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Universities, Public Research and Regional Innovation Output: An Empirical Study of 19 Technologies in Germany

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Abstract:

It has been repeatedly shown that universities and public research institutes contribute to local innovation generation and facilitation. The mechanisms behind this contribution are well discussed in the literature. However, detailed empirical examinations are missing. We analyse the impact of universities and public research on regional innovation output. Thereby we analyse separately 19 technologies and distinguish whether university education and public research are rather innovation generators or innovation facilitators. All analyses are conducted on German data.

Keywords: regional innovation systems, innovation output, university, public research.

JEL Classifications: C13, I25, O31, R12

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I. Introduction

The impact of universities and public research activities on the innovation output of nearby firms has been repeatedly shown in the literature (e.g. Jaffe, 1989; Acs et al., 1992, 2002; Feldman, 1994; Anselin et al., 1997; Blind and Grupp, 1999, Autant-Bernard, 2001; Graf and Henning, 2006, D'Este and Iammarino, 2010 among others). Therefore, it is a well documented fact that universities and public research support firms through direct and indirect trajectories in their innovation activities (Fritsch et al., 2007). The strength of this impact, however, depends on a broad range on factors.

Recent policy discussion has moved a step further. It is discussed whether public research activities and university education should be especially supported if they match economic activities present in a region (see BMBF, 2009). Firms should especially profit from local university education and public research that is adapted to the regional industrial structure, so that it enables and facilitates regional cooperation and spillover processes and thus innovations. This brings up the question whether university graduates and research institutes in a certain field impact the whole regional economic development or only the regional development of matching industries. Furthermore, the importance of universities and public research for the economy differs between industries. In some industries innovation processes depend more on firm-internal competences while firms in other industries rely strongly on new scientific findings (Pavitt, 1984). In addition, the relevance of scientific findings and higher education changes when industries develop through their life-cycle. Thus, the question arises what kind of industries benefit most from nearby university education and public research?

To answer the above questions, insights are necessary that are not given so far in the literature. On the one hand, we have to see how universities and public research impact regional development. Is this impact multiplicative or additive (see Brenner and Broekel, 2011 for an extensive discussion)? In other words, do universities and research institutes have a direct, independent impact on regional innovativeness through generating innovations and people who will find a way commercialising them? Or do universities and research institutes only have an indirect impact through supporting firms in their innovation activity, implying a regional impact only if such firms are present in the region? These effects can be studied empirically by using different regression equations. So far, in empirical studies the choice of the functional form of the impact is rather based on statistical characteristics of the used data and ignores this question.

On the other hand, we have to know more about the differences between industries as well as the difference between the effects of university education and those of public research. These differences are not studied empirically so far.

This paper takes a step in both these directions. It analyses the patent activities in Germany and their dependence on local university education and public research. Publications in the relevant field in the region are used as a proxy for the number of researchers active in the equivalent field. First, we use a flexible functional form as proposed by Brenner and Broekel (2011) for the empirical analysis. Therefore, we allow for additive and multiplicative effects and test statistically which kind of effect better fits the empirical data. Second, we analyse 19 technological fields separately. Finally, university education and public research activities are distinguished.
In order to examine innovation generation in a region according to the concept of Brenner and Broekel (2011), we also study which population in a region does best describe the number of potential innovators. We examine three different specifications: all inhabitants, all employees in industries relevant for the studied technology and R&D employment in the relevant industries. The literature suggests that the R&D employment should be most adequate (Brenner and Broekel, 2011). However, innovators might recruit from all these populations.

The paper proceeds as follows. In Section II the existing theories and the available empirical knowledge is presented. Based on the theoretical background we describe the empirical method in Section III. This contains the description of the statistical model as well as the statistical approach and the empirical data. In Section IV the results of the statistical analysis are presented and discussed. Section V concludes.

II. Theoretical background

This paper is based on the ideas developed by Brenner and Broekel (2011). They argue that three mechanisms should be distinguished in a discussion or analysis of regional innovation systems. First, there are *innovation attractors* in a region that attract innovation activities to the region. Second, there are *innovation generators*, meaning people creating innovations within the region. Third, there are *innovation facilitators* making innovation generators more or less efficient and productive in their innovation activities. According to Brenner and Broekel (2011) the first mechanisms has to be studied separately from the latter two mechanisms. Therefore, we focus on the latter two mechanisms.

Universities and public research are well-known for their impact on regional innovation output (e.g. Jaffe, 1989; Acs et al., 1992, 2002; Feldman, 1994; Anselin et al., 1997; Blind and Grupp, 1999, Autant-Bernard, 2001; Graf and Henning, 2006, Czarnitzki and Hottenrott, 2009, D'Este and Iammarino, 2010 among others). Nevertheless, some details of the mechanisms and connections between university activities and innovation activities remain unclear. Universities might be involved in all three kinds of mechanisms described above: They might attract innovators to the region, they might contain innovators, and they might facilitate innovators.

Let us first reflect on what is known about the effects of universities from the literature in Subsection II.1. followed by the presentation of the concept developed by Brenner and Broekel (2011) in Subsection II.2. From this we deduce some hypotheses in Subsection II.3.

II.1 Knowledge on the impact of public research and university education on innovation activities

Universities and research institutes have always been seen as key elements of regional innovations systems in the respective literature as they produce and thus spread knowledge. Hence, they are known to promote the innovativeness of nearby firms. There are several explications for the positive influence of universities and public research institutes on regional development. Knowledge spillover and knowledge flows are generated through various mechanisms such as cooperation, graduates, internships, movement of employees and informal contacts between employees (Fritsch et al., 2008). In addition, universities and research institutes offer support for business foundations, consultancy and use of laboratory equipment and they are important sources for spin-offs among other transfer channels (ISI, 2000, Geuna and Muscio, 2009). Fritsch et al. (2008) distinguish between direct and indirect knowledge transfer, where for example research cooperation count for the former and graduates and scientific publications for the latter. Some of these transfer mechanisms like transfer offices, science parks and incubators have been institutionalized during the last decades when the transmission of knowledge between different actors has been moved to the centre of interest of researchers and politicians. This is often called “the third mission” of universities. Given that universities and researchers differ in the way they transmit knowledge, firms also differ in the way they absorb knowledge (Geuna and Muscio, 2009). Thus, researchers might influence firms (in the region) through different channels depending on the characteristics of firms, researchers, universities and research institutes.
Most of the literature on the effects of research activities concentrates on the US, but there are some examples from European countries (e.g. Jaffe, 1989; Acs et al., 1992, 2002; Feldman, 1994; Anselin et al., 1997; Blind and Grupp, 1999; Autant-Bernard, 2001; Fritsch et al. 2008). Among other empirical studies, Cohen et al. (2002) report that the impact of university research on firms is substantial compared to other influences. Fritsch et al. (2008) highlight the importance of knowledge produced in universities. Their study focuses on research cooperation, but graduates are stated as equally important. With only some exceptions, most of these empirical works found a decline of knowledge flows from public research with growing geographical distance (e.g. Fischer and Varga, 2003; Varga, 2000; Fritsch et al., 2008). But a lot of these studies allude to the fact that

not only distance influences the impact on firms' innovative behaviour and success, but also a bunch of other aspects depending on industry branch, size of firm etc (e.g Czarnitzki and Hottenrott, 2009).

The importance of graduates and human capital is discussed in several ways. A highly skilled workforce is important for the innovativeness of firms. R&D employees and other highly qualified workers develop new products and processes, helping the firm to be innovative (e.g.Czarnitzki and Hottenrott, 2009). "Man- (or, better, brain-) power as well as certain equipment are needed for creating innovations" (Brenner and Broekel, 2011:12). Graduates from universities are one of the main sources for R&D workers and other highly qualified employees to bring up to date knowledge into firms to enable these processes. Highly skilled workers also enhance firms' capacity to absorb new knowledge which is an important prerequisite for R&D and firms' innovativeness (Cohen and Levinthal, 1990). Employment pools in regions are often specialized and nearby firms are able to source their labour force from these highly qualified workers. As university research is often conducted by diploma and doctoral work, the regional labour market and the research focus of universities is often strongly connected (e.g. Blind and Grupp, 1999; Bräuninger et al., 2008; Fritsch et al., 2008; Fritsch and Slavtchev, 2007 among others). Graduates and academics are among the most mobile groups (Mohr, 2002). For Germany, a study showed that around 30 percent of graduates from university are likely to leave their region of education ten years after graduation depending on personal and macroeconomic aspects. The likelihood of leaving is highest in the first year after graduation. A higher GDP, thus economic development, hampers out-migration (Busch, 2007). Therefore, the existence of a university does not automatically lead to a pool of highly qualified graduates that stays in a region. Regional development is only likely to be enhanced by graduates if there are corresponding jobs in the regional economy. Otherwise, nearly a third of all graduates tend to leave the region in favour for a job (see, Leßmann and Wehrt, 2005; Fritsch et al., 2008).

The (geographical) distance to public research becomes important because of the tacitness of knowledge (Boschma, 2005). People and institutions are still less mobile then capital (see, Blind and Grupp, 1999). As long as the transmission of knowledge is not possible through codified transmission channels, frequent personal contacts, personal mobility and interaction are important. But also if codification is possible, there is a time span during which the ongoing knowledge is not yet published and therefore face-to-face contacts are of major importance. Thus, geographic distance plays an important role, especially for on-going research with a high proportion of applied research (see, Anselin et al., 2000; Del Barrio-Castro and García-Quevedo, 2005). However, the importance of geographical proximity may decline with declining relevance of tacit knowledge. The term distance also applies for cultural and linguistic proximity, which play a role for personal contacts (see, Arundel and Geuna, 2004; Boschma, 2005). It seems that especially larger manufacturing firms conducting their own R&D are more often recipients and profiteers of knowledge emitted by universities and public research. There is also a higher importance for industries in the applied science fields (see, Cohen et al., 2002; Lööf and Broström, 2008; Czarnitzki and Hottenrott, 2009).

To conclude, the simple presence of a university or a research institute does not lead to a high regional innovativeness. An industrial structure that is capable to absorb the transmitted knowledge and that relies on university deliveries is essential for the regional effect of universities (e.g. Fritsch and Slavtchev, 2007). Nevertheless, the influence of universities and research institutes is not mono-directional. Regional firms and industries may also affect the direction of universities and public research.

II.2 Theoretical concept

Brenner and Broekel (2011) depicted the innovation process in an abstract form as shown in Figure 1. They argue that a region's characteristics, denoted as innovation attractors, attract more or less innovation generators to a region. However, all kinds of characteristics and factors might have an innovation attracting role, even the innovation generators themselves when they attract further innovation generators to the region. Hence, feedback loops exist in this process. All these interactions in a region in combination with historical events shape the structure and content of the spatial unit. This historical process has self-reinforcing characteristics and involves social, economic, and institutional developments. It determines the number of innovation generators in a region. Brenner and Broekel (2011) state, that this interactive process is too complex for a representation in a simple mathematical model. Thus, we refrain from studying this process. Instead, we focus on innovation generators and innovation facilitators in this paper. We analyse the process of innovation generation that is depicted in Figure 1 as the arrow leading to innovation output.

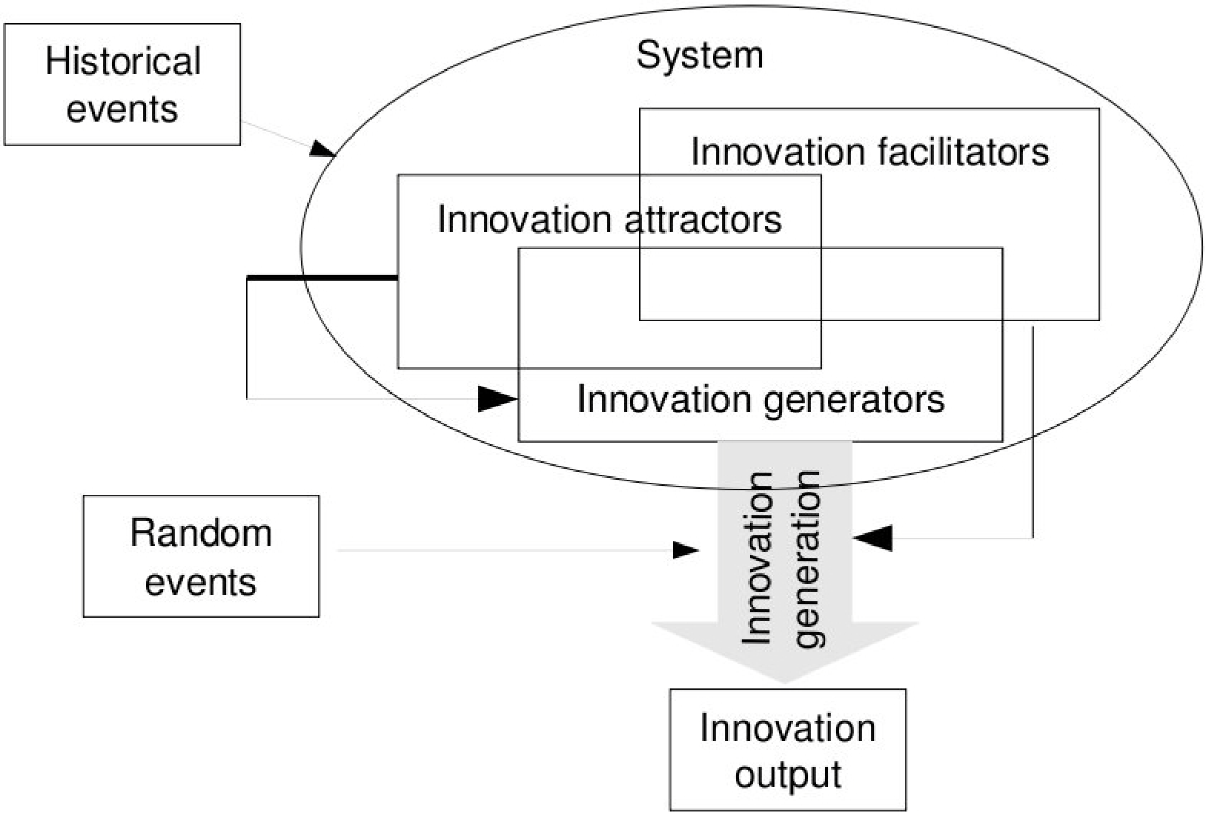

Figure 1*: Interactions that cause the innovation output of a spatial unit.*

According to Brenner and Broekel (2011), R&D employees in firms are the dominant innovation generators. Other innovation generators might be found in form of other employees in firms, in public research institutes and universities. There are also some private inventors. A region contains a limited number of such actors that are able to generate innovations. All people that might produce innovation are called innovation generators. This is in line with the literature on innovation systems where innovation generation is often, but of course not only, seen in the range of firms (see, e.g. Thomi and Werner, 2001; Asheim et al., 2011). This does not mean that firms are able to conduct innovations based on their work alone given that they depend on knowledge input, reflection and feedback-loops from other actors. Anyhow, firms are generally those who diffuse new products or processes and thus innovations to the market (e.g. Schumpeter, 1983; Kline and Rosenberg, 1986). Employees from research institutes and universities are also involved in innovation generation but to a lesser extent.

One of the tasks of this paper is to identify an adequate empirical variable that reflects the number of innovation generators in a region. The arguments of Brenner and Broekel (2011) suggest that either the R&D employment in firms or a combination of various sources, such as R&D employment, total employment, public research, universities and the number of inhabitants should be adequate.

Innovation generators depend on the regional circumstances in their innovation activities. For example, the presence of a university – that might function as a cooperation partner in research projects – can make innovation generation more or less effective. Many other local factors might also influence the innovation activities of innovation generators in a region (Czarnitzki and Hottenrott, 2009). These kind of local factors are called innovation facilitators (Brenner and Broekel, 2011). In this paper we will examine especially whether university graduates and public research represent such innovation facilitators.

Brenner and Broekel (2011) furthermore state that some factors are at the same time innovation facilitators, innovation generators and innovation attractors. Universities and public research are such factors. As stated above, whether they are innovation attractors is difficult to study. Hence, we focus here on the question of whether university education and public research are rather innovation generators or innovation facilitators or both at the same time.

II.3 Hypotheses

Three questions will be addressed in the empirical analysis. Before the empirical analysis is conducted, we will deduce for each of these questions a hypothesis on the basis of the literature.

First, we analyse the main sources of innovation generators. In the context of the model above, Brenner and Broekel (2011) argue that R&D workers in firms should be the dominant group of innovation generators, because firms are the main actors in innovation generation measured by patents. Other employees in firms, employees in public research institutes and universities and private persons should also contribute, but with much less importance.

Hypothesis 1:
a) A number of populations, such as employees in firms, R&D employees, universities and public research institutes, are sources of innovation generators in a region. The total number of inhabitants might also contribute.
b) The dominant source of innovation generators are the R&D employees in firms. University graduates and public research activities play a minor role.

Second, we will examine the question whether universities and public research institutes play a role for the innovation output generated from regional firms. The literature, which is reported above, clearly shows that they are important players. However, we do not expect that university education and public research are important for all industries. Pavitt's classifies a number of industries as science based (Pavitt, 1984). It can be expected that these industries benefit more from public research. Alternatively, a distinction between high- and low-tech industries can be used (see, e.g., Legler and Frietsch, 2006). High-tech industries can be assumed to benefit more from public research as well as from university education. Finally, while there is some literature that shows the importance of university graduates, public research seems to be more important for the regional innovation output. This is confirmed by the fact that university graduates are quite mobile, while benefiting from university research often requires proximity. Hence, we can state:

Hypothesis 2:

a) Public research has a positive impact on the regional innovation output, especially in science-based industries.

b) University education and public research have a positive impact on the regional innovation output, especially in high-tech industries.

c) Public research has a stronger impact on the regional innovation output than university education.

Third, we address the question of whether universities and public research are rather innovation generators or innovation facilitators. If universities and public research are innovation generators, they increase the regional innovation output independent of the present industry structure. If universities and public research only function as innovation facilitators, they have an impact on the regional innovation output only if corresponding firms are present. The literature mainly studies the impact that public research and university education has on the innovation performance of firms. Hence, the innovation facilitating function is strongly proved in the literature. Little is said about the contribution of universities directly to the generation of innovations. Only few patents are applied for by universities. However, often patents are the joint work of firms and university, but the firm applies for the patent. In addition, universities often deliver their innovative results to firms before these are developed into a patent. From the literature it seems as if such direct involvement in the patent generation plays a less important role. Hence, we state:

Hypothesis 3:

University education and public research are more important as innovation facilitators than as innovation generators.

III. Empirical method and data

In the following section we describe the mathematical model that is used in our analysis (Subsection III.1) as well as the empirical approach (Subsection III.2). Finally, we present and discuss the empirical data in Subsection III.3.

III.1 Mathematical model

Our aim is to analyse to what extent universities and public research function as innovation generators and/or innovation facilitators. Hence, we need a model describing the innovation output in a region as a function of the presence of innovation generators and innovation facilitators. We start with the model set up by Brenner and Broekel (2011):

$$E(I_s) = \sum_{i=1}^{G_s} \eta_i(c_i, F_s) \qquad (1)$$

$E(I_s)$ denotes the expected number of innovations in region s and G_s the number of innovation generators in this region. $\eta_i(c_i, F_s)$ indicates the productivity of innovation generator i dependent on her characteristics c_i and the regional innovation facilitators F_s. We simplify Equation (1) for the empirical approach used here: we assume that the impact of the innovation facilitators is the same on all innovation generators in a region. Hence we can write

$$E(I_s) = \sum_{i=1}^{G_s} \left[\eta_{c,i}(c_i)\right] \cdot \eta_F(F_s) \qquad (2)$$

Furthermore, we are not able to distinguish the characteristics of each innovation generator. There is evidence that the likelihood of a R&D worker in a firm to generate an innovation differs from the likelihood of a student just graduated from university to generate an innovation. These two kinds of innovation generators can easily be differentiated in an empirical approach. Two different R&D workers, instead, cannot be distinguished in an analysis on the regional level.

Hence, we assume that there are different kinds k of innovation generators. The number of innovation generators of type k in region s is denoted by $g_{k,s}$. It is presumed that the characteristics of innovation generators of the same kind are the same. Hence, their innovation output is given by $\eta_k * \eta_F(F_s)$. We obtain:

$$E(I_s) = \sum_{k=1}^{n} \left[\eta_k \cdot g_{k,s}\right] \cdot \eta_F(F_s) \qquad (3)$$

where n denotes the number of different kinds of innovation generators. Equation (3) can be transformed into

$$E(I_s) = \left[\sum_{k=1}^{n} \left(\eta_k \cdot g_{k,s}\right)\right] \cdot \eta_F(F_s). \qquad (4)$$

In a next step, we have to examine the term $\eta_F(F_s)$. In order to be able to estimate this part with the help of a regression, we have to determine the functional form of this term. Let us discuss its meaning. The first part of the right-hand side of Equation (4) shows the number of potential innovation generators within a region. Therefore, the second part can be interpreted as the probability of each of these potential innovation generators to produce an innovation. We use the standard logistic specification for this probability given by

$$\eta_F(F_s) = \frac{1}{1 + \exp\left[c - \sum_f \left(a_f \cdot v_{f,s}\right)\right]} \qquad (5)$$

where c is a constant, f is the index for each innovation facilitator and $v_{f,s}$ is the value of the innovation facilitator f in region s. The logistic functional form is a general approach for probabilities in statistical approaches, especially in decision making (Cramer, 2003).

Hence, we are finally able to write that the expected number of innovations in region s is given by

$$E(I_s) = \frac{\left[\sum_k \left(\eta_k \cdot g_{k,s}\right)\right]}{1 + \exp\left[c - \sum_f \left(a_f \cdot v_{f,s}\right)\right]}. \qquad (6)$$

III.2 Empirical approach

Above we have deduced the mathematical model (Equation (6)) based on theoretical considerations. We use this equation to conduct regressions. However, innovation numbers are not normally distributed. They can be expected to be binomially or poisson distributed. Hence, we have to use a respective regression approach.

However, the standard negative binomial distribution – the one mostly used in such a case – contains two parameters. One reflects the probability of events and is estimated dependent on the independent variables. The other reflects the number of counter-events that occur before we see the measured number of events (dependent variable). This second parameter is usually fixed or estimated as a parameter. In our approach, we intend to describe both parameters, the probability and the number of potential events, as functions of the independent variables. On the basis of the theoretical considerations above we derived Equation (6): the number of potential innovations given by the upper term on the right-hand side and the probability that these potential innovations become real given by the lower term on the right-hand side.

Therefore, we model the binomial distribution[1] in an explicit way and define the total number of potential innovations as

$$Pot(I) = c_{pot} + \sum_{k} \left(\eta_k \cdot g_{k,s} \right). \qquad (7)$$

The value of η_k determines to what extent each kind of population *k* contributes to the potential number of innovations. Furthermore, we included a constant in order to obtain a standard regression equation. A value of c_{pot} above zero would imply that there are additional innovation generators that are not reflected by our independent variables.

Explicitly we consider the following populations:

- [Empl] Employment in the relevant industries in the region
- [RandD] R&D employees in the relevant industries in the region
- [Inhab] Inhabitants in the region
- [Research-*gen*] Publications in the relevant field in the region, as a proxy for the number of researchers active in this field
- [Uni-Grad-*gen*] Number of graduates (technical, diploma, bachelor and master) in the relevant subject in the region

The lower term on the right-hand side of Equation (7) determines the probability for the realisation of a potential innovation. This probability depends in a logistic form on various regional characteristics (Equation (5)). In our empirical study we consider the following characteristics:

- [Highschool] Share of school leavers in the region with a high-school degree
- [GDP] GDP per inhabitant in the region
- [Dens] Population density in the region
- [Unempl] Unemployment rate in the region (this variable also reflects east-west differences in Germany, it is highly correlated with an potential East-West dummy so that we do not include such a dummy)
- [Research-*fac*] Publications in the relevant field in the region, as a proxy for the number of researchers active in this field
- [Uni-Grad-*fac*] Number of graduates (technical, diploma, bachelor and master) in the relevant subject in the region

The first four variables represent factors that are repeatedly found in the literature to influence the innovation activities in regions. Descriptive statistics for all variables can be found in the appendix

[1] For small event probabilities the number of counter-events (r=n-k in the binomial distribution) and of potential events (n) are nearly the same. Hence, using a binomial or negative binomial distribution leads to nearly the same results. However, our theoretical approach leads to a substantial definition of the number of potential events. Therefore, we use the binomial distribution instead of the, within econometric approaches, more common negative binomial distribution.

in Table A.2. The regressions are conducted numerically[2].

III.3 Empirical data

Aware of the strengths and weaknesses of the information provided by patents (see Feldman and Florida, 1994; Malerba and Orsenigo, 1996; Deyle and Grupp, 2005), we will use them as dependent variables in this study. The analysis builds on data extracted from the European Patent Organisation's (EPO) Worldwide Statistical Patent Database version October 2011, the so-called 'PATSTAT October 2011' database.

For the purpose of this paper we selected all patents in the Patstat database that are filed between 1999 and 2009[3] for which at least one applicant was located in Germany. To this end all patent inventors with addresses in Germany[4] have been assigned to German regions. The unit of analysis is the labour market area, called 'Arbeitsmarktregion', of which there are 270 in Germany (according to the definition of the German Labour Office). We use inventor's addresses, as usual in the literature, because the headquarters of large firms tend to be located far away from the place where the innovation took place (Paci and Usai, 2000).

In the next step, we assigned all patents to different technological fields. This involved the identification of the International Patent Classification (IPC) for the relevant patents. Based on these IPCs, we matched the patents to 19 technological fields (see Table A.1 for a list of these fields) with the help of a concordance developed by Schmoch and colleagues (the concordance is a current version of the concordance published in Schmoch et al. (2003) and was obtained directly from the author). The patent data, as well as all other data that is available for the time period from 1999 to 2009, is aggregated in order to reduce fluctuations.

We use three kinds of independent variables (see Table 1). First, there are a number of control variables that are included in the analysis. These variables are frequently found to have an influence on the innovation output in a region. We use the GDP per capita [GDP], the share of school leavers that have a high-school degree [Highschool], the unemployment rate in the region [Unempl] and the population density [Dens] as control variables. All data is obtained for 2000 from INKAR 2002 database. These variables enter the regression equation as potential innovation facilitators.

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2 The regression is programmed and conducted in C++. The likelihood is maximised with the help of an optimisation algorithm that mixes an evolutionary strategy with a gradient approach.

3 No patent application after 2009 is contained in the used data.

4 We assigned all inventors with a postal code and city name that match the list of German municipalities.

Second, we include a number of variables that represent potential innovation generators. According to Hypothesis 1, the main innovation generators are R&D employees in firms [RandD]. The data on R&D employees is taken from the employment panel of the German Institute for Employment Research (Institut für Arbeitsmarkt- und Berufsforschung) for the years 1999 to 2009. We follow Bade (1987) and define R&D employees as the occupational groups of engineers, chemists and natural scientists.[5] The data on R&D employees is organized by occupational groups as well as industries (WZ03). Based on the work of Schmoch et al. (2003) industry classes (WZ03) are assigned to the 19 technology classes (Table A.1 in the appendix).

Furthermore, all employees in firms [Empl] contribute to innovation activities. Data on the total number of employees is also taken from the employment panel of the German Institute for Employment Research. Again, industries are included according to their assignment to technology classes (see Table A.1). In order to reflect private persons generating innovations, we include the total number of inhabitants [Inhab] as a potential source of innovation generators. The data is obtained from INKAR 2002.

Third, we apply variables that are related to universities and research institutes. Universities have two functions: education and research. Hence, we use two measures: the number of graduates and the number of publications. The latter measure embraces the research activities of universities and research institutes. Publications originating from the private sector are rare, so that we assume publication to be an adequate measure for public research activities.

Publications are taken from the Web of Science for the years 1999 to 2009 and are assigned to IPC classes according to keywords appearing in their abstracts. To this end, approximately 16000 keywords have been identified that distinguish IPC classes well (high Gini coefficient). The proportional appearance of these keywords within IPC classes has been calculated on the basis of patent abstracts. Then, all publications have been assigned to IPC classes according to the keywords that appear in their abstracts. The number of university graduates was obtained from the German Statistical Office for the years 1999 to 2009. Graduates are distinguished according to the subject they studies. We identified all German inventors with a title for a professor in the PATSTAT database. If possible, we identified for these professors the faculty that they are affiliated to. From this we obtain the contribution shares for each faculty to patents in each technology. Graduates are assigned to the technologies according to these contribution shares.

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[5] Bade (1987) defines R&D workers as employees belonging to the occupational groups 032, 60, 61 or 883 of the German occupation classification (Bundesanstalt für Arbeit, 1988)

IV. Empirical results and discussion

In the following subsections we test the hypotheses deduced in chapter II.3.

IV.1 Innovation generators (Hypothesis 1)

First we address the question which variables do best represent the number of innovation generators in a region. Five sources of innovation generators are tested in our regression models: R&D employees [RandD], total employment [Empl], inhabitants [Inhab], university education [Uni-Grad-gen], and public research [Research-gen]. Table 1 lists the results (the complete regression results are listed in Table A.3 in the appendix).

Table 1: Estimated coefficients for the variables that describe potential innovation generators (p-values in parentheses, significance level: ***=0.001, **=0.01, *=0.05)

No.	Technological Field	[RandD]	[Empl]	[Inhab]	[Research-gen]	[Uni-Grad-gen]
1	Electrical machinery, apparatus, energy	0.0432 (0.204)	0.0322*** (0.000)	0.000215*** (0.000)	0.00000004 (0.961)	0 (1.000)
2	Electronic components	0.00011 (0.563)	0.0934** (0.005)	0.000144*** (0.000)	0.00000005 (0.622)	0.0000191 (0.655)
3	Telecommunications	1.06*** (0.000)	0.00000554 (0.819)	0.000545*** (0.000)	0.00000004 (0.819)	0 (1.000)
4	Audio-visual electronics	1.05 (0.051)	0.0868*** (0.001)	0.000000 (0.897)	0.00000001 (0.872)	0 (1.000)
5	Computers, office machinery	1.54 (0.650)	1.93 (0.257)	0.0016 (0.000)	0 (1.000)	0.0000877 (0.945)
6	Measurement, control	0.0000776 (0.547)	0.241** (0.008)	0.000687*** (0.000)	0 (1.000)	0.000487 (0.657)
7	Medical equipment	1.46*** (0.000)	0.000000 (0.961)	0.000229*** (0.000)	0 (1.000)	0.22 (0.355)
8	Optics	0.226*** (0.000)	0.116** (0.001)	0.00000153 (0.361)	0.000000002 (0.893)	0.00000275 (0.861)
9	Basic chemicals, paints, soaps, petroleum products	1.54*** (0.000)	0.0343* (0.047)	0.0000384* (0.038)	0 (1.000)	0 (1.000)
10	Polymers, rubber, man-made fibres	4.33*** (0.000)	0.0155*** (0.000)	0.00407*** (0.000)	3.49*** (0.000)	0.0000422 (0.942)
11	Non-polymer materials	0.0475 (0.110)	0.00519*** (0.000)	0.000129*** (0.000)	0 (1.000)	0.00000007 (0.826)
12	Pharmaceuticals	0.451*** (0.000)	0.0697*** (0.000)	0.000000 (0.691)	0.0257*** (0.000)	0.00000006 (0.903)
13	Energy machinery	0 (1.000)	0.204* (0.027)	0.00121*** (0.000)	0.0000511 (0.961)	0.416 (0.232)
14	General machinery	0.0521 (0.131)	0 (1.000)	0.000137*** (0.000)	0.0407 (0.563)	0 (1.000)

15	Machine-tools	23.1** (0.001)	0.0000243 (0.945)	0.000896*** (0.001)	13.8 (0.177)	0 (1.000)
16	Special machinery	6.57*** (0.000)	0.0284 (0.549)	0.00289*** (0.000)	0.00259 (0.785)	0 (1.000)
17	Transport	0.00146 (0.837)	0.247 (0.264)	0.00779*** (0.000)	0 (1.000)	0.0000228 (0.918)
18	Metal products	0.130 (0.150)	0.386*** (0.000)	0.000696*** (0.000)	0 (1.000)	0.000348 (0.824)
19	Textiles, wearing, leather, wood, paper, domestic appliances, furniture, food	0.000125 (0.875)	0.00000149 (0.875)	0.00184*** (0.000)	0.000129 (0.874)	0.0000294 (0.874)
Number of significant relations		**8**	**11**	**15**	**1**	**0**

Our results confirm Hypothesis 1 only partly. Hypothesis 1a states that there are a number of regional factors that provide innovation generators. This is confirmed. Especially R&D employees, total employees and inhabitants play a significant role as innovation generators for several technologies. For most technologies various sources of innovation generators exist.

Hypothesis 1b states that R&D employees in firms play a dominant role as innovation generators. This is not confirmed. The variable [Inhab] shows a very significant relationship with the number of innovation generators in most cases (15 out of 19). The number of R&D employees and the number of total employees is found to be significant in fewer cases. One possible reason for this finding is the fact that R&D employees and total employees are strongly correlated[6]. Hence, they might explain innovation generation to a similar extent. In most cases (15 out of 19) one of the two variables is found to be significant. Another possible reason for the strong findings for inhabitants as innovation generators might be the fact that the assignment of industry classes to technologies does only partly represent innovation activities in regions. In each region actors from different industries might be responsible for the innovation activity in one technology. Therefore, the assigned industries represent the relevant actors only partly. This implies that patent activities from other industries are not directly included in the regression equation. As a consequence a significant part of the impact of other, not considered industries will be represented by the variable [Inhab].

Nevertheless, looking at the estimated coefficients, R&D employees have the highest innovation probability whenever they are found to be significantly contributing. Total employment shows estimated coefficients that are smaller than those of R&D employees and larger than those of inhabitants, if they are significant. Hence, the innovation productivity shows the expected order, with a R&D employee contributing more than a general employee, who still contributes more than a general inhabitant.

[6] Nevertheless, the correlation between these variables does not cause multicolinearity problems. Tests for multicolinearity do not detect any problem for any of the technologies.

University education [Uni-Grad-gen] is not significant for any technology. The variable [Uni-Grad-gen] can be seen as representation of two factors. On the one hand, it represents the number of students that graduate. On the other hand, it can also be seen as a proxy for the number of people teaching at universities, who might also be involved in innovation activities. However, we do not find any evidence for their involvement as innovation generators. A possible reason is the mobility of graduates given that some regions might lose a certain number of highly skilled employees that influences the overall results. Similar results are obtained for the variable [Research-gen]. Only in the case of pharmaceuticals researchers seem to contribute as innovation generators. In all other technologies no evidence for an involvement of public researchers as innovation generators is found.

To sum up, we find that R&D employees, general employees and inhabitants are important for the innovation process as innovation generators. R&D employees have, as expected, the highest innovation productivity. Public research contributes significantly as innovation generator only in the case of pharmaceuticals. University education is not found to function as innovation generator. Hence, universities and public research are not found to have an impact on the regional innovation output independent of the industry structure in the region, except for the case of pharmaceuticals.

IV.2 Impact of public research institutes and universities (Hypothesis 2)

The main aim of this paper is to get more insights about the impact of universities and public research institutes on the innovation activities in regions. Whether they rather function as innovation generators or as innovation facilitators is examined in the next subsection. Here we focus on the question whether university education and public research are related to regional innovation activities and whether this holds for all or only specific technologies. Above we found that public research is only significantly relevant as innovation generator in the case of pharmaceuticals. For university education no significant result was found. Table 2 presents the results for the various factors, including university education and public research that might show a relationship with the probability of innovation generators to produce innovations.

Table 2: Results for university variables within the best fitting model for each technology (p-values in parentheses, significance level: ***=0.001, **=0.01, *=0.05)

No.	Technological Field	[Dens]	[GDP]	[Unempl]	[High-school]	[Research-fac]	[Uni-Grad-fac]
1	Electrical machinery, apparatus, energy	0.00044* (0.041)	0.118*** (0.000)	-0.110*** (0.000)	0 (1.000)	14.2 (0.937)	183 (0.069)
2	Electronic components	0 (1.000)	0.15*** (0.000)	-0.161*** (0.000)	0.153*** (0.001)	1024* (0.022)	583 (0.335)

3	Telecommunications	0.00035 (0.092)	0.131*** (0.000)	-0.126*** (0.000)	0.00302 (0.481)	144 (0.236)	292** (0.002)
4	Audio-visual electronics	0.000303 (0.491)	0.157*** (0.000)	0.0196 (0.727)	0.149** (0.001)	3515 (0.182)	2412** (0.008)
5	Computers, office machinery	0.0008*** (0.000)	0.0514** (0.005)	-0.185 (0.000)	0.0185 (0.394)	193 (0.338)	269 (0.147)
6	Measurement, control	0.000597*** (0.000)	0.0692*** (0.000)	-0.145*** (0.000)	0.0181 (0.179)	199 (0.271)	331* (0.025)
7	Medical equipment	0.000448* (0.047)	0.0438* (0.019)	-0.167*** (0.000)	0.0316 (0.095)	484 (0.341)	0.00367 (0.949)
8	Optics	0.000736 (0.162)	0.222*** (0.000)	0 (1.000)	0.0897*** (0.001)	3219 (0.190)	1222 (0.339)
9	Basic chemicals, paints, soaps, petroleum products	0.000823*** (0.000)	0.0285 (0.206)	-0.148*** (0.000)	0.0223 (0.156)	514 (0.308)	157* (0.013)
10	Polymers, rubber, man-made fibres	0.000588*** (0.000)	0.0597*** (0.000)	-0.127*** (0.000)	0 (1.000)	29 (0.847)	-6.56 (0.777)
11	Non-polymer materials	0.000944*** (0.000)	0.0891*** (0.000)	-0.114*** (0.000)	-0.0152 (0.118)	934** (0.008)	32.1 (0.615)
12	Pharmaceuticals	0.00159*** (0.000)	0.146*** (0.000)	-0.00624 (0.379)	0 (1.000)	104 (0.691)	1304*** (0.000)
13	Energy machinery	0.000762** (0.001)	0.037** (0.007)	-0.265*** (0.000)	-0.00489 (0.324)	-966 (0.755)	0 (1.000)
14	General machinery	0.00105*** (0.000)	0.0886*** (0.000)	-0.253*** (0.000)	0.0415*** (0.000)	0.00527 (0.883)	68.1 (0.138)
15	Machine-tools	0.000772** (0.002)	0.0588*** (0.000)	-0.23*** (0.000)	0.039 (0.054)	-3262 (0.123)	66.8 (0.719)
16	Special machinery	0.000754*** (0.000)	0.016* (0.036)	-0.231*** (0.000)	0.000471 (0.862)	273 (0.461)	35.7 (0.324)
17	Transport	0.000517* (0.015)	0.0662*** (0.000)	-0.22*** (0.000)	-0.0246 (0.059)	0.0053 (0.961)	25.4 (0.463)
18	Metal products	0.0011*** (0.000)	0.000863 (0.823)	-0.278*** (0.000)	0.000008 (0.777)	-1448 (0.233)	131 (0.131)
19	Textiles, wearing, leather, wood, paper, domestic appliances, furniture, food	0.000676*** (0.000)	0.0731*** (0.000)	-0.259*** (0.000)	0.0348* (0.016)	0 (1.000)	0 (1.000)
Number of significant relations		**15**	**17**	**17**	**5**	**2**	**5**

We find clear relationships for the population density, GDP and the unemployment rate, which appear in almost all technologies. The results confirm that innovation generators are more productive in big cities (high population density) and in economically successful regions (high GDP). In Germany, the unemployment rate separates quite well West Germany from East Germany. Hence, our results for the unemployment rate can be interpreted in two ways: Innovation generators are more productive in regions with less unemployment or in regions in West Germany. For the share of population with high school education we find significant results for some technologies, indicating higher innovation productivity in regions with higher shares.

However, the focus of this paper is on the relationships between university education and public research activities and regional innovation activities. We find significant relationships only for a few technologies. Of course, the statistical analysis does not allow us to conclude that such a relationship is not given. However, in comparison to the other factors that are included in the analysis conducted here university education and public research seem to play a minor role in most technologies.

In Hypothesis 2a we stated the expectation that public research is especially relevant in science based technologies. Significant results are found for public research for three technologies: Pharmaceuticals (innovation generation), electronic components (innovation facilitation) and non-polymer materials (innovation facilitation). Two of these technologies are science based according to Pavitt (1984). Hence, science based technologies are overrepresented in this group, but three technologies do not allow to make a final significant statement about this. Hence, we do not find significant evidence for Hypothesis 2a.

Hypothesis 2b states that university education and public research should be especially relevant in high-tech industries. Significant results for university education are found for five technologies: Telecommunications, audio-visual electronics, measurement and control, basic chemicals etc. and pharmaceuticals. For public research we find significant results only for two out of 19 industries, electronic components and non-polymer materials. Hence, all technologies for which we find significant results for university education or public research are high-tech, except for non-polymer materials. However, most studied technologies that are analysed are high-tech. Thus, we only find a tendency but no significant confirmation.

Interesting results are found for two technologies. First, innovation activities in non-polymer materials show a significant connection to public research. This technology is classified neither as science based nor as high-tech. Maybe this field has recently seen innovative developments based on public research on new materials. Second, pharmaceuticals are the only technology field for which we find a significant relationship for patents with university education and public research. Furthermore public research is found to fulfil an innovation generation function, while university education fulfils an innovation facilitation function. This confirms the strong relevance of university education and public research for innovations in pharmaceuticals.

Hypothesis 2c states that public research is more important than university education for regional innovation activities. This is not confirmed by our study. Significant results are found for public research in only three cases, while in five cases significant results are obtained for university education. Hence, the provision of university graduates within a region seems to be quite important for innovation processes. Despite the high mobility of university graduates, companies seem to benefit in their innovation activity from nearby university education.

IV.3 Innovation generators or innovation facilitators (Hypothesis 3)

Our regression model contains two parts (Equations (6) and (7)). One describes the potential innovation generators, so it captures the innovation generating function of the independent variables. The other describes the innovation probability, capturing the innovation facilitation function of the independent variables. University education and public research are included in both equations.

In Hypothesis 3 we formulate the expectation that university education and public research function rather as innovation facilitators than as innovation generators. This is confirmed by our results. Especially in the case of university education we do not find any significant result for an innovation generation function. This means that university education rather supports regional firms and other actors in their innovation activity than providing innovation generators itself. As a consequence, university education increases the innovation output of a region only if there are innovation activities - meaning innovation generators - in this region that they can support. Therefore, it seems to be important for the universities' impact on innovations that a corresponding economic surrounding is given.

The results are not similarly clear in the case of public research. Significant contributions to innovation generation are found for one technology, while significant contributions to innovation facilitation are found for two technologies. Hence, public research might also cause the generation of innovations in a region without other innovation generators around. However, whether this also holds outside the pharmaceutical field remains unclear.

V. Conclusions

The aim of this paper is to analyse the impact of universities and public research institutes on the innovation output of regions. The literature provides strong evidence for such an impact. However, this impact has manifold characteristics and details are less studied. This paper focuses mainly on two detail issues: first, the question of whether university education or public research are especially relevant for certain types of industries and, second, whether they contribute to innovation generation themselves, independent of the regional economic activity, or facilitate the innovation generation by other regional economic actors present. Additionally, we analyse what population is mainly involved in the generation of innovations in a region.

We find that university education mainly functions as innovation facilitator. As innovation generator, universities, more precisely, university graduates do not play a direct role. Thus, the main effect of university education on regional innovation output is supporting private actors in their innovation generation. Knowledge transfer via university graduates seems of importance to firms as R&D workers and other employees have positive impacts on the creation of innovations. This implies that an active economic surrounding with corresponding industries and branches is necessary for universities to have their full impact on the innovative output of regions.

The findings for the impact of public research are mixed. Significant results are only found for three technologies. In the case of pharmaceuticals public research contributes to innovation generation. In two cases, audio-visual electronics and non-polymer materials, public research contributes to innovation facilitation. More research is needed to substantiate these findings. Nevertheless, given that public research conducts basic research and applied research, the impact of public research is more mixed compared to the impact of university graduates and depends on the differences between industries and branches.

This paper presents a first approach to statistically study the mechanisms behind the relationship between universities, public research and regional innovation activities. More investigations should be done to obtain detailed insights on these relationships. These insights can then be used to improve the location and extent of university education and public research dependent on industrial specialisation. First attempts of policy measures that focus their financing on public research and universities that match industries and branches present in a region are already implemented. Findings of this paper lead to the presumption that this is a successful strategy. Nevertheless, more insights and research are necessary to improve focus and purpose of future policy measures.

References

ACS, Z.; ANSELIN, L. and VARGA , A. (2002). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy.* 31, (7): 1069-1085.

ACS, Z.; AUDRETSCH, D. and FELDMAN, M. (1992). Real effects of academic research: comment, *American Economic Review.* 82, (1): 363-367.

ANSELIN, L.; VARGA, A. and ACS, Z. (1997). Local geographic spillovers between university research and high technology innovations, Journal *of Urban Economics.* 42, (3): 422—448.

ANSELIN, L.; VARGA, A. and ACS, Z. (2000). Geographical spillovers and university research: A spatial econometric perspective. *Growth and Change.* 31, (4): 501-515.

ARUNDEL, A. and GEUNA, A. (2004). Proximity and the use of public science by innovative European firms. *Economics of Innovation & New Technology.* 13, (6): 559-580.

ASHEIM, B. T.; SMITH, H. L. and OUGHTON, C. (2011). Regional Innovation Systems: Theory, empirics and policy. *Regional Studies.* 45, (7): 875 - 891.

AUTANT-BERNARD, C. (2001). Science and knowledge flows: evidence from the French case. *Research Policy.* 30 (7): 1069-1078.

BADE, F.-J. (1987). Regionale Beschäftigungsentwicklung und produktionsorientierte Dienstleistungen. Sonderheft 143. *Deutsches Institut für Wirtschaftsforschung*, Berlin.

BLIND, K. and GRUPP, H. (1999). Interdependencies between the science and technology infrastructure and innovation activities in German regions: empirical findings and policy consequences. *Research Policy.* 28, (5): 451-468.

BMBF (2009). InnoProfile. Wirtschaftsorientierte Nachwuchsforschungsgruppen geben Regionen in den Neuen Ländern ein neues Profil. Bonn, Berlin.

BOSCHMA, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies.* 39, (1): 61 - 74.

BRÄUNINGER, M.; SCHLITTE, F.; STILLER, S. and ZIERHAHN, U. (2008). Deutschland 2018- Die Arbeitsplätze der Zukunft. Regionen im Wettbewerb-Faktoren, Chancen und Szenarien.

BRENNER, T. and BROEKEL, T. (2011). Methodological issues in measuring innovation performance of spatial units. *Industry and Innovation.* 18, (1): 7-37.

BUNDESANSTALT FÜR ARBEIT (1988). Klassifizierung der Berufe. Nürnberg: Graphische Betriebe F. Willmy GmbH.

BUSCH, O. (2007). When have all the graduates gone? Internal cross-state migration of graduates in Germany 1984–2004. *SOEPpapers on Multidisciplinary Panel Data Research* (26): 1-17.

CRAMER, J.S. (2003). Logit Models From Economics and Other Fields. Cambridge: Cambridge University Press.

COHEN, W and LEVINTHAL, D. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly.* 35, (1): 128-152.

COHEN, W.; NELSON, R. and WALSH, J. (2002). Links and impacts: The influence of public

research in industrial R&D. *Management Science.* 48, (1): 1-23.
CZARNITZKI, D. and HOTTENROTT, H. (2009). Are local milieus the key to innovation performance? *Journal of Regional Science.* 49, (1): 81.
DEL BARRIO-CASTRO, T. and GARCÍA-QUEVEDO, J. (2005). Effects of university research on the geography of innovation. *Regional Studies.* 39, (9): 1217-1229.
D'ESTE, P. and IAMMARINO, S. (2010). The spatial profile of university-business research partnerships. *Papers in Regional Science.* 89, (2): 335-350.
DEYLE, H. and GRUPP, H. (2005). Commuters and the regional assignment of innovative activities: A methodological patent study of German districts. *Research Policy.* 34, (2): 221–234.
FELDMAN, M. (1994): *The Geography of Innovation.* Kluwer. Dordrecht.
FELDMAN, M. and FLORIDA, R. (1994).The geographic sources of innovation: Technological infrastructure and product innovation in the United States. *Annals of the Association of American Geographers.* 84, (2): 210–229.
FISCHER, M. and VARGA, A. (2003). Spatial knowledge spillovers and university research: Evidence from Austria. *The Annals of Regional Science.* 37, (2): 303 - 322.
FRITSCH, M. and SLAVTCHEV, V. (2007). Universities and Innovation in Space. *Industry und Innovation.* 14, (2): 201 - 218.
FRITSCH, M. ; HENNING, T. ; SLAVTCHEV, V. and STEIGENBERGER, N. (2007). Hochschulen, Innovation, Region. Ed. Sigma, Berlin.
FRITSCH, M; SLAVTCHEV, V. and STEIGENBERGER, N. (2008). Hochschulen als regionaler Wachstumsmotor? Innovationstransfer aus Hochschulen und seine Bedeutung für die regionale Entwicklung. Hans-Böckler-Stiftung, Düsseldorf.
GEUNA, A. and MUSCIO, A. (2009).The Governance of University Knowledge Transfer: A Critical Review of the Literature. *Minerva.* 47, (1): 93-114.
GRAF, H. and HENNING, T. (2006). Public Research in Regional Networks of Innovators: A Comparative Study of Four East-German Regions. *Jenaer Schriften zur Wirtschaftswissenschaft.* 19/2.
INKAR (2002). INKAR – Indikatoren und Karten zur Raumentwicklung. Aktuelle Daten zur Entwicklung der Städte, Kreise und Gemeinden. Berichte Band 14, CD-Rom, Federal Office for Building and Regional Planning, Bonn, Germany.
ISI (2000). Regionale Verteilung der Innovations- und Technologiepotentialen in Deutschland und Europa. Endbericht an das BMBF. Fraunhofer Institut für Systemtechnik und Innovationsforschung, München.
JAFFE, A. (1989). Real effects of academic research. *American Economic Review.* 79, (5): 957-970.
KLINE, S. and ROSENBERG, N. (1986). An overview of innovation. In: Landau, R. (Ed.): The positive sum strategy: Harnessing technology for economic growth. The National Academies Press: 275-305.

LEGLER, H. and FRIETSCH, R. (2006). Neuabgrenzung der Wissenswirtschaft – forschungsintensive Industrien und wissensintensive Dienstleistungen (NIW/ISI-Listen 2006). Studie des NIW und des ISI zum deutschen Innovationssystems Nr. 22-2007, Hannover/Karlsruhe.

LEßMANN, G. and WEHRT, K. (2005). Der Standorteffekt ostdeutscher Hochschulen. Verbesserung der Humankapitalbasis durch mehr Studienplätze? *Zeitschrift für Wirtschaftsgeographie.* 49, (1): 42-49.

LÖÖF, H. and BROSTRÖM, A. (2008). Does knowledge diffusion between university and industry increase innovativeness? *Journal of Technology Transfer.* 33, (1): 73-90.

MALERBA, F. and ORSENIGO, L. (1996). Schumpeterian patterns of innovation are technology-specific. *Research Policy*. 25,(3): 451–478.

MOHR, H. (2002). Räumliche Mobilität von Hochschulabsolventen. Bellmann, L. and Velling (Eds). Arbeitsmärkte für Hochqualifizierte: 249–281. Nürnberg.

PACI, R. and USAI, S. (2000). Technological enclaves and industrial districts: An analysis of the regional distribution of innovative activity in Europe. *Regional Studies*. 34, (2): 97-114.

PAVITT, K. (1984). Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy.* 13, (6): 343-373.

SCHMOCH, U.; LAVILLE, F.; PATEL, P. and FRIETSCH, R. (2003). Linking technology areas to industrial sectors. Final report to the European Commission, DG Research.

SCHUMPETER, J. A. (1983). The theory of economic development. Transaction Books, New Brunswick.

THOMI, W. and WERNER, R. (2001). Regionale Innovationssysteme. Zur territorialen Dimension von Wissen und Innovation. *Zeitschrift für Wirtschaftsgeographie.* 45, (3-4): 202-218.

VARGA, A. (2000). Local academic knowledge transfers and the concentration of economic activity. *Journal of Regional Science.* 40, (2): 289 - 309.

Appendix

Table A.1: Overview of technological fields and the related IPC codes and NACE codes and the classifications as science based and high-tech.

No.	Technological Field	IPC codes	NACE codes (WZ03)	Science based	High-tech
1	Electrical machinery, apparatus, energy	B60M, B61L, F21H, F21K, F21L, F21M, F21P, F21Q, F21S, F21V, G08B, G08G, G10K, G21C, G21D, H01H, H01K, H01M, H01R, H01T, H02B, H02H, H02K, H02M, H02N, H02P, H05C, H99Z	31.1 – 31.6	yes	yes
2	Electronic components	B81B, B81C, G11C, H01C, H01F, H01G, H01J, H01L	32.1	yes	yes
3	Telecommunications	G09B, G09C, H01P, H01Q, H01S, H02J, H03B, H03C, H03D, H03F, H03G, H03H, H03M, H04B, H04J, H04K, H04L, H04M, H04Q, H05K, H04W	32.2	yes	yes
4	Audio-visual electronics	G03H, H03J, H04H, H04N, H04R, H04S	32.3	yes	yes
5	Computers, office machinery	B41J, B41K, B43M, G02F, G03G, G05F, G06C, G06D, G06E, G06F, G06G, G06J, G06K, G06M, G06N, G06T, G07B, G07C, G07D, G07F, G07G, G09D, G09G, G10L, G11B, H03K, H03L, G06Q	30	yes	yes
6	Measurement, control	F15C, G01B, G01C, G01D, G01F, G01H, G01J, G01K, G01L, G01M, G01N, G01R, G01S, G01V, G01W, G04B, G04C, G04D, G04F, G04G, G05B, G08C, G12B, G99Z	33.2, 33.3, 33.5	no	yes
7	Medical equipment	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, A62B, B01L, B04B, C12M, G01T, G21G, G21K, H05G	33.1	no	yes
8	Optics	G02B, G02C, G03B, G03D, G03F, G09F	33.4	no	yes
9	Basic chemicals, paints, soaps, petroleum products	B01J, B09B, B09C, B27K, C01B, C01C, C01D, C02F, C07B, C07C, C07F, C07G, C09B, C09C, C09D, C09F, C09K, C10B, C10C, C10G, C10H, C10J, C10K, C10L, C11D, C12S, D06L, F17C, F17D, F25J, G21F, A01N, C05B, C05C, C05D, C05F, C05G, A62D, C06B, C06C, C06D, C08H, C09G, C09H, C09J, C10M, C11B, C11C, C14C, D01C, F42B, F42C, F42D, G03C, G21J, A01P, C99Z	24.1 (not 24.16, 24.17), 24.2, 24.3, 24.5, 24.6, 23	yes	yes
10	Polymers, rubber, man-made fibres	A45C, B29B, B29C, B29D, B60C, B65D, B67D, C08B, C08C, C08F, C08G, C08J, C08K, C08L, D01F, E02B, F16L, H02G	25, 24.7, 24.16, 24.17	yes/no	yes/no
11	Non-polymer materials	B21C, B21G, B22D, B22F, B24D, B28B, B28C, B32B, C01F, C01G, C03B, C03C, C04B, C21B, C21C, C21D, C22B, C22C, C22F, C23C, C23D, C23F, C23G, C25B, C25C, C25D, C25F, C30B, C25B, D07B, E03F, E04B, E04C, E04D, E04F, E04H, F27D, G21B, H01B	26, 27	no	no
12	Pharmaceuticals	A61K, A61P, C07D, C07H, C07J, C07K, C12N, C12P, C12Q, C40B, A61Q	24.4	yes	yes
13	Energy machinery	B23F, F01B, F01C, F01D, F03B, F03C, F03D, F03G, F04B, F04C, F04D, F15B, F16C, F16D, F16F, F16H, F16K, F16M, F23R	29.1	no	yes
14	General machinery	A62C, B01D, B04C, B05B, B61B, B65G, B66B, B66C, B66D, B66F, C10F, C12L, F16G, F22D, F23B, F23C, F23D, F23G, F23H, F23J, F23K, F23L, F23M, F24F, F24H, F25B, F27B, F28B, F28C, F28D, F28F, F28G, G01G, H05F	29.2	no	yes

15	Machine-tools	B21D, B21F, B21H, B21J, B23B, B23C, B23D, B23G, B23H, B23K, B23P, B23Q, B24B, B24C, B25D, B25J, B26F, B27B, B27C, B27F, B27J, B28D, B30B, E21C, B99Z	29.4	no	yes
16	Special machinery	A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01M, A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03C, B03D, B05C, B05D, B06B, B07B, B07C, B08B, B21B, B22C, B26D, B27L, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21D, E21F, F04F, F16N, F26B, H05H, F41A, F41B, F41C, F41F, F41G, F41H, F41J	29.5, 29.3, 29.6	no	yes
17	Transport	B60B, B60D, B60G, B60H, B60J, B60K, B60L, B60N, B60P, B60Q, B60R, B60S, B60T, B62D, E01H, F01L, F01M, F01N, F01P, F02B, F02D, F02F, F02G, F02M, F02N, F02P, F16J, G01P, G05D, G05G, B60F, B60V, B61C, B61D, B61F, B61G, B61H, B61J, B61K, B62C, B62H, B62J, B62K, B62L, B62M, B63B, B63C, B63H, B63J, B64B, B64C, B64D, B64F, B64G, E01B, F02C, F02K, F03H, B63G, B60W, F99Z	34, 35	no	Yes
18	Metal products	A01L, A44B, A47H, A47K, B21K, B21L, B25B, B25C, B25F, B25G, B25H, B26B, B27G, B44C, B65F, B82B, E01D, E01F, E02C, E03B, E03C, E03D, E05B, E05C, E05D, E05F, E05G, E06B, F01K, F15D, F16B, F16P, F16S, F16T, F17B, F22B, F22G, F24J, G21H, E99Z	28	no	No
19	Textiles, wearing, leather, wood, paper, domestic appliances, furniture, food	A21B, A41B, A41C, A41D, A41F, A41G, A42B, A43B, A43C, A44C, A45B, A45D, A45F, A46B, A46D, A47B, A47C, A47D, A47F, A47G, A47J, A47L, A63B, A63C, A63D, A63F, A63G, A63H, A63J, A63K, B01B, B27D, B27H, B27M, B27N, B41M, B42D, B42F, B43K, B43L, B44D, B44F, B62B, B68B, B68C, B68G, C06F, D04D, D04G, D04H, D06C, D06F, D06J, D06M, D06N, D06P, D06Q, D21C, D21H, D21J, E04G, E06C, F23N, F23Q, F24B, F24C, F24D, F25C, F25D, G10B, G10C, G10D, G10F, G10G, G10H, H05B, A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, A23P, A24B, A24D, A24F, C12C, C12F, C12G, C12H, C12J, C13F, C13J, C13K, A99Z	15 – 22, 29.7, 36	no	no

Table A.2: Descriptive statistics for the used variables

Variable	Technology No.	Mean	Variance	Minimum	Maximum
Patents	1	10.1519	1002.55	0	376
[Empl]	1	1464.02	1.03758e+07	0.0163636	28744.8
[RandD]	1	355.673	792222	0	8621.41
[Research]	1	5304.64	1.59663e+08	0	114239
[Uni-Grad]	1	271.067	457067	0	5915.93
Patents	2	5.59259	927.716	0	429
[Empl]	2	356.582	971734	0	9254.19
[RandD]	2	97.0974	95506.9	0	3379.4
[Research]	2	9846.31	5.50084e+08	0	211806
[Uni-Grad]	2	90.8918	46773.8	0	1822.28
Patents	3	12.6444	3852.35	0	883
[Empl]	3	255.641	569302	0	6061.76

[RandD]	3	51.4227	27824.7	0	1194.14
[Research]	3	26891	4.10574e+09	0	579059
[Uni-Grad]	3	278.173	468486	0	5945.16
Patents	4	1.3963	57.5504	0	96
[Empl]	4	99.5327	90310.2	0	2385.82
[RandD]	4	27.4708	8574.88	0	690.818
[Research]	4	3406.35	6.59171e+07	0	73375.1
[Uni-Grad]	4	50.3856	14631.9	0	910.29
Patents	5	9.11111	1621.79	0	549
[Empl]	5	155.702	416748	0	7998.44
[RandD]	5	24.8396	14154.9	0	1540.64
[Research]	5	19307.5	2.11588e+09	0	415835
[Uni-Grad]	5	222.32	288604	0	4675.51
Patents	6	12.0778	1561.4	0	454
[Empl]	6	840.033	2.85509e+06	0.172727	12385.8
[RandD]	6	197.722	220713	0	3740.79
[Research]	6	7179.15	2.92566e+08	0	154641
[Uni-Grad]	6	250.628	392938	0	5216.68
Patents	7	7.9037	584.954	0	245
[Empl]	7	499.916	754679	8.76364	7963.45
[RandD]	7	35.9908	13656.1	0	1106.53
[Research]	7	7499.44	3.19134e+08	0	161551
[Uni-Grad]	7	280.126	547700	0	6030.04
Patents	8	2.25926	99.6958	0	110
[Empl]	8	124.715	175823	0	5740.6
[RandD]	8	11.6984	2612.13	0	623.292
[Research]	8	3048.22	5.27485e+07	0	65652.1
[Uni-Grad]	8	58.7282	22024.4	0	1214.68
Patents	9	13.7407	2288.83	0	480
[Empl]	9	1077.82	9.76332e+06	0.00727273	36751.8
[RandD]	9	80.0359	89507.4	0	3793.53
[Research]	9	8969.71	4.56759e+08	0	193305
[Uni-Grad]	9	707.648	2.93206e+06	0	14587.5
Patents	10	13.7296	1101.91	0	253
[Empl]	10	1455.12	2.23709e+06	7.36091	11245.4
[RandD]	10	76.5242	13500.1	0	867.345
[Research]	10	8047.08	3.67671e+08	0	173403
[Uni-Grad]	10	218.58	315070	0	4579.54
Patents	11	8.31111	400.807	0	150
[Empl]	11	1801.66	6.35227e+06	24.8018	24119.8
[RandD]	11	130.172	47338	0	1648.56
[Research]	11	7386.64	3.09839e+08	0	159150
[Uni-Grad]	11	423.415	1.19511e+06	0	9044.71
Patents	12	18.1889	3003.02	0	381
[Empl]	12	402.633	1.14925e+06	0	8732.23
[RandD]	12	26.6004	7299.93	0	717.054
[Research]	12	22220.8	2.7963e+09	0	477458
[Uni-Grad]	12	149.025	141469	0	3133.62
Patents	13	11.0889	1183.31	0	411

[Empl]	13	491.989	1.36155e+06	0	13279.5
[RandD]	13	84.8246	52265.5	0	2338.91
[Research]	13	3694.82	7.76008e+07	0	79665.1
[Uni-Grad]	13	226.984	359691	0	5005.07
Patents	14	6.74815	615.789	0	360
[Empl]	14	471.399	622190	0	8622.76
[RandD]	14	60.0315	17276.2	0	1402.84
[Research]	14	5246.07	1.56203e+08	0	113037
[Uni-Grad]	14	373.562	876066	0	7852.1
Patents	15	4.87407	371.51	0	276
[Empl]	15	128.74	53875	0	1531.79
[RandD]	15	13.442	1061.17	0	327.615
[Research]	15	2653.25	3.9953e+07	0	57193.8
[Uni-Grad]	15	282.147	526682	0	6169.39
Patents	16	15.2481	877.831	0	243
[Empl]	16	1026.52	2.46506e+06	2.55364	13864.6
[RandD]	16	113.841	46987.6	0	2271.89
[Research]	16	8842.18	4.43884e+08	0	190539
[Uni-Grad]	16	749.194	3.81257e+06	0	16133.1
Patents	17	30.2852	18178.9	0	2034
[Empl]	17	1320.71	7.79043e+06	0.363636	23326.6
[RandD]	17	282.808	468902	0	5342.5
[Research]	17	8657.02	4.25821e+08	0	186589
[Uni-Grad]	17	813.909	3.79308e+06	0	16888.1
Patents	18	6.42222	330.021	0	214
[Empl]	18	2110.89	9.34766e+06	37.6382	24616.6
[RandD]	18	325.966	339682	0.685455	4611.48
[Research]	18	3369.22	6.44937e+07	0	72611.6
[Uni-Grad]	18	397.443	1.05376e+06	0	8660.26
Patents	19	11.6593	807.306	0	278
[Empl]	19	2447.83	5.96218e+06	167.178	17246.1
[RandD]	19	15.0125	502.797	0	143.547
[Research]	19	12338	8.64513e+08	0	266040
[Uni-Grad]	19	789.813	3.71659e+06	0	16671.2
[Inhab]		304785	1.58352e+11	63566.6	3.40144e+06
[Dens]		289.939	172155	39.6655	3815.16
[GDP]		21.3497	29.9736	12.4	43.9439
[Unempl]		10.0931	29.5903	3.2	25.3
[Highschool]		21.5161	21.7939	9.2	33.8857

Table A.3: Regression results

Technology No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
c_{pot}	−13.0483 (0.00093323***)	0.000385873 (0.621647)	−33.6318 (0.000203609***)	2.60479 (0.0177963*)	−100.781 (0.000273407***)	−45.4352 (1.63913e−05***)	−13.561 (0.00306481**)	5.09665 (0.00251102**)	0 (0.960934)	−288.994 (0.000123858***)	−6.91846 (1.96099e−05***)	14.2485 (5.96046e−08***)	−77.4477 (5.50151e−05***)	−5.76001 (6.35982e−05***)	0.000237218 (0.948579)	−190.137 (0.000171602***)	−374.238 (0.00448108**)	−50.6503 (0.000524342***)	0.000184699 (0.873814)
[Inhab]	0.000214789 (0.000109553***)	0.000144416 (0.00010711***)	0.000544813 (5.96046e−08***)	1.51358e−11 (0.896584)	0.00159875 (5.96046e−08***)	0.000687387 (5.96046e−08***)	0.000229354 (5.96046e−08***)	1.53455e−06 (0.360562)	3.84227e−05 (0.0380414*)	0.00406606 (1.19209e−07***)	0.000128945 (5.96046e−08***)	0 (0.691458)	0.0012119 (5.96046e−08***)	0.000136772 (5.96046e−08***)	0.000896055 (0.000674963***)	0.00289293 (5.96046e−08***)	0.00779233 (5.96046e−08***)	0.000696247 (0.000148475***)	0.00184423 (5.96046e−08***)
[Empl]	0.0322375 (0.000209987***)	0.0933768 (0.00461352**)	5.5368e−06 (0.819097)	0.0868302 (0.000878572***)	1.93179 (0.257002)	0.240797 (0.0078699**)	6.31231e−08 (0.960934)	0.116069 (0.00125217**)	0.0342577 (0.0470748*)	0.0154781 (6.95586e−05***)	0.00518947 (0.00017947***)	0.0696943 (0.000353873***)	0.20383 (0.0272433*)	0 (0.960934)	2.42788e−05 (0.94501)	0.0284246 (0.549338)	0.247293 (0.264047)	0.0386066 (3.92795e−05***)	1.48616e−06 (0.875347)
[RandD]	0.0432459 (0.203707)	0.000109513 (0.563291)	1.06388 (0.000223279***)	1.05036 (0.0509681)	1.53794 (0.64982)	7.76247e−05 (0.54709)	1.45605 (0.000284612***)	0.225809 (1.78218e−05***)	1.54135 (7.34329e−05***)	4.32566 (8.50558e−05***)	0.0475116 (0.109682)	0.451455 (2.58088e−05***)	0 (0.960934)	0.0521431 (0.130873)	23.1056 (0.00118577**)	6.56998 (5.96046e−08***)	0.00145808 (0.837227)	0.130337 (0.150079)	0.000124524 (0.87473)
[Research-*gen*]	4.1953e−09 (0.960934)	5.28454e−09 (0.621895)	4.40225e−09 (0.819097)	1.01143e−09 (0.871788)	0 (0.960934)	0 (0.960934)	0 (0.960934)	2.15371e−10 (0.892502)	0 (0.951304)	0.0358649 (0.00018096**)	0 (0.960934)	0.000256879 (6.07967e−06***)	5.10544e−07 (0.960934)	0.000406834 (0.563084)	0.13761 (0.176787)	2.58598e−05 (0.78539)	0 (0.960934)	0 (0.960934)	1.29091e−06 (0.874424)
[Uni-Grad-*gen*]	0 (0.960934)	1.90761e−05 (0.655351)	0 (0.960934)	0 (0.960934)	8.7653e−05 (0.94501)	0.000487422 (0.656692)	0.219552 (0.355223)	2.75179e−06 (0.860639)	0 (0.951304)	4.22211e−05 (0.942416)	7.42207e−08 (0.825738)	6.22826e−08 (0.902618)	0.416053 (0.231863)	0 (0.88281)	0 (0.960934)	0 (0.960934)	2.28134e−05 (0.918443)	0.000348286 (0.823976)	2.93807e−05 (0.873511)
c	−5.71187 (5.96046e−08***)	−11.6596 (5.96046e−08***)	−6.98636 (5.96046e−08***)	−14.2105 (5.96046e−08***)	−6.44753 (5.96046e−08***)	−5.8151 (5.96046e−08***)	−4.64418 (5.96046e−08***)	−13.385 (5.96046e−08***)	−4.19215 (5.96046e−08***)	−6.09433 (5.96046e−08***)	−4.01379 (5.96046e−08***)	−7.92621 (5.96046e−08***)	−3.52696 (5.96046e−08***)	−4.00194 (4.82798e−06***)	−6.75109 (5.96046e−08***)	−4.13173 (5.96046e−08***)	−4.71784 (5.96046e−08***)	−2.73924 (5.96046e−08***)	−5.32649 (5.96046e−08***)
[Dens]	0.00044379 (0.0413128*)	0 (0.960934)	0.000349676 (0.0917769)	0.000303196 (0.491041)	0.000800363 (0.000286996***)	0.000597441 (0.000128269***)	0.000447807 (0.0470489*)	0.00073606 (0.161842)	0.000823211 (0.000144005***)	0.000588203 (0.000407338***)	0.000943554 (5.36442e−06***)	0.00158679 (1.22786e−05***)	0.000761538 (0.0010609**)	0.00105451 (5.96046e−08***)	0.000772102 (0.00230259**)	0.000753694 (1.7643e−05***)	0.000517254 (0.0151709*)	0.00109933 (5.96046e−08***)	0.000675827 (0.00014168***)
[GDP]	0.117677 (2.89679e−05***)	0.149954 (5.96046e−08***)	0.131109 (1.19209e−07***)	0.15714 (0.000118852***)	0.0514288 (0.00479817**)	0.0692482 (5.96046e−08***)	0.0437812 (0.019384*)	0.222334 (4.17233e−07***)	0.0284632 (0.206012)	0.0596858 (5.96046e−08***)	0.0891268 (2.98023e−07***)	0.146281 (5.96046e−08***)	0.0369906 (0.00726694**)	0.0886406 (5.96046e−08***)	0.0587679 (1.19209e−06***)	0.0160216 (0.0355874*)	0.0661926 (2.68221e−05***)	0.000862657 (0.823491)	0.0731456 (0.000139236***)
[Unempl]	−0.109732 (1.19209e−07***)	−0.161225 (0.000147581***)	−0.125529 (5.96046e−08***)	0.0195865 (0.727407)	−0.184395 (5.96046e−08***)	−0.14491 (5.96046e−08***)	−0.166886 (5.96046e−08***)	0 (0.960934)	−0.147644 (5.96046e−08***)	−0.127406 (5.96046e−08***)	−0.114316 (5.96046e−08***)	0.00624361 (0.378644)	−0.26526 (5.96046e−08***)	−0.253108 (5.96046e−08***)	−0.230406 (5.96046e−08***)	−0.230756 (5.96046e−08***)	−0.220494 (5.96046e−08***)	−0.278378 (5.96046e−08***)	−0.259097 (5.96046e−08***)
[Highschool]	0 (0.960934)	0.15277 (0.000888467***)	0.00302124 (0.480736)	0.148983 (0.00110352**)	0.0184668 (0.394482)	0.0181221 (0.179092)	0.0316339 (0.0953641)	0.0896996 (0.000629961***)	0.0222961 (0.156309)	0 (0.960934)	−0.0151603 (0.117669)	0 (0.960934)	−0.00489425 (0.324256)	0.0415281 (0.000112951***)	0.0389654 (0.0543255)	0.000471389 (0.86163)	−0.0245815 (0.0594433)	8.24252e−06 (0.776684)	0.0347935 (0.0155001*)
[Research-*fac*]	0.142346 (0.936843)	10.2436 (0.0224589*)	1.4447 (0.236026)	35.1531 (0.182173)	1.92877 (0.338336)	1.99451 (0.270661)	4.84021 (0.340843)	32.1855 (0.190423)	5.1374 (0.308032)	0.293553 (0.846562)	9.34021 (0.00810617**)	1.04198 (0.691458)	−9.65949 (0.755087)	5.27224e−05 (0.88264)	−32.6248 (0.123327)	2.73219 (0.461472)	5.30395e−05 (0.960934)	−14.4789 (0.232814)	0 (0.873511)
[Uni-Grad-*fac*]	183.151 (0.0685818)	582.753 (0.334966)	291.71 (0.00192773**)	2412.23 (0.00790477**)	269.436 (0.146802)	330.603 (0.0252831*)	0.00367415 (0.948579)	1222.26 (0.339111)	156.867 (0.0132227*)	−6.5584 (0.777203)	32.0642 (0.615294)	1303.79 (1.10865e−05***)	0 (0.960934)	68.0823 (0.137599)	66.8087 (0.719272)	35.7491 (0.324162)	25.4035 (0.463403)	130.776 (0.131384)	0 (0.960934)
AIC:	1153.09	660.718	1043.74	294.586	919.221	1151.2	977.504	460.37	1034.07	1367.83	1139.61	1122.04	1223.99	981.273	899.82	1442.25	1672.88	1019.75	1333.67
McFadden adj. R^2	0.163459	0.136743	0.362966	0.222164	0.399904	0.452018	0.183904	0.49166	0.377366	0.162244	0.183408	0.157498	0.154605	0.409063	0.172349	0.596822	0.1557	0.207043	0.654731