schmude et al., 2011), which is available only for universities and the period 2001 to 2012. Employing regressions on the patent level, our findings reveal that the type of institution and the corresponding scientific orientation matter for the quality of inventions. Centrality of respective institutions within innovation networks thereby reinforces the radicalness of inventions. However, we do not find support for the general assumption that an entrepreneurial orientation of universities augments the quality of inventions in terms of radicalness, originality and generality. Our results give impetus to more nuanced public sector entrepreneurship policies that take both the type of institution as well as the optimal level of regional embeddedness into account.

The remainder of this paper is structured as follows. Section 2 presents the literature review and derives our central research questions. Section 3 describes the German research landscape, outlines our data and methodological approach as well as presents descriptive statistics. Section 4 reveals our findings. Section 5 discusses the implications of our results and derives policy recommendations. A final section concludes.

2. Literature review

2.1 The quality of inventions: radicalness, originality, and generality

Research on innovation that changes ‘the rules of the game’ has a long tradition not only since Schumpeter (1934) who described the process of ‘creative destruction’ that pushes technological boundaries and drives economic growth. In comparison to Kirzner (1973), who argued that the entrepreneur utilizes existing knowledge and information to create (incremental) innovation, Schumpeter (1934) believed in the creation of new information that ultimately leads to radical change and major innovations. Shane (2003: 20) summarizes these two contrasting perspectives as follows: “Schumpeterian opportunities result from disequilibrating forces, making Schumpeterian entrepreneurship a disequilibrating activity. In contrast, Kirznerian

opportunities are the result of equilibrating forces, meaning that Kirznerian entrepreneurship brings the economy closer to equilibrium. Therefore, Kirznerian opportunities reinforce established ways of doing things, whereas Schumpeterian opportunities disrupt the existing system". Obviously, innovations differ in terms of direction, intensity, and novelty content. To account for the specific qualities and impacts of innovations, a variety of concepts along with respective indicators has been proposed.

Radical innovations have a transformative nature that may supersede existing knowledge. Despite the establishment and broad acceptance of radical innovation as a concept, it remains rather difficult to operationalize. Shane (2001) proposes an index for the *radicalness* of patents based on the variety of cited technologies outside the domain of the patent itself. As such, a patent is considered more radical the larger the difference between the paradigms it relies upon and its field of application. Dahlin and Behrens (2005) use patent data and introduce ex ante indicators (novelty and uniqueness) as well as ex post indicators (impact) in order to measure the radicalness of inventions. By contrast, Chandy and Tellis (2000) make use of expert assessments to evaluate ex post the radicalness of innovations. Both approaches of course have their limitations: whereas patent data is restricted to patentable inventions, expert evaluations may suffer from arbitrariness and a selection bias.

Another concept that captures the novelty content of an invention is *originality*. Many scholars consider inventions as a process of recombination and synthesis of existing technologies and knowledge (Weitzmann, 1998; Fleming & Sorenson 2001; Strumsky & Lobo, 2015; Verhoeven et al., 2016). An invention is then considered more original if it draws on a broader variety of knowledge sources or combines more distinct technologies. In developing their index of originality, Trajtenberg et al. (1997) assume that synthesizing divergent ideas characterize basic research; however, they do not observe a higher level of originality for university patents when compared with corporate patents.

The transformative character of an invention can also be captured by looking at its impact on subsequent technological developments. A particularly large impact is assumed for general purpose technologies which enable or affect a variety of industries and technologies. Hall and Trajtenberg (2004) identify general purpose technologies by using an index of *generality* developed by Trajtenberg et al. (1997). This index is based on the technological breadth of forward citations so that a patent which is cited in many distinct technological fields is considered particularly valuable because of its apparent general applicability.

More recently, approaches that employ text mining techniques have been developed to capture the transformative character of innovations. For example, Kaplan and Vakili (2015) use topic modeling to identify patents that introduce new topics to the respective knowledge field. Arts et al. (2018) argue that patent citations suffer from examiner bias and therefore suggest using text-based measures to identify novel patents. The variety of approaches to qualify the novelty content and transformative potential of inventions and innovations makes it difficult to generalize findings on the sources and effects of radical innovation. Accordingly, Colombo et al. (2015: 666) state that “the research agenda on radical science and innovation is still far from being exhausted”. Open questions remain with regard to the conditions on the regional and organizational level that lead to the emergence of such radical, original or general innovations, which roles are played by specific actors and their scientific orientation and whether the embeddedness in local and non-local linkages are supportive for particularly novel innovations.

2.2 The role and impact of network embeddedness on the quality of inventions

Knowledge flows and associated knowledge spillovers influence innovation activities (Peri, 2005). Already Griliches (1992) noted that spillovers constitute a major source of endogenous growth through fostering innovation activities. The knowledge spillover theory of entrepreneurship (Acs et al., 2009; Audretsch, 1995; Audretsch et al., 2006) subsumes these

insights as it states that contexts that are rich in knowledge are more likely to generate more entrepreneurial opportunities. Ultimately, more entrepreneurial opportunities will then result in higher levels of innovation output. As a consequence, being embedded in a network of innovative entities may positively affect innovation performance (Owen-Smith & Powell, 2004, Powell et al., 1996).

A higher degree of regional network embeddedness suggests that more knowledge diffuses between network entities. Given sufficient absorptive capacities of respective network entities (see Audretsch et al., 2020), this larger knowledge base facilitates the recombination of existing knowledge as well as the creation of new knowledge, thus more likely leads to a higher quality of inventions and novel combinations. Among various measures for regional network embeddedness, especially the concept of centrality has gained popularity among scholars focusing on social network analyses (Freeman, 1978). Centrality thereby describes the position of network entities in relation to others as well as to the entire network. Hence, centrality measures convey the influential role that network entities possess: the higher the centrality of a network entity, the more influence it has on communication flows, thus on the diffusion of knowledge – the prerequisite for high quality innovations. However, it is also argued that the relation between embeddedness and innovation depends on the innovation mode. Rowley et al. (2000) show that a network position within a dense local neighborhood is favorable to exploitation whereas exploration benefits from non-redundant collaborations, i.e. network relations that are characterized by structural holes. Others have shown that there are limits to the benefits of embeddedness and identify an inverted-U shaped relationship with innovation (Laursen & Salter, 2006; Molina-Morales & Martínez-Fernández, 2009). Hervas-Oliver et al. (2017) argue that central actors in clusters might have little incentives to introduce or develop radical innovations for the fear of losing their status-quo. It has to be noted though that these studies focus on firms that balance access to external knowledge with secrecy to avoid outgoing

spillovers. Consequently, embeddedness in regional networks is expected to be higher for public research institutions for which knowledge transfer is part of their mission (Graf & Krueger, 2011). Since our knowledge about the relation between network embeddedness, in particular if different measures of centrality are employed, and the quality of inventions is still quite limited, we phrase the following research question.

Research question 1: How is network embeddedness related to the quality of inventions?

2.3 The link between scientific orientation and the quality of inventions

Besides the consideration of network structures and the embeddedness of network entities within those structures, also the type and scientific orientation (basic vs. applied research) of network entities may decisively affect innovation performance and outcomes (Coriat & Weinstein, 2002). Whereas the role of the private sector in capitalizing knowledge has not changed significantly over time, the perception of the public sector and associated public research institutions has undergone a radical paradigm shift. Beyond the well-known function as suppliers of new knowledge, the role changed with the increasing awareness that public research outcomes could be commercialized by public research institutions themselves, translating research findings into intellectual property – often referred to as the third mission or second academic revolution (Etzkowitz et al., 1998, 2000b). Hence, public research institutes matter and play a key role in pushing technological boundaries, contributing to industrial innovations, delivering new and radical scientific ideas and inventions as well as ultimately monetizing them (Beise & Stahl, 1999).

This paradigm shift within the academic sector blurred the boundaries between basic and applied research, as now, also universities as well as non-university research institutes had

an interest in patenting and licensing public research outcomes as well as engaging in consultancy and contract research (Leyden & Link, 2015). Thus, the previously assumed distinction – public sector institutes engage in basic research, private businesses engage in applied research – became obsolete. By contrast, the awareness arose that basic and applied research may cross-fertilize each other, affecting also the role of governments as facilitators of interactions between basic and applied research (Leyden & Menter, 2018).

In the context of radical innovation, both basic and applied research are important, yet to a different extent and at different points in time. Whereas basic research is likely to set the spark without a clear vision of practical usage, applied research shapes and refines existing knowledge and translates inventions into marketable products and services: “One characteristic of radical innovation is that often it initially has no developed or recognized market, and it is the “iteration” process which eventually generates a market. In the future, underlying basic scientific research will be far more tightly coupled to use-inspired research, and applied research leading to a successful commercialization” (Miller et al., 2005: 70). Also in terms of originality and generality, basic research may have the advantage of non-mission oriented research approaches, facilitating ‘out-of-the-box’ thinking.

Classifying research organizations in terms of their scientific orientation is not an easy task, in particular if organizations within the same group are substantially different (see section 3.1). For example, in Germany, the group of institutes of higher education can be distinguished into polytechnical universities with a focus on teaching and applied research, technical universities with an emphasis on engineering, and general universities. Since the boundaries between these different types of organizations are rather fuzzy, we propose that the embeddedness of any particular type will tell us something about their mission. A university that is highly embedded within the regional knowledge network is probably more concerned with its third mission than a peripheral one and might concentrate its research activities on

applied science. Contrary, and from a knowledge source perspective, one could expect that the relationship between the focus on basic research and the quality of inventions is positively moderated by regional network embeddedness (see Echols & Tsai, 2005). The more embedded an entity is within a network, the more this entity might benefit from interactions with other network entities as well as associated knowledge spillovers, which might then be ultimately translated into higher quality inventions. Because of these ambiguities of theoretical arguments and the scarcity of empirical findings, we explore this complex relationship between scientific orientation and the quality of inventions taking into account network embeddedness in our second research question.

Research question 2: How is scientific orientation (basic vs. applied research) related to the quality of inventions?

2.4 The effect of entrepreneurial orientation on the quality of inventions

External characteristics play a role in pursuing higher quality inventions, yet only constitute one side of the coin, as also internal characteristics may decisively affect innovation performance and output. Miller (1983) was among the first scholars to introduce the concept of entrepreneurial orientation. Based on his work, Covin and Slevin (1989) conceptualized entrepreneurial orientation as a construct of three dimensions – innovativeness, proactiveness, and risk-taking – that together comprise a unidimensional “gestalt”. Studies show that higher degrees of entrepreneurial orientation result in higher levels of firm performance (Rauch et al., 2009; Tang et al., 2008).

Considering the academic context, all the above-mentioned attributes are incorporated in the concept of entrepreneurial universities. Klofsten et al. (2019: 149) describe

entrepreneurial universities as catalysts for development, facilitators of knowledge transfer as well as creators of new knowledge: “An understanding of the roles of present-day entrepreneurial universities is a prerequisite for appreciating how, as key enablers in technology, innovation, and economic development, they act as change agents in current competitive society”. Hence, entrepreneurial universities may particularly contribute to the creation of higher quality inventions, as respective institutions proactively engage in research activities that more likely result in marketable products and services. Public sector entrepreneurship policies may thereby reinforce the position of entrepreneurial universities. However, we lack empirical findings about the relationship between the entrepreneurial orientation of public research and the quality of their inventions. Do entrepreneurial activities within universities lead to more radical and original research projects? Will it make them produce results with more general applicability or will they perform incremental steps that promise faster commercialization? This leads us to our final research question.

Research questions 3: How is entrepreneurial orientation related to the quality of inventions?

3. Data and methodology

3.1 The German research landscape

We want to investigate the link between public research and the quality of inventions, taking into account the regional network embeddedness of public research institutes as well as the corresponding scientific and entrepreneurial orientation. A prerequisite for our analysis is the consideration of the heterogeneity of public research institutions. In sum, Germany has over 1,000 publicly funded research institutions (BMBF, 2017). Besides nearly 120 universities and 220 polytechnics (also known as universities of applied sciences), Germany has a variety of

research institutions, among which the Fraunhofer-Gesellschaft, the Helmholtz Association, the Leibniz Association as well as the Max Planck Society are the most renowned:

- *Fraunhofer* is the leading application-oriented research organization in Europe. The Fraunhofer-Gesellschaft consists of 72 institutes and research facilities with more than 26,000 employees, which focus on six major research areas: (1) health, (2) security, (3) communication, (4) mobility, (5) energy, and (6) environment.
- The *Helmholtz Association* is the largest German scientific organization and contains 19 autonomous research centers with more than 40,000 employees that conduct research in the following six areas: (1) energy, (2) earth and environment, (3) health, (4) aeronautics, space and transport, (5) matter, and (6) key technologies.
- The *Leibniz Association* connects more than 90 independent research institutes that employ around 20,000 employees. The research focus is rather broad, ranging from natural sciences to social sciences and humanities.
- The *Max Planck Society* maintains 86 institutes and research facilities and employs more than 23,000 employees who conduct basic research in natural sciences, life sciences, humanities, and social sciences.

All public research institutes receive their core funding from the government. However, besides public funding, also private funding plays an important role for these institutes, yet to a varying degree. Whereas the Fraunhofer-Gesellschaft heavily relies on private funding, the Max Planck Society, the Leibniz Association and the Helmholtz Association as well as universities and polytechnics are much less focused on industry projects. These differences in funding streams are also reflected in the scientific orientation of the institutes. Whereas Fraunhofer institutes primarily engage in applied research, other institutions such as Max Planck institutes have a

clear focus on basic research. Figure 1 illustrates these differences between various public research institutes in Germany with regard to their scientific orientation and their funding models.

– Insert figure 1 about here –

3.2 Data

Patent selection: university patents and control patents

Our level of analysis is the patent. In a first step, we selected patents of all German universities and polytechnics from the OECD Regpat and HAN databases¹. In the Regpat database, identical applicants appear with different versions of the name, which makes identification of all patents of an organization challenging. The HAN (Harmonized Applicant Names) database offers a solution to this problem by providing common applicant IDs for organizations that appear with different spellings or typos. However, even after consulting the HAN database, there were still many different variants of names for unique applicants so that we performed a manual search to identify all HAN IDs referring to each public university of our interest with the objective to establish consistency within our data². We then collected all patents from HAN and additional information on the patent from Regpat, taking into consideration the geographical location (NUTS 3 regions) of the applicant. In a second step, we identified ‘control patents’ for each university patent, which had to be located in the same region (inventor location), the same technology (according to the 35 technologies provided in the OECD indicators table), and the same application year. Following this procedure, we ended up with data on 82,625 unique patent applications. For each of the control patents, we categorized the applicant as either a firm

¹ Version: July 2019

² The number of different HAN IDs for a single university ranges between 1 and 83 with a median of 12.

or one of the previously mentioned public research institutes. Of all patents, 60,271 are applications by firms, 5,655 by universities, 4,504 by Fraunhofer, 735 by Helmholtz, 683 by Max Planck, 281 by Leibniz, and 171 by polytechnics. 10,325 patents could not be assigned to one of the aforementioned groups and have mostly been filed by individual applicants.

Dependent variables

In order to evaluate the innovation content of each patent, we used three patent quality indicators provided by the OECD³ as dependent variables in the regressions: (1) radicalness, (2) originality and (3) generality.

The *radicalness* of a patent is based on the ideas of cross-fertilization and new combinations. The broader the set of technologies a patent builds upon, the more radical is the novelty content. More specifically, radicalness is measured as the number of IPC technology classes in which the backward citations of the focal patent are classified, but in which the patent itself is not classified (Squicciarini et al., 2013). The indicator is calculated on the IPC four-digit level and has been normalized with respect to the total number of IPC classes in the backward citations, so that its value ranges from zero to one. The higher the ratio, the more diversified the array of technologies on which the patent relies upon.

The *originality* of a patent is also based on the diversity of fields to which its backward citations are allocated. Different from radicalness, it takes into account all fields and not just the ones outside the IPCs of the focal patent as well as the distribution of IPC fields and not merely the count. Again, the idea is that a patent is original if it draws on many distinct sources.

The *generality* of a patent is based on the number and distribution of forward citations. This indicator captures the importance of a patent for later inventions and relies on 4-digit IPC

³ A detailed description of the database and indicator construction is documented in Squicciarini et al. (2013).

classes, yet does not account for technical distance between IPC classes (Squicciarini et al., 2013). A high generality index thereby indicates a wider applicability of the respective patent across different technology groups, whereas a low score indicates a more specific application of the patent.

Independent and control variables

We follow Graf (2017) and operationalize regional network embeddedness by collecting all patents for each of the previously identified university regions on the NUTS 3 level and by reconstructing innovator networks (applicants linked by common inventors). We use two alternative concepts to measure embeddedness of each of the patent applicants within its regional network: the rank based on degree centrality and betweenness centrality. Degree rank is represented by the rank of a network entity relative to all other entities, whereby a higher (smaller) rank indicates a more central position within the network, i.e. an entity has more relations within the network in comparison to others. We use the rank because it is independent of the size of the regional network and less skewed than other centrality measures. Betweenness centrality indicates the position of a network entity as a boundary spanner, hence refers to the control of information flows. A high betweenness centrality thus signals that a network entity is more often on the shortest non-redundant path between two other network entities⁴.

We take account of the heterogeneity of regional innovation systems by differentiating various types of network entities (see Figure 1): Max Planck Society, Leibniz Society, Helmholtz Association, Fraunhofer-Gesellschaft, universities, polytechnics and firms. The scientific orientation (basic vs. applied research) of each network entity is thereby implicitly inherent to each type of institution (see Figure 1). Hence, we measure the scientific orientation indirectly by considering the differences in the research outcome of all types of network entities:

⁴ We use the normalized version of betweenness as calculated by the *igraph* package for R.

whereas scientists from the Max Planck Society may be mainly concerned about producing scientific papers, hence focus on basic research, scholars from the Fraunhofer-Gesellschaft may be more concerned about the applicability of knowledge by producing patents, hence focus more on applied research.

Entrepreneurial orientation is operationalized by utilizing an entrepreneurship ranking developed by Schmude et al. (2001, 2003, 2005; 2007; 2009; 2011). Based on a biennial evaluation of German universities, Schmude and co-authors constructed an overall entrepreneurship score as well as sub category scores⁵ (utilized categories are (1) entrepreneurship education, (2) extracurricular qualification and support, (3) external networking, (4) cooperation and coordination, (5) communication, and (6) spin-off activities), which both serve as an indicator for entrepreneurial orientation and performance in our study. The underlying idea of this ranking was to assess the change in the academic start-up landscape in Germany over time. All categories should thereby reflect different facets of an entrepreneurial university that offers valuable teaching in the domain of entrepreneurship as well as necessary support structures for academic entrepreneurs. A high score in the ranking indicates a higher entrepreneurial orientation of the respective university. Overall, the increasing score levels of all universities indicate that an entrepreneurship culture has been established within the German academic landscape over time (Schmude et al., 2011).

We control for regional GDP per capita and regional population density (measured by the number of citizens per square kilometer of land area). In regressions that only include university patents, we further control for university third-party funding (measured by the third-

⁵ Due to consistency reasons, we were not able to use all eight sub category scores (university policy framework conditions and mobility are missing in our empirical analysis), since two categories changed in the survey over time.

party funding activities per professor) and the number of university scientific staff. All control variables are retrieved from the German Statistics Office.

3.3 Descriptive statistics and methodological approach

The bivariate correlations between our utilized variables are rather low (see Appendix A). More insights concerning the quality of inventions can be retrieved from the descriptive statistics (see Table 1). The sample of German patent applications score on average rather high with regard to their originality but rather low with regard to their radicalness and generality. Differences also exist with regard to the entrepreneurial orientation of German universities: based on a maximum total score of 400 points, the most entrepreneurial university in Germany achieves 316 points, whereas the least entrepreneurial university only scores 67 points. These disparities also hold true for regions in terms of regional GDP per capita as well as population density.

– Insert table 1 about here –

To assess the relationship between actor characteristics and the novelty content of inventions, we estimate the following model:

$$Pat.Ind_i = \beta_0 + \beta_1 NW.Embed_i + \beta_2 Sci.Orient.D_i + \beta_3 Entr.Orient_i + \beta_4 Controls_i + \varepsilon_i$$

where *Pat. Ind* refers to the quality of patent *i* as measured by the indicators radicalness, originality, and generality. By definition, these dependent variables are bound between 0 and 1 so that we rely on Tobit regressions to account for left and right censoring (see Barbieri et al., 2020). Since, in our sample, originality and generality never reach the theoretical maximum,

we impose only the left-censoring limit at 0. *NW.Embed* refers to the embeddedness of patent applicants in the regional knowledge network. It is measured by the two centrality measures discussed above. *Sci.Orient.D* is a set of dummy variables that distinguishes the patent applicants according to the actor types with their differential scientific orientation (basic vs. applied research). *Entr.Orient* are the indicators of entrepreneurial orientation from the Schmude ranking only available for universities. In addition, we take into account regional economic indicators as well as technology and time effects (*Controls*).

As we are interested in both the impact of the scientific orientation as well as the entrepreneurial orientation of network entities, considering the respective regional network embeddedness, we employ two estimation approaches. Our first estimation approach (Model I to III) captures the impact of regional network embeddedness and scientific orientation on the novelty content of public research patents for the full sample of university and control patents. These regressions are estimated without variables for entrepreneurship orientation since this information is only available for universities. Our second estimation approach (Model IV to IX) is restricted to university patents and examines the impact of regional network embeddedness and entrepreneurial orientation on the novelty content of public university patents only.

4. Results

4.1 The impact of regional network embeddedness and scientific orientation

Table 2 shows the results of our first estimation approach. Overall, centrality seems to negatively affect the quality of inventions in terms of originality and generality. Degree rank, our indicator for the relative centrality rank within an innovation network, has a negative impact on both the originality of inventions ($\beta = -0.018$; $p < 0.05$) as well as on the generality of inventions ($\beta = -0.048$; $p < 0.05$): the less central a network entity is embedded within an

innovation network, the more conducive for the quality of inventions in terms of originality and generality. The same holds true for betweenness centrality in the context of the originality of inventions ($\beta = -0.110$; $p < 0.01$): possessing the position as a boundary spanner within an innovation network seems to negatively affect the novelty content of inventions. Our analyses do not reveal any significant results for the radicalness of inventions, but apparently, a central network position seems more conducive to incremental innovation whereas novel ideas are produced by peripheral actors.

– Insert table 2 about here –

With regard to the scientific orientation (basic vs. applied research) of network entities, a focus on basic research seems to be conducive for the creation of radical inventions as shown by the positive and significant coefficients of Max Planck institutes ($\beta = 0.076$; $p < 0.01$), Leibniz institutes ($\beta = 0.141$; $p < 0.01$), Helmholtz institutes ($\beta = 0.056$; $p < 0.01$) as well as universities ($\beta = 0.044$; $p < 0.01$). Vice versa, the orientation towards applied research, as present in Fraunhofer institutes ($\beta = -0.026$; $p < 0.01$) or firms ($\beta = -0.023$; $p < 0.01$) seems to negatively affect the creation of radical inventions. For the quality indicators originality and generality, our results are rather mixed.

To understand if network embeddedness has a differential influence on the novelty content of inventions depending on scientific orientation, we add interaction terms between degree rank and the type of institution. Our results show that degree centrality partly reinforces the radicalness of inventions, which might explain why there is no overall effect of embeddedness. Fraunhofer institutes produce even less radical inventions when they are central to the network ($\beta = -0.300$; $p < 0.01$). More basic research oriented institutions such as Max Planck institutes ($\beta = 0.234$; $p < 0.01$) and Leibniz institutes ($\beta = 0.248$; $p < 0.01$) produce

even more radical inventions when they are well embedded. Again, the results for the quality indicators originality and generality are rather mixed. However, the overall impression is that the tendency of basic research to produce more radical, original, and general patents is reinforced by a central network position. An exception is the lower generality of Leibniz patents ($\beta = -0.479$; $p < 0.01$). Interestingly, firms produce more original patents ($\beta = 0.033$; $p < 0.01$) and general patents ($\beta = 0.072$; $p < 0.01$) when they are central in the network.

Our control variables indicate that the regional context also matters for the quality of inventions. High levels of regional GDP per capita thereby seem to negatively affect all quality dimensions. Regional population density seems to positively affect the radicalness of inventions, yet seems to have a negative effect on the generality of inventions.

4.2 The impact of regional network embeddedness and entrepreneurial orientation

Table 3 shows the results of our second estimation approach analyzing the impact of regional network embeddedness and entrepreneurial orientation of universities. A central network position of universities, i.e. a high relative centrality rank, seems to stimulate the creation of more general patents ($\beta = 0.283$; $p < 0.05$ in Model VI and $\beta = 0.286$; $p < 0.05$ in Model IX), hence confirms our previous results. Betweenness centrality does not show any significant coefficients. Our results for models IV to VI reveal that an entrepreneurial orientation of universities in general (*EO_total*) does not have a significant effect on the quality of inventions. The sub category scores of the entrepreneurship ranking (models VII to IX) largely confirm these non-significant effects and partially even suggest a negative impact of an entrepreneurial orientation on the quality of inventions. Extracurricular qualification and support seems to negatively affect the originality of inventions ($\beta = -0.001$; $p < 0.05$), whereas external networking ($\beta = -0.004$; $p < 0.1$) and communication ($\beta = -0.003$; $p < 0.1$) seem to negatively affect the generality of inventions. Merely the sub category score ‘spin-off activities’

($\beta = 0.002$; $p < 0.05$) shows a positive and significant impact on the quality dimension originality.

– Insert table 3 about here –

Whereas the regional context does not seem to matter for the quality of inventions of universities, the intensity of university-industry collaborations, as indicated by the variable ‘university third-party funding’, another proxy for being an entrepreneurial university, seems to have a negative impact on the generality of inventions ($\beta = -0.0002$; $p < 0.05$ in Model VI and $\beta = -0.0003$; $p < 0.05$ in Model IX). The university scientific staff seems to negatively affect the originality of inventions ($\beta = -0.0001$; $p < 0.05$ in Model VI and $\beta = -0.0001$; $p < 0.05$ in Model IX), yet seems to be conducive for the generality of inventions ($\beta = 0.0002$; $p < 0.05$ in Model VI and $\beta = 0.0002$; $p < 0.05$ in Model IX).

5. Discussion

The findings of our study show that general statements on the impact of regional network embeddedness (“the more central, the better”) on the quality of inventions without considering the type of institution and the corresponding scientific orientation (basic vs. applied research) are inappropriate and misleading. Our paper confirms that network embeddedness matters, yet to a varying degree and thereby reinforces existing studies highlighting that different network positions yield different outcomes (Gisling et al., 2008; Vanhaverbeke et al., 2009). Whereas centrality seems to negatively affect the quality of inventions in terms of radicalness and originality of Fraunhofer institutes, Max Planck and Leibniz institutes produce even more radical and original inventions, given a high degree of regional network embeddedness. In the context of industrial (applied) research, also firms seem to benefit from higher degrees of

centrality within networks, at least with respect to the creation of more original and general patents. Especially the outcomes of basic research thereby seem to be reinforced by a central network position: institutions focusing on basic research seem to produce more radical, original, and general patents in the context of a more central network position. Hence, a one-size-fits-all approach with regard to strengthening the regional network embeddedness of all public research institutions may most likely lead to some unintended negative consequences (see Broekel & Graf, 2012).

The same holds true for statements directed towards the entrepreneurial orientation of an institution (“the more entrepreneurial, the better”). We cannot confirm the generally assumed stimulating effect of a higher degree of entrepreneurial orientation of public research institutes on the quality of inventions (see also Jones-Evans et al., 1999; O’Shea et al., 2005). In the context of our study, entrepreneurial universities do not seem to produce more radical, original, or general patents. Some aspects of an entrepreneurial university may even be counterproductive for more original or general patents. The transformation of a university and the associated adoption of an entrepreneurial paradigm is therefore no panacea for an enhanced quality of inventions. Table 4 summarizes the results and provides an overview of all research questions.

– Insert table 4 about here –

These results give impetus to more nuanced policy approaches aiming at an increase of the quality of inventions, which are necessary and relevant especially in the context of the ongoing discussion about the return on investment of publicly funded research. In particular, institutions with a core focus on basic research such as Max Planck or Leibniz institutes should be encouraged and incentivized to abandon an ivory culture (Etzkowitz et al., 2000b) and move

towards a more active and central role within regional innovation systems. This might in turn result in positive externalities for the private sector with a core focus on applied research, requiring the access to a solid knowledge base. Policy makers therefore need to create environments that offer favorable conditions for innovation by securing a skilled labor base, providing adequate resources for collaborations and reducing administrative burdens. Hence, from a policy perspective, not single aspects of a network entity but an entire innovation system needs to be considered while taking into account the dynamics of innovation. An entrepreneurial orientation might of course facilitate this paradigm shift making the public sector more proactive and market-oriented. However, an entrepreneurial orientation should rather be seen as an enabler of a transformation process of public research institutions, taking on a more central role within innovation networks, instead of a means in itself. Ultimately, it is about a better coordination and integration of basic and applied research outcomes: “While basic and applied [research] feed off each other, they also succeed by working separately (the two stacks). Thus, what is needed is a better mechanism for coordinating the two paths to knowledge, allowing each to nurture the other yet allowing each to do what it does best” (Leyden & Menter, 2018: 236). Each type of public research institution enjoys an excellent reputation with clearly defined competencies and agendas. Policy makers should desist from streamlining the missions of the various network entities, but appreciate the individual strengths of each institution. Whereas Max Planck and Leibniz institutes may be better suited to produce radical inventions, Helmholtz institutes and universities may be better suited for inventing general purpose technologies – given a more central position within the network. Ultimately, it is the interplay between all different network entities that triggers high levels of innovation and drives the novelty content of public research patents. Policy makers need to orchestrate public research activities and take advantage of the plurality of public research institutions that may ideally complement each other.

6. Conclusion

This study aims at exploring the relation between network embeddedness, scientific orientation (basic vs. applied research), entrepreneurial orientation and the quality of inventions in terms of radicalness, originality and generality. Our results show that the scientific orientation that is inherent to each network entity and thereby shapes the goals and strategies towards innovation decisively affects the novelty content and transformative potential of public research patents. Especially a basic research focus seems to induce more radical inventions, whereby a more central network position may reinforce the production of more radical, original, and general patents. In contrast, an entrepreneurial orientation does not seem to per-se stimulate a higher quality of inventions. These findings call for a higher degree of integration of public research institutes within innovation networks. A sole focus on the entrepreneurial transformation of the public sector that is currently on the agenda of policy makers worldwide may thus not be sufficient in order to leverage the full potential of knowledge created within public research institutions. Instead, more support and guidance should be offered in creating linkages with other network entities along with incentives to commercialize new knowledge.

As with all empirical research, our study is subject to several limitations. First, the quality dimensions radicalness, originality, and generality do not cover the full spectrum reflecting the quality of inventions, yet particularly address the impact dimension of respective inventions. Second, our measures for centrality also only partially reflect the entire and complex network structures. Parameters such as network density should also be considered in future studies to fully capture innovation networks and underlying mechanisms. Third, in order to take the plurality of public research institutions fully into account, a more fine-grained classification would be needed, considering also the respective fields and areas of expertise (e.g. social sciences vs. natural sciences vs. humanities). However, taking the umbrella organizations as the unit of analysis as in our case at least gives an indication concerning the respective

contribution of public research institutes. Fourth, our utilized entrepreneurship ranking only reflects the entrepreneurial orientation of an entire university, but not the entrepreneurial orientation of specific departments of the respective university, such as physics or engineering, which might be contrary to the overall entrepreneurial orientation of the university. Ultimately, it is the individual scientist and his/her department and not the entire university that conducts research and discloses inventions. Finally, our quantitative approach cannot fully capture the various feedback mechanisms that shape the innovation mode of various actors, which are interrelated in such a complex research and innovation environment.

Future studies should advance our understanding of the linkages between basic and applied research as well as the impact of regional network embeddedness on the quality of inventions. Questions thereby relate to how an orchestration of basic and applied research can be implemented, which incentive mechanisms are needed to change the position of network entities within innovation systems, as well as how public-private sector interactions can be facilitated. Moreover, it is necessary to investigate the optimal mix of radical, original, and general inventions and how this mix is ultimately translated into higher economic performance: Are more radical inventions always desirable? Which prerequisites are necessary to adopt and translate radical inventions? Do radical inventions lead to competitive advantages? These and further questions need to be addressed by scholars in order to augment the effectiveness as well as the impact of public research.

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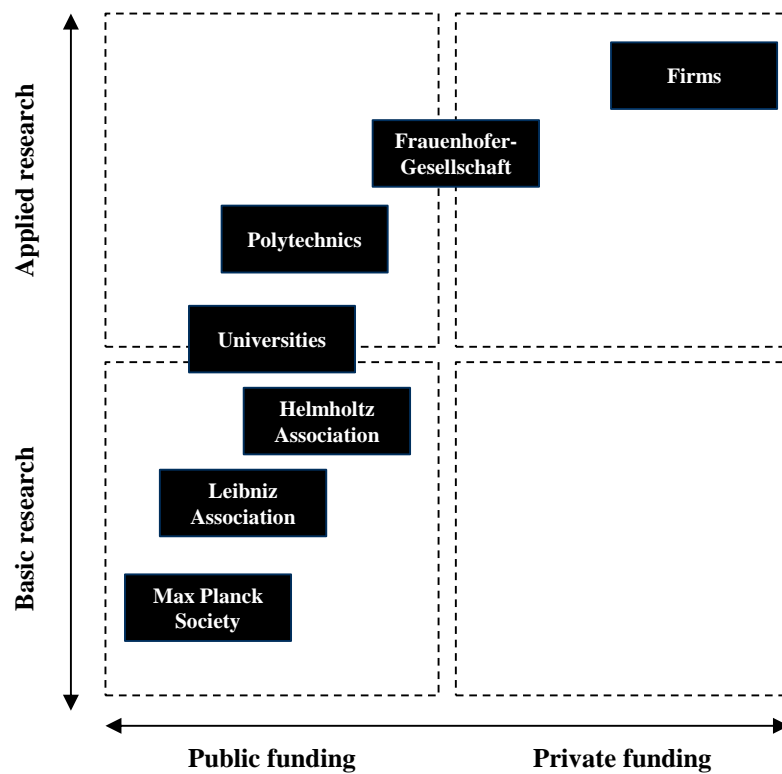
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Figure 1 – The German Research Landscape



Note: Own representation based on BMBF (2012, 2014, 2020).

Table 1: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Pctl(25)	Pctl(75)	Max
<i>Dependent variables</i>							
Radicalness	79,287	0.381	0.273	0.000	0.154	0.579	1.000
Originality	79,261	0.722	0.217	0.000	0.649	0.872	0.980
Generality	23,936	0.362	0.273	0.000	0.000	0.602	0.908
<i>Independent variables</i>							
Degree rank	82,625	0.246	0.293	0.001	0.011	0.443	0.888
Betweenness centrality	82,625	0.015	0.029	0	0	0.015	0.227
EO_total	3,216	198.195	48.591	67.000	169.000	231.000	316.000
EO_education	3,216	26.858	19.099	0.000	12.000	39.000	87.000
EO_extracurr. qualification	3,216	37.081	9.553	0.000	30.000	43.000	59.000
EO_external networking	3,216	21.544	6.572	0.000	17.000	27.000	38.000
EO_cooperation	3,216	17.454	9.602	0.000	10.000	23.000	40.000
EO_communication	3,216	30.179	12.985	8.000	22.000	36.000	74.000
EO_spin-off activities	3,195	14.096	7.589	1.000	8.000	18.000	39.000
<i>Control variables</i>							
Regional GDP per capita	81,062	47,069	18,303	14,094	32,133	58,072	91,969
Regional population density	81,062	2,074	1,140	60.306	1,326	2,981	3,981
University third-party funding	5,435	301.782	138.688	49.319	196.279	406.005	925.012
University scientific staff	5,649	4,690.961	1,951.197	204	3,409	6,101	10,031

Note: This table reports descriptive statistics of all variables of interest. EO is the abbreviation for ‘entrepreneurial orientation’.

Table 2: Novelty content of public research patents – the impact of regional network embeddedness and scientific orientation

	Model I	Model II	Model III
	<i>Radicalness</i>	<i>Originality</i>	<i>Generality</i>
Degree rank ⁺	-0.012 (0.011)	-0.018** (0.007)	-0.048** (0.024)
Betweenness centrality	-0.028 (0.047)	-0.110*** (0.032)	0.001 (0.116)
Type Max Planck Society	0.076*** (0.015)	-0.011 (0.010)	0.075*** (0.026)
Type Leibniz Association	0.141*** (0.027)	0.050*** (0.019)	-0.240*** (0.083)
Type Helmholtz Association	0.056*** (0.016)	-0.015 (0.011)	0.050 (0.036)
Type University	0.044*** (0.006)	0.003 (0.004)	-0.003 (0.015)
Type Polytechnic	-0.011 (0.049)	-0.022 (0.034)	-0.020 (0.163)
Type Fraunhofer-Gesellschaft	-0.026*** (0.007)	-0.030*** (0.005)	-0.099*** (0.017)
Type Firm	-0.023*** (0.005)	0.018*** (0.003)	-0.001 (0.011)
Degree rank X Type Max Planck Society	0.234*** (0.082)	0.195*** (0.057)	-0.018 (0.123)
Degree rank X Type Leibniz Association	0.248*** (0.063)	0.084* (0.044)	-0.479*** (0.161)
Degree rank X Type Helmholtz Association	-0.017 (0.061)	0.079* (0.043)	0.536*** (0.179)
Degree rank X Type University	0.056 (0.042)	0.042 (0.029)	0.259** (0.110)
Degree rank X Type Polytechnic	-0.112 (0.093)	-0.092 (0.065)	0.055 (0.323)
Degree rank X Type Fraunhofer-Gesellschaft	-0.300*** (0.064)	-0.141*** (0.045)	-0.137 (0.157)
Degree rank X Type Firm	-0.005 (0.011)	0.033*** (0.008)	0.072*** (0.026)
Regional GDP per capita	-0.00000** (0.00000)	-0.00000*** (0.00000)	-0.00000*** (0.00000)
Regional population density	0.00000* (0.00000)	0.00000 (0.00000)	-0.00001** (0.00000)
Constant	-9.264*** (0.584)	-0.180 (0.406)	11.940*** (1.422)
Year dummies	Yes	Yes	Yes
Tech. field Dummies	Yes	Yes	Yes
Observations	77,821	77,795	23,914
Log Likelihood	-28,208.240	4,544.856	-13,620.950
Wald Test (df = 53)	5,384.621***	8,690.103***	2,511.757***

Notes: This table reports the results of Tobit regressions focused on the impact of regional network embeddedness and scientific orientation on the quality of inventions. We rely on a sample of 82,625 patents for the years 1998 to 2016. The dependent variable is novelty of invention, operationalized by (1) radicalness, (2) originality, and (3) generality, respectively. Since generality is based on forward citations, this indicator is only defined for patents that have been cited, therefore the lower number of observations in Model III. Standard errors are in parentheses.

⁺ Rank would imply higher centrality with lower values. For ease of interpretation, we recoded this variable so that it increases with centrality. A positive coefficient implies a positive relationship between centrality and the quality of invention.

*p<0.1; **p<0.05; ***p<0.01

Table 3: Novelty content of public research patents – the impact of regional network embeddedness and entrepreneurial orientation

	Model IV <i>Radicalness</i>	Model V <i>Originality</i>	Model VI <i>Generality</i>	Model VII <i>Radicalness</i>	Model VIII <i>Originality</i>	Model IX <i>Generality</i>
Degree rank ⁺	-0.012 (0.055)	0.050 (0.037)	0.283** (0.129)	-0.001 (0.056)	0.050 (0.038)	0.286** (0.131)
Betweenness centrality	-0.249 (0.258)	-0.094 (0.176)	-0.187 (0.529)	-0.320 (0.265)	-0.148 (0.181)	-0.279 (0.553)
EO_total	-0.0002 (0.0001)	-0.0001 (0.0001)	-0.0002 (0.0003)			
EO_education				0.001 (0.0004)	0.00000 (0.0003)	0.0003 (0.001)
EO_extracurr. qualification				-0.001 (0.001)	-0.001** (0.001)	0.002 (0.002)
EO_external networking				-0.001 (0.001)	-0.001 (0.001)	-0.004* (0.003)
EO_cooperation				-0.001 (0.001)	-0.0002 (0.001)	0.002 (0.002)
EO_communication				-0.001 (0.001)	-0.00004 (0.001)	-0.003* (0.002)
EO_spin-off activities				0.0005 (0.001)	0.002** (0.001)	0.001 (0.002)
Regional GDP per capita	0.00000 (0.00000)	-0.00000 (0.00000)	0.00000 (0.00000)	0.00000 (0.00000)	-0.00000 (0.00000)	0.00000 (0.00000)
Regional population density	0.00000 (0.00001)	0.00000 (0.00001)	0.00001 (0.00002)	0.00000 (0.00001)	0.00000 (0.00001)	0.00001 (0.00002)
University third-party funding	-0.00005 (0.0001)	0.00002 (0.00004)	-0.0002** (0.0001)	-0.00004 (0.0001)	0.00001 (0.00004)	-0.0003** (0.0001)
University scientific staff	0.00000 (0.00000)	-0.00001** (0.00000)	0.00002** (0.00001)	0.00000 (0.00000)	-0.00001** (0.00000)	0.00002** (0.00001)
Constant	-26.117*** (4.902)	-4.484 (3.339)	-1.381 (10.307)	-28.401*** (6.873)	-12.274*** (4.692)	11.637 (14.663)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Tech. field Dummies	Yes	Yes	No	Yes	Yes	No
Observations	2,954	2,953	1,002	2,937	2,936	1,000
Log Likelihood	-1,197.731	86.776	-635.054	-1,189.031	85.973	-631.192
Wald Test	272.096*** (df = 42)	269.625*** (df = 42)	17.487** (df = 8)	274.849*** (df = 47)	279.785*** (df = 47)	23.710** (df = 13)

Notes: This table reports the results of Tobit regressions focused on the impact of regional network embeddedness and entrepreneurial orientation on the quality of inventions. We rely on a sample of 71 German universities for the years 2001 to 2012. The dependent variable is novelty of invention, operationalized by (1) radicalness, (2) originality, and (3) generality, respectively. Since generality is based on forward citations, this indicator is only defined for patents that have been cited, therefore the lower number of observations in Models VI and IX. Tech.field dummies were dropped in these two models. EO is the abbreviation for ‘entrepreneurial orientation’. Standard errors are in parentheses.

⁺ Rank would imply higher centrality with lower values. For ease of interpretation, we recoded this variable so that it increases with centrality. A positive coefficient implies a positive relationship between centrality and the quality of invention.

*p<0.1; **p<0.05; ***p<0.01

Table 4: Overview results and (policy) implications

	Research Questions	Results and (Policy) Implications
1	How is network embeddedness related to the quality of inventions?	<ul style="list-style-type: none"> ▪ General statements on the impact of regional network embeddedness (“the more central, the better”) on the quality of inventions are inappropriate and misleading ▪ Network embeddedness matters, yet to a varying degree and may especially reinforce the outcomes of basic research ▪ One-size-fits-all approaches with regard to strengthening the regional network embeddedness of all public research institutions may most likely lead to some unintended negative consequences ▪ Nuanced policy approaches are needed that incentivize a higher degree of integration of public research institutes within innovation networks
2	How is scientific orientation (basic vs. applied) related to the quality of inventions?	<ul style="list-style-type: none"> ▪ There is a tendency of basic research to produce more radical, original, and general patents which seems to be reinforced by a central network position ▪ Institutions with a core focus on basic research should therefore be encouraged and incentivized to abandon an ivory culture and move towards a more active and central role within regional innovation systems ▪ Policy makers need to orchestrate public research activities and take advantage of the plurality of public research institutions and the diverse scientific orientation that may ideally complement each other
3	How is entrepreneurial orientation related to the quality of inventions?	<ul style="list-style-type: none"> ▪ General statements directed towards the entrepreneurial orientation of an institution (“the more entrepreneurial, the better”) considering the quality of inventions are inappropriate and misleading ▪ Our results do not confirm the generally assumed stimulating effect of a higher degree of entrepreneurial orientation of public research institutes on the quality of inventions which may even be counterproductive for more original or general patents ▪ Higher levels of entrepreneurial orientation may facilitate a paradigm shift making the public sector more proactive and market-oriented, yet may not serve as a panacea for an enhanced quality of inventions

Appendix A: Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Radicalness	---	0.40 ***	0.07 ***	0.00	0.00	0.01 **	-0.01 *	0.00	0.00	-0.01	-0.02	0.00	0.05 **	0.05 **	-0.06 ***	-0.04 **
(2) Originality	0.00	---	0.26 ***	-0.01 **	-0.06 ***	-0.05 ***	0.03 ***	-0.05 ***	-0.03 *	-0.05 **	-0.03 *	-0.03 *	-0.04 **	0.00	-0.01	0.00
(3) Generality	0.00	0.00	---	0.00	-0.05 ***	-0.07 ***	0.01 *	-0.10 ***	0.02	-0.04	-0.03	-0.01	-0.03	0.01	-0.04	-0.02
(4) Degree rank	0.81	0.04	0.56	---	-0.41 ***	-0.09 ***	-0.07 ***	-0.21 ***	-0.25 ***	-0.06 ***	0.13 ***	-0.14 ***	-0.18 ***	-0.14 ***	0.12 ***	-0.03
(5) Betweenness centrality	0.37	0.00	0.00	0.00	---	0.38 ***	-0.03 ***	0.29 ***	0.47 ***	0.13 ***	-0.07 ***	-0.01	0.20 ***	0.15 ***	-0.15 ***	0.00
(6) Regional GDP per capita	0.01	0.00	0.00	0.00	0.00	---	-0.08 ***	0.14 ***	0.21 ***	-0.12 ***	-0.11 ***	-0.15 ***	0.07 ***	0.01	-0.10 ***	-0.20 ***
(7) Regional population density	0.07	0.00	0.05	0.00	0.00	0.00	---	0.06 ***	0.10 ***	0.22 ***	0.18 ***	0.18 ***	0.25 ***	0.10 ***	0.07 ***	0.10 ***
(8) University third-party funding	0.78	0.00	0.00	0.00	0.00	0.00	0.00	---	0.32 ***	0.31 ***	-0.02	0.25 ***	0.38 ***	0.35 ***	-0.15 ***	0.07 ***
(9) University scientific staff	0.74	0.06	0.42	0.00	0.00	0.00	0.00	0.00	---	0.08 ***	-0.07 ***	0.12 ***	0.17 ***	0.08 ***	-0.14 ***	-0.08 ***
(10) EO_total	0.67	0.01	0.21	0.00	0.00	0.00	0.00	0.00	0.00	---	0.69 ***	0.70 ***	0.38 ***	0.44 ***	0.50 ***	0.58 ***
(11) EO_education	0.24	0.09	0.37	0.00	0.00	0.00	0.00	0.23	0.00	0.00	---	0.39 ***	-0.03 *	-0.01	0.58 ***	0.42 ***
(12) EO_extracurr. qualification	0.94	0.06	0.87	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	---	0.27 ***	0.24 ***	0.37 ***	0.38 ***
(13) EO_external networking	0.01	0.03	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	---	0.49 ***	-0.33 ***	-0.12 ***
(14) EO_cooperation	0.01	0.88	0.66	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.58	0.00	0.00	---	-0.25 ***	0.01
(15) EO_communication	0.00	0.63	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.58 ***
(16) EO_spin-off activities	0.02	0.97	0.53	0.11	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	---

Note: This table reports bivariate correlations between all variables of interest (upper triangle) and p-values (lower triangle). EO is the abbreviation for ‘entrepreneurial orientation’.

*p<0.1; **p<0.05; ***p<0.01

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