Swiss Leading House
Economics of Education • Firm Behaviour • Training Policies

Working Paper No. 117

Regional Innovation Effects of Applied Research Institutions

Curdin Pfister, Miriam Koomen, Dietmar Harhoff and Uschi Backes-Gellner

Universität Zürich
IBW – Institut für Betriebswirtschaftslehre

UNIVERSITÄT BERN

Working Paper No. 117

Regional Innovation Effects of Applied Research Institutions

Curdin Pfister, Miriam Koomen, Dietmar Harhoff and Uschi Backes-Gellner

January 2021 (first version: April 2016)

This paper was previously circulated under the title "University-Industry Knowledge Transfer: The Role of UAS in Fostering Regional Innovation" (2016).

Published as: “Regional innovation effects of applied research institutions.“ *Research Policy*, 50(2021)4. By Curdin Pfister, Miriam Koomen, Dietmar Harhoff and Uschi Backes-Gellner.

DOI: https://doi.org/10.1016/j.respol.2021.104197

Die Discussion Papers dienen einer möglichst schnellen Verbreitung von neueren Forschungsarbeiten des Leading Houses und seiner Konferenzen und Workshops. Die Beiträge liegen in alleiniger Verantwortung der Autoren und stellen nicht notwendigerweise die Meinung des Leading House dar.

Disussion Papers are intended to make results of the Leading House research or its conferences and workshops promptly available to other economists in order to encourage discussion and suggestions for revisions. The authors are solely responsible for the contents which do not necessarily represent the opinion of the Leading House.

The Swiss Leading House on Economics of Education, Firm Behavior and Training Policies is a Research Program of the Swiss State Secretariat for Education, Research, and Innovation (SERI).

www.economics-of-education.ch

Regional Innovation Effects of Applied Research Institutions

Curdin Pfister [a], Miriam Koomen [b],
Dietmar Harhoff [c], and Uschi Backes-Gellner [d, 1]

[a] *Department of Business Administration, University of Zurich and Swiss Contractors' Association*

[b] *Swiss National Bank*

[c] *Max Planck Institute for Innovation and Competition, Munich*

[d] *Department of Business Administration, University of Zurich*

[1] Corresponding author: Dietmar Harhoff

Email addresses: backes-gellner@business.uzh.ch (Plattenstrasse 14, 8032 Zürich, Switzerland) cpfister@baumeister.ch (Weinbergstrasse 49, 8042 Zürich, Switzerland), miriam.koomen@snb.ch (Börsenstrasse 15, P.O. Box, 8022 Zürich, Switzerland), dietmar.harhoff@ip.mpg.de (Marstallplatz 1, 80539 Munich, Germany).

Acknowledgements

The authors would like to thank Eric Bettinger, Bernd Fitzenberger, Simon Janssen, Fabian Gaessler, Edward Lazear, Jens Mohrenweiser, Samuel Mühlemann, Laura Rosendahl Huber, Guido Schwerdt, Dinand Webbink, Ludger Woessmann, and Conny Wunsch for helpful comments. We received further suggestions from seminar participants at University of Zurich, and participants of the conferences DRUID17 in New York, 12th European Policy for Intellectual Property (EPIP) in Bordeaux, 5th Research in VET Congress in Bern, 20th Colloquium on Personnel Economics in Zurich, 31st Congress of the European Economic Association in Geneva, XXV Conference of Association of Education Economics in Badajoz, Annual Meeting of Economics of Education Session of German Economic Association in Bern, and VET Research Congress in Basel. Furthermore, this paper benefited greatly from helpful comments by the editor, Adam Jaffe, and two anonymous reviewers.

We also thank Natalie Reid for language consulting and the Swiss Federal Statistical Office for data provision of the Survey of Higher Education Graduates (contract number 160410 Ref. 662.410-1), "Schweizer Hochschulinformationssystem" (SHIS) (contract number 160355, Ref. 660.1-1), and the Business Census (contract number 180096 Ref. 511.0- 1, used in the Online Appendix).

This study was partly funded by the Swiss State Secretariat for Education, Research and Innovation through its Leading House on the Economics of Education, Firm Behavior and Training Policies (contract number 1315000868). Harhoff acknowledges support by Deutsche Forschungsgemeinschaft (SFT/TR 190). The views expressed in this study are the authors' and do not necessarily reflect those of the Swiss National Bank or the Contractors Association or Zurich University.

Regional Innovation Effects of Applied Research Institutions

ABSTRACT

We analyze the effect of applied research institutions on regional innovation activity. Exploiting a policy reform that created tertiary education institutions conducting applied research, the Universities of Applied Sciences (UASs) in Switzerland, we apply difference-in-differences estimations to investigate their effect on innovation quantity and quality. Findings show a 6.8% increase in regional patenting activity (i.e., quantity), and an increase of patent quality of up to 9.7% (measured by patent family size, and the number of claims, and citations per patent). Findings are robust to various model specifications, suggesting that applied research taught in UASs boosts regional innovation.

Keywords: innovation, applied R&D, higher education, patents, difference-in-differences

JEL code: O33, O38, I23

1. Introduction

To foster innovation, many governments have embarked on utilizing instruments from an increasingly sophisticated policy toolbox. For example, they may attempt to shift the composition of public sector demand toward high-tech goods, establish R&D tax credits or provide public funding for venture capital (Commission of Experts for Research and Innovation, 2017). Potential justifications for such interventions are credit constraints and market failures, in particular externalities due to knowledge spillovers (Chatterji et al., 2013).

An essential instrument in the innovation policy toolbox are interventions via educational policies, such as the creation of new universities. The number of studies examining the effects of universities on national and regional innovation has been growing considerably in recent years. Jaffe's (1989) pioneering study on "the real effects of academic research" analyzed the innovation effects of university research. Since then, numerous researchers have investigated the role played by major centers of academic research and education in enhancing a country's innovation activities (e.g., Audretsch and Stephan, 1996; Cowan and Zinovyeva, 2013; Mansfield and Lee, 1996; Saxenian, 2000). More recently, some studies have also successfully addressed endogeneity problems and identified causal effects of government policies such as educational expansions (e.g., Andersson, Quigley, and Wilhelmsson, 2009; Toivanen and Väänanen, 2016; Valero and Van Reenen, 2016).

However, two issues remain unresolved to date. First, the literature has mainly examined the innovation effects of universities that predominantly focus on basic research (e.g., Rosenberg and Nelson, 1994) and recruit students from academic tracks (i.e., high schools). Institutions that conduct and teach applied research, and that recruit students from vocational education pathways—with labor market experience and solid professional knowledge—have not been analyzed yet. Second, regional heterogeneity in innovation activities can be substantial. Thus, what works for the major innovation centers, which often draw upon many top-ranked academic research institutions and large research-intensive companies, might not work for other types of regions. Whether the implementation of institutions focusing on applied research and education can drive innovation activities in regions outside of major centers of commercial innovation remains largely unknown. But given their focus on applied research and the strong role that small and medium-sized enterprises (SMEs) may have in such regions, reliable evidence is urgently required.

This paper directly tackles these two issues by investigating the effect of the establishment of applied research institutions on regional innovation activities. To do so, we exploit an educational policy intervention in Switzerland in the mid-1990s, the establishment of Universities of Applied Sciences (UASs[1]). According to their legal mandate, UASs must (a) focus their research and teaching on applying scientific methods and knowledge, (b) collaborate with firms when conducting their research, and (c) collaborate with other research-oriented institutions, including both academic universities and other UASs. Because UASs were created and funded to both conduct and teach applied research, their establishment allows us to estimate the effects of applied research on innovation activities.

We study the effect of the establishment of UASs and the supply shock in applied research that it generated on regional innovation activities by using a difference-in-differences (DiD) approach which allows us to compare treated regions (with newly established UASs) to untreated regions (with no UASs). Identification using DiD requires both the treated and the untreated regions to have parallel trends before the UAS establishment took place: We investigate this assumption and

[1] "Universities of Applied Sciences" is used for Swiss institutions called "Fachhochschulen" or for German institutions that are historically called "Fachhochschulen" and more recently "Hochschulen für angewandte Wissenschaften (HAW)". We use the abbreviation UASs for Universities of Applied Sciences, plural, and UAS for University of Applied Sciences, singular.

find strong empirical support for it. To determine whether a region is treated or untreated, we first discuss the possible mechanisms through which a UAS affects the region's innovation activities. Second, using the distance and travel time from each municipality to the closest UAS, we define the geographical area in which these mechanisms are likely to appear.

To measure innovation effects, we use patent data, which provides us with comprehensive information on the emergence of new technologies (Nagaoka, Motohashi, and Goto, 2010; Giuri et al., 2007). From administrative records of the European Patent Office (EPO) we obtain data on the location of applicants and inventors to determine the geographic origin of inventions. From these data we compute the number of patent applications in the respective region.

A large literature has established that patents are highly heterogeneous in terms of their value. (e.g., Scherer, 1965; Griliches, 1979, 1990; Harhoff et al., 1999; Scherer and Harhoff, 2000; Acs et al., 2002; Giuri et al., 2007). A simple analysis of patent quantity could therefore be misleading. Estimating the effect of the establishment of UASs on patent quality requires further measures. We test if the grant rate has been affected as well, and we make use of information on forward citations, number of claims and size of the international patent family to assess patent quality. These have been shown to be positively correlated with the monetary value of patents (e.g., Trajtenberg, 1990; Putnam, 1996; Harhoff et al., 2003; Hall, Jaffe, and Trajtenberg, 2005).

Our empirical results show an increase in both the quantity and the quality of innovation activities after the establishment of UASs: In our baseline econometric models (see Table 6), we estimate an increase of 6.8% in regional patenting activity due to the introduction of UASs. Depending on the quality indicator we use, we measure an increase in the quality of regional patents of up to of 9.7%. Several robustness checks show that our estimated effect on innovation is highly robust, sets in a couple of years after the establishment of a UAS and increases over time. To test whether our effects may only stem from economically stronger and thus more powerful regions, which could have influenced the UAS establishment decision in their favor, we exclude the largest cities from our sample and find that results remain unchanged. These results clearly indicate that economic powerful regions do not drive our results. To test whether the innovation effects of UASs may largely be driven by large R&D-intensive firms, we eliminate firms with large patent portfolios from our estimations and find that the effect remains strong. To also test whether UASs have an effect at the extensive margin of patent applicants, i.e., the number of first-time applicants (and not just at the intensive margin, i.e., the number of inventors with already existing patents) we re-estimate our baseline model by using first-time applicants as our dependent variable. We find that the establishment of UASs increases first-time applicants by more than 3 percent. Thus, our estimated innovation effect is neither only driven by already R&D-intensive firms nor by firms which already have a record of patenting activity. The effect is for a substantial part also driven by inventors patenting for the first time.

To tackle the question of the relative importance of the newly established applied research institutions in comparison to traditional universities with their focus on basic research we provide additional analyses on student expansions in our robustness checks section. Unlike UAS, which were growing at the extensive margin, traditional universities only grew at the intensive margin. The increase in the number of students at traditional universities was not only substantial, but also varied significantly across regions and time. Exploiting this variation, we provide an estimate of the relative importance of a change of the number of students in applied research universities in comparison to a change of the number of students in traditional research universities. Our results clearly indicate that the effect of an increase in UAS students is much larger than that of traditional research university students, at least in the given educational landscape at the time. Although results are far from final, they provide a clear indication of the relative importance of applied research universities in addition to traditional research universities. For higher education policies, these results suggest that given a foundation of well-established research universities it could be worthwhile to complement these traditional research universities with applied research universities, and to bring together the advantages of solid vocational knowledge with applied research knowledge.

For national or regional innovation policy makers, our results also suggest that the establishment of applied research and higher education institutions helps fostering regional innovation by spreading innovation activities to areas outside major innovation centers, often through more traditional and small or medium-sized firms. The UASs intensify applied research and innovation in these enterprises by providing graduates who combine thorough vocational knowledge (acquired through mandatory pre-UAS apprenticeships) with applied research skills.

The remainder of the paper proceeds as follows. Section 2 presents the institutional background and outlines the Swiss education system. Section 3 explains how we created and prepared the data. Section 4 describes our empirical strategy, and Section 5 shows the results. Section 6 provides a number of robustness checks, and Section 7 discusses the findings and concludes.

2. Institutional Background

Before the UAS reform and the resulting establishment of UASs in the 1990s, the higher education system in Switzerland was essentially built upon two pillars: (a) 10 cantonal[2] and two federal universities that together served approximately 10% of the country's population as students, and (b) professional vocational education and training (PVET) institutions for approximately 15%

[2] Switzerland comprises 26 cantons, which are similar to U.S. states (see http://www.bfs.admin.ch/bfs/portal/de/index/regionen/11/geo/institutionelle_gliederungen/01b.html).

of the population.[3] This situation changed structurally with the establishment of UASs, as a result of a policy reform aimed at revitalizing and strengthening the Swiss economy.[4] The Swiss federal government's decision to establish UASs throughout the country aimed at providing apprenticeship graduates from the dual vocational education and training system (VET) with an academic career perspective by offering them an opportunity to earn a three-year bachelor's degree in addition to their apprenticeship degree.

To support innovation by UASs, educational policy makers gave UASs a legal mandate, which required them to conduct and teach applied R&D and to provide related services to, and collaborate with, public or private sector firms (or both).[5] The underlying idea was that UASs should provide

[3] The Swiss education system had and still has both an academic and a vocational track at the upper secondary and at tertiary levels. The large majority of Swiss students (about two thirds of the youth cohorts) follow the vocational track completing an apprenticeship and receiving a nationally recognized certificate, which grants access to tertiary level vocational institutions. Before the establishment of UASs these were two pathways: Professional Education and Training (PET) Colleges, and (Advanced) Federal Professional Education and Training Exams (e.g., SCCRE, 2007, 2010, and 2014). These institutions allow vocational graduates to acquire formal, continuous training, but they did not have a legal mandate to conduct research (Bereuter, 2011; EFHK, 2000). The establishment of UASs opened a third pathway in institutions with a legal mandate to conduct research.

[4] For further information about the reform, see Schweizerischer Bundesrat (1994, 2009), OPET (2009), Bundesgesetz Fachhochschulen 1995, Bundesgesetz HFKG 2011, EFHK (2000, 2002), Kiener (2013), Projektgruppe Bund-Kantone Hochschullandschaft 2008 (2004), or Weber and Tremel (2010).

[5] UAS campuses were partly remodeled Professional Education and Training Colleges (vocational institutions at tertiary level). However, they all became new legal mandates that for the first time included conducting and focusing on applied research and development. During the UAS establishment process, more than 70% of the campuses underwent substantial structural changes (such as relocations of campuses or relocation and change of subject areas).

a steady supply of highly skilled individuals with both practical and scientific knowledge,[6] thereby fostering the direct transfer of knowledge and technology between the research institutions and public or private sector firms that could profit from that knowledge and technology (see SBFI, 2015, or Schweizerischer Bundesrat, 1994).

In terms of research, UASs are legally required to adhere to the practical needs of Swiss firms and to focus on applied research and development projects and public services. UAS teaching therefore combines practical expertise, theoretical skills, and R&D-related experience.[7] In contrast, the traditional academic universities perform basic research, provide academic training, and are expected to compete internationally in terms of scientific output. Their curricula concentrate on theory and abstract conceptual knowledge (see, e.g., Kiener, 2013; Projektgruppe Bund-Kantone Hochschullandschaft 2008, 2004; Schweizerischer Bundesrat, 1994).

Although fields of study may overlap between universities and UASs—e.g., engineering, business administration, and chemistry—and graduates may end up in very similar occupations and jobs, their educational careers differ substantially. While students in Swiss academic universities come directly from college preparatory high schools (known as "Gymnasium" or

[6] The number of UAS graduates increased constantly from approximately 2,000 in year 2000 to almost 10,000 in year 2008 (SFSO/SHIS – Studierende und Abschlüsse der Hochschulen, 2019). In 2016/2017, the Bern UAS had 1,606 first-year students, the UAS of Eastern Switzerland 1,352, the UAS of Zurich 3,911, the UAS of Central Switzerland 1,462, and the UAS of Northwestern Switzerland 2,205. The UAS in the French speaking area had 5,540 first-year students, the UAS in the Italian speaking area 1,089 in 2016/2017 (SFSO/SHIS, Studierende und Abschlüsse der Hochschulen, 2019).

[7] UAS professors are required to have a university degree (of a UAS, an academic university, or a Federal Institute of Technology (ETH)) and, generally, a PhD, sufficient labor market experience in the respective field, as well as research and didactical competences (Swiss Science and Technology Council, 2010). They thus have a combination of (academic) research skills and practical skills from the private economy.

Baccalaureate schools), UAS students usually come from a dual VET system apprenticeship, which involves both classroom education and practical training, including work experience at a training firm. In addition, while students from both the academic university and the UAS track may study the same field (e.g., engineering), the academic group focuses on the abstract and theoretical aspects of the subject, whereas the UAS group focuses on the application of theoretical knowledge to the more short-term needs of firms and markets. Therefore, the second group often collaborates with local firms, including small and medium-sized enterprises (SMEs). The reform thus added a new type of higher education institution, with a clear focus on conducting and teaching applied research, to the traditional university sector, which maintained its basic academic research and general scientific training (see, e.g., Schultheiss et al., 2019).

To estimate the effect of the UAS reform on innovation quantity and quality, we exploit the variation in the establishment of UAS campuses across location and time. The variation emerged historically as a result of the Swiss political system. The federal government—the political authority that decides on whether to confer accreditation—did more than simply require the fulfillment of core characteristics (the legal mandates of teaching, services, collaboration, and applied R&D). It also restricted the maximum number of UASs, required a regional distribution that gave apprenticeship-trained individuals equal access to UASs throughout Switzerland, and consolidated existing (and new) UAS campuses to ensure a sufficiently large size and solid financial base. These federal location decisions provoked heated political discussions among cantons—the political unit that carried the main financial burden of the UASs—about the location of UASs and their campuses. In addition, the requirements for consolidating UAS campuses and programs led to political trench warfare between—and even within—cantons. The restrictions and the resulting debate thus led not only to the establishment of new campuses and the relocation and closing down of old ones, but also to time delays in the establishment of some UASs.

By extensively analyzing these decision processes for all newly established UAS we come to the conclusion that the location and timing is quasi-random. We analyzed the large number of documents and reports of all relevant stakeholders (e.g. the federal, cantonal, and municipal governments, the UAS-Commission, UAS councils, employer organizations, etc.), which in total amounted to more than 1,000 pages. In addition, we used chronicles and official bulletins (including almost 40 documents) and studied articles from newspapers for the relevant period (more than 100 articles from 16 different newspapers). We complemented our analysis with further sources, such as the webpages of all UAS and the UAS annual reports (more than 1,200 pages), as well as official statements and position papers of the relevant stakeholders (more than 500 pages), and documents on the legislation process[8].

Based on a thorough analysis of all these documents, it is safe to conclude that the establishment of a particular campus at a given point in time is primarily a result of a political trench warfare (between and within the cantons), micro politics, package deals and concessions with any other deals, historical coincidences, and personalities.[9] Given that this development was highly driven by political factors, the decision of where and when a UAS campus was to be established was hardly foreseeable and remained open until the very end of the process—and was therefore not likely related to already existing innovation activities. Thus, the timing and location of UAS campuses appear related more to political factors and all kinds of coalition building rather than to

[8] These documents include intercantonal agreements, i.e. contracts between cantons required by the federal system to regulate the legal basis, interpellations, and federal and cantonal laws.

[9] Pfister (2017, chapter 2.2) provides a detailed analysis of the process through which the establishment of UASs was determined. The analysis is available at http://tiny.uzh.ch/Pd

underlying differences in economic, technical, or innovative factors.[10] It is thus unlikely that this variety of factors would be consistently correlated with innovation potential, and the common trends tests support our assumption as well.

3. Data

3.1. Definition of Treatment and Control Groups

The establishment of the UASs was staggered, with the first campuses opening in 1997 and the last in 2003.[11] For our analysis, we use the establishment of all UAS campuses with programs in engineering, IT, chemistry, and the life sciences, because these particular fields are the most likely to have an effect on innovation as measured by patents. Moreover, these fields have been used in previous studies on similar topics (e.g., Toivanen and Väänänen, 2016; Schartinger, Rammer, Fischer, and Fröhlich, 2002). We restrict our analysis to the German-speaking part of Switzerland, which has a long tradition in training apprentices and, therefore, the highest share of individuals following the vocational track.[12] The German-speaking part constitutes of about two-thirds of the

[10] We thus proceed similarly to Che and Zhang (2018) who exploit a natural experiment—the expansion of higher education in China in the late 1990s—and apply difference-in-differences estimations (to analyze the effect of human capital on productivity). Similarly, Salinas, and Solé-Ollé (2018) apply the difference-in-differences method to analyze the effect of decentralization policies on educational outcomes in Spain.

[11] Similar to the University of California system, which comprises over 10 university campuses such as Berkeley in the north and UCLA in the south, the Swiss UAS's also constitute a system of campuses spread throughout different regions of Switzerland. We reconstruct the history of all UAS and their campuses and focus on these campuses, as the federal government accredited each UAS campus individually.

[12] Language and culture among the German-speaking part of Switzerland (i.e., the Northeast of Switzerland) and the Latin parts of Switzerland (i.e., the French-speaking part in the West, the Italian-speaking part in the South, and the Romansh-speaking part in the East) differ substantially (Eugster et al., 2011; Funk and Gathmann, 2013). So does

economy of Switzerland. Figure 1 shows the 15 UAS campuses that were newly established between 1997 and 2003. Table 1 provides an overview of the locations and their years of establishment.

Table 1 The UASs, the location of their campuses, and the year of establishment

University of Applied Sciences	Location of Campuses	Year of establishment
Bern University of Applied Sciences	Bern	1997-2003[13]
	Burgdorf	1997
	Biel	1997
University of Applied Sciences of Eastern Switzerland	St. Gallen	2000
	Rapperswil	2001
	Buchs	2001
	Chur	2000
University of Applied Sciences of Zurich	Winterthur	1998
	Wädenswil	1998
	Zürich	1998
University of Applied Sciences of Central Switzerland	Horw	1997
University of Applied Sciences of Northwestern Switzerland	Oensingen	1998-2003
	Olten	2003-2006
	Brugg-Windisch	1998
	Muttenz	1997

Source: Authors' illustration, based on Schweizerischer Bundesrat (1994), Bundesgesetz Fachhochschulen (1995), EFHK (2000, 2002), Kiener (2013), articles from local newspapers, and interim reports.

Our definition of whether a municipality was treated or untreated by the UAS reform builds on a commonly accepted finding in innovation and urban economics: Knowledge spillovers and innovation are spatially concentrated and geographically localized (Feldman and Kogler, 2010;

the distribution of firms that train apprentices (Backes-Gellner et al., 2017). We therefore focus on the German-speaking part of Switzerland, in which vocational education has much stronger roots.

[13] The campus in Bern opened its doors in 1997. Due to relocation and concentration processes imposed by the federal government, the campus closed its doors in 2003. The same applies to Oensingen and Olten (Northwestern-Switzerland).

Moretti, 2011).[14] A sizable and growing literature stream within these fields investigates the role of universities in generating and fostering such regional innovation clusters (Bonander et al., 2016; Drucker and Goldstein, 2007; Liu, 2015). This literature suggests that universities affect regional innovation (and other economic outcomes such as productivity, growth, and entrepreneurial activity) not only by producing (basic) research, but also by generating direct and indirect spillovers (Liu, 2015).[15] Direct spillovers result from the interaction between universities and firms, and from graduates entering the local labor market, remaining in it, and enhancing its quality (Lehnert et al., 2020). Indirect spillovers arise from agglomeration economies, i.e., the benefits or increasing returns accruing from nearby resources, such as firms or skilled people (Feldman and Audretsch, 1999; Glaeser, 2010; Glaeser et al., 2003; Schlegel et al., 2019).

Both types of spillovers are sensitive to geographical distance, because proximity implies lower costs (Feldman and Kogler, 2010; Moretti, 2011). Moreover, tacit knowledge—a fundamental driver of these spillovers—is regionally embedded (Feldman and Kogler, 2010; Lundvall and Johnson, 1994; Maskell and Malmberg, 1999). Given the non-codifiable nature of tacit knowledge, its transfer therefore requires "face-to-face exchange, routines, habits and norms, conventions of communication and interaction" (Feldman and Kogler, 2010, p. 389).[16] This sensitivity to distance

[14] See e.g. Rosenthal and Strange (2008) who find that human capital externalities, with respect to e.g. productivity, are spatially concentrated.

[15] See, e.g., Helmers and Overman (2017) who find that scientific research is geographically distributed within a radius of 25 km.

[16] Carlino et al. (2007) review, amongst others, the studies by Andersson, Burgess, and Lane (2007), Anselin, Varga, and Acs (1997), Audretsch and Feldman (1996), Jaffe, Trajtenberg, and Henderson (1993), and Rosenthal and Strange (2001), and conclude that spillovers are highly localized, i.e., at the ZIP code level or within metropolitan areas. Such spillovers might include co-agglomeration of invention (see, e.g., Forman et al., 2016). Andersson et al.

implies that the effects of a UAS campus on the economy should be geographically restricted. We are therefore able to identify this local effect by defining the area of influence of a UAS campus, its catchment area.

To define this UAS catchment area, we focus on the first form of direct spillovers, UAS graduates—highly skilled individuals who enter a labor market, remain in it, and improve its quality. These graduates are likely to enhance the quality of labor market supply because they possess a new type of human capital that includes vocational and academic education, and that particularly focuses on applied research and development and on the transfer of scientific knowledge into practice. Assuming that these UAS graduates have a low mobility (i.e., rarely relocating or going for very long commutes), we are able to localize their effect on regional innovation. Such stable mobility behavior involves two factors: (a) potential UAS students studying at a UAS campus nearby and (b) UAS graduates staying in the area in which they completed their studies. In Section 6, Robustness Checks, which analyzes the question of potential contamination due to different forms of mobility of UAS graduates, we show that UAS graduates exhibit very low levels of mobility after graduation. The assumption of limited mobility is therefore very plausible.[17]

(2009), exploiting a natural experiment of decentralization of higher education in Sweden, find highly localized creativity and productivity effects.

[17] The large majority of UAS graduates continue living in the same area where they graduated five years earlier (see 2.6 Robustness Checks in Pfister, 2017). The relocating behavior of potential UAS students is likely to be even lower, as previous regional studies using Swiss data show that young adults exhibit a very low level of mobility (e.g., Muehlemann, Ryan and Wolter, 2013; Muehlemann and Wolter, 2011). Thus, contamination due to potential UAS students' relocating from the control group to the treatment group is very unlikely.

The low mobility of UAS graduates allows us to measure the local effect of a UAS campus. To limit the area in which such a local effect appears, we focus on the distance between the place where UAS graduates live and the place where they work. In other words, in line with previous regional studies[18], we define the optimal size of a UAS catchment area by focusing on the commuting patterns of individuals living in Switzerland: travel distance, travel time, and typical commuting behavior. The city in which the campus is located thereby constitutes the center of the catchment area.[19] The appropriate distance from the UAS campus to the border of the catchment area is based on empirical evidence of commuting patterns from the mobility and transport microcensus (SFSO/ARE, 2007) of those individuals living in that area. This representative survey shows the typical commuting behavior in 2005: almost 90% of employed individuals living in Switzerland commute less than 25 km (approximately 15 miles) from home to work.[20]

[18] For Switzerland, Muehlemannn, Ryan, and Wolter (2013) and Muehlemann and Wolter (2011) specify local labor markets by using commuting information. They argue that political borders are inappropriate for defining a region of economic activity in Switzerland because cantons—the largest political level—are too small. In addition, given Switzerland's numerous mountains and lakes, calculating travel distances using coordinates is misleading. They therefore calculate travel times using automobile route guidance systems from the 67 largest Swiss cities and towns to the surrounding municipalities. Their travel limit, which relies on Swiss census information from 2000, equals 30 minutes.

[19] Section 6, Robustness Checks, also analyzes the potential contamination due to UAS graduates commuting not to the center of the catchment area but to another direction. The results show that such contamination does not affect our results.

[20] The low mobility of Swiss citizens may surprise US observers, but can be demonstrated using various data sources. Swiss youth in vocational training seek initial jobs close to their parental homes. Moreover, the locations of their UAS and their employers after graduation are in close regional proximity. To arrive at 25 km for our treatment definition, we use a representative survey that concentrates on the end of our observation period because commuting

We therefore define a municipality as a "treated region" if it is located within 25 kilometers of a UAS campus.[21] Because a linear distance measure may be distorted by the unique Swiss topography, we use the actual travel distance as measured by geo-statistical data (SFSO, GEOSTAT 2007).[22] This data provides information on the actual travel distance (in car kilometers) rather than the linear distance between all Swiss municipalities. Figure 1 shows the catchment area for the UAS campus in St. Gallen as an example.

This definition of the UAS catchment area means that we compare the treatment group—the "treated regions" consisting of all municipalities within a 25-kilometer radius around a UAS campus—with the control group, the "untreated regions" (i.e., all other regions). Given that we rely on empirical evidence of commuting behavior, we measure the effect of the first form of direct spillovers explained in this section: highly skilled UAS graduates entering the labor market, remaining in it, and enhancing its quality.

This definition of the UAS catchment area might also measure the second form of direct spillovers (interaction between UASs and firms) and indirect spillovers (agglomeration economies), because these forms of spillovers appear locally (Liu, 2015). However, disentangling the different spillovers is beyond the scope of this study. For example, whether interaction between

---

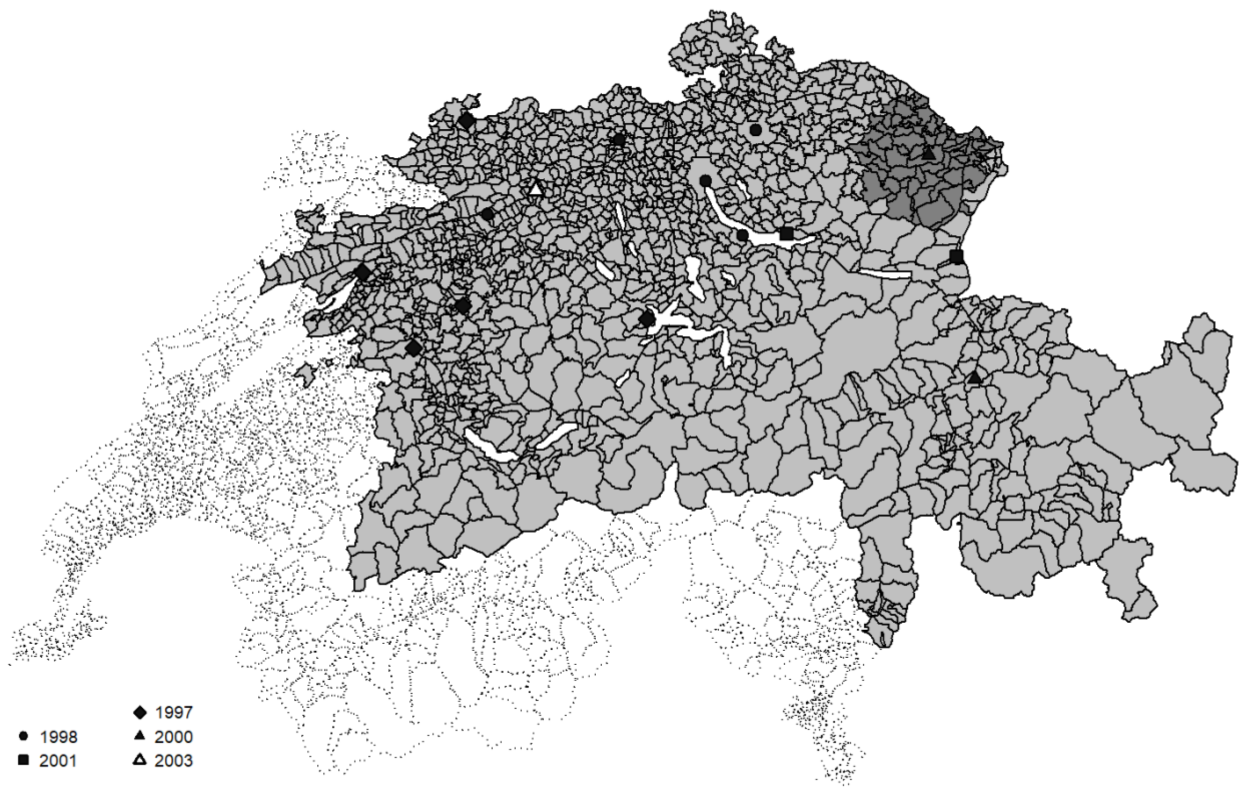
behavior increased between 1990 and 2008: In 1990, 96% of employed individuals living in Switzerland had a commute of 25 kilometers or less, and 94% a commute of 45 minutes or less (SFSO, 1997).

[21] If a municipality is located within two UAS catchment areas, it is classified according the closest UAS campus.

[22] The mobility and transport microcensus (SFSO/ARE, 2007) shows that 90% of employed individuals have a commute of 45 minutes or less. To test the robustness of our measure, we use "travel time," which we calculate using the respective Google application programming interface. We thus follow Belenzon and Schankerman (2013), who used Google Maps to calculate their geographic distance measures. The results Pfister (2017) show that our definition of the UAS catchment area well represents the region in which 90% of Swiss people regularly commute.

UASs and firms is sensitive to distance remains unclear. As the exploitation rights of inventions generated by such interaction are not regulated, collaboration between UASs and firms does not appear in the patent database.[23] Consequently, calculating the distance between UASs and firms is not possible.

Figure 1 Locations of all UAS campuses in German-speaking part of Switzerland and catchment area for the campus in St. Gallen as example



Source: Authors' calculations, based on Grenzen 2016, SFSO GEOSTAT / swisstopo and on SFSO GEOSTAT, 2007.

Note: German speaking part of Switzerland depicted in grey, French and Italian speaking parts of Switzerland (not part of the data) are depicted in white.

[23] UASs might not appear in the patent database as a firm's collaboration partner because many of them do not pursue a patent portfolio strategy. Thus, while universities and federal institutes of technology never assign the complete intellectual property rights to the cooperating firm, a large percentage of UAS do (Hotz-Hart, 2010).

Nevertheless, we try to investigate these different spillovers separately: In Section 6, Robustness Checks, we focus on UAS graduates entering the labor market and show that a large part of the innovation effect is related to these graduates. However, a substantial percentage of the innovation effect remains unexplained and is therefore not attributable to this type of direct spillovers. Therefore, collaboration between UASs and firms, and agglomeration economies might constitute further important spillovers of UASs.

3.2. Patent Data

To measure patenting activity, we use patent data from the PATSTAT Worldwide Patent Statistical Database, which is publicly available from the European Patent Office (EPO). The most recent (2020) version of the database contains data on more than one million patent applications with at least one inventor in Switzerland) from 1888 through 2019, provides information about the filing dates and the inventors' and applicants' names, affiliations, and addresses.

We wish to analyze if the presence of UASs leads to an increase in inventive activity. To capture inventions broadly, the relevant units of analysis are patent families that have at least one patent filing with inventors located in Switzerland. The patent families identified by us usually include at least one Swiss national patent, or a filing at the European Patent Office or a PCT filing. In our analysis, we also take the size of the patent family and the grant status of the filings into account and interpret them as measures of invention quality. We use the priority year as an approximation for the year of invention. For the period between 1990 and 2008, we identify 300,243 patent applications and 80,722 priority filings. We then use our data to extract the ZIP codes for applicant and inventor locations.[24] Data for locations identified by ZIP codes are then aggregated at the level of municipalities (which are or are not in the catchment areas, depending on the distance rule we apply). Our dataset used in the regressions then has 27,365 entries (19 years, 1435 municipalities).

To localize a patent's geographic origin, we use the applicant's address, which we consider most relevant as employment location for former UAS graduates and for receiving knowledge spillovers. However, we conduct a robustness test using inventor location information as well.[25] We assign each patent application to the applicant's municipality, Switzerland's smallest political unit.[26] Whenever applicant information is not available, we use the locations of inventors to approximate

[24] For the 80,722 priority filings in our sample, we are able to identify applicant and inventor address information in 51,267 cases. In 21,953 cases we only have inventor location data (including cases where the inventor is the applicant), and in 7,502 cases only applicant information.

[25] See Table A8. Using inventor address locations, we find slightly stronger statistical results. For each of our dependent variables, the significance levels and effect sizes are maintained or improved. We chose to use the more conservative results based on applicant location information in all analyses presented in the body of the paper.

[26] Switzerland has approximately 2,300 municipalities, 148 districts, and 26 cantons. Each municipality generally includes several ZIP codes. Overall, Switzerland has about 3,500 ZIP codes.

the relevant location. In cases with multiple locations (e.g., due to several inventors or applicants) we use fractional weights to compute the local counts of filings, citations etc.[27]

To construct our outcome variable "regional patenting activity," we take the sum of priority patent applications by priority year and by treated vs untreated regions. We choose 1990 as our first year of observation, because the creation of the UASs started in 1997, and we want to ensure a sufficiently long pre-treatment period for testing the common trends assumption. We end our observation period in 2008 because in that year some UASs started to introduce Master's level programs, possibly causing additional effects on patenting activity and the potential for systematic biases across UASs.

To create our outcome measures for patent quality, we use the following quality indicators that approximate different aspects of value (e.g., Squicciarini et al., 2013): *the number of forward citations, the number of claims (both in US and EPO filings),* and *the size of the international patent family*.[28] We also analyze the number of granted patents relative to the number of filings (grant rate).

[27] We link these to location information in 1,435 municipalities of which 1,043 were treated at some point. The share of treated municipalities is 26% in 1997, increasing to 45% in 1998 and to 73% in 2003. Due to relocations and concentrations of UAS campuses, the share decreases to 68% in 2004 and to 60% in 2006.

[28] We compute these statistics from the PATSTAT database. As g*ranted patents* fulfill the patentability criteria (inventive step, novelty, and industrial applicability), they are usually technologically and economically more valuable than unsuccessful applications. However, as a large percentage of applications are granted, the indicator is not very informative (OECD, 2009). *Forward Citations* refer to the number of citations a patent receives in later patents. The literature provides empirical evidence that the more a patent is cited, the more valuable it is for the owner (higher private economic value for the patent holder) (e.g., Hall et al., 2005; Harhoff et al., 1999), and for those not holding the patent (higher social value) (Trajtenberg, 1990). However, although the number of forward citations is correlated with the economic value of a patent, the relationship is noisy (Harhoff et al., 1999). Empirical evidence shows that

The PATSTAT database contains a binary variable indicating whether a patent application was granted. We take this variable to compute our qualitative indicator *grant rate*. The indicator *forward citations* includes the number of citations for each patent application. Since citation practice differs between patent offices, we use the citations as recorded by the European Patent Office. We use a five-year citation lag and alternatively a three-year lag between the application date of the cited patent and the application date of the citing patent.[29]

To create the indicator *number of claims*, we use the number of claims in the latest publication of the respective application. Finally, the indicator *patent family size* refers to a variable that indicates the number of jurisdictions in which applications were filed to protect the invention. As foreign patent filings are relatively expensive due to translations, office fees and patent attorney costs, the latter variable reflects the applicant's assessment of the patent's value.

Table 2 provides descriptive statistics for the regional patent quantity and quality measures for our treated and untreated regions before and after the establishment of UASs in absolute numbers, and Table 3 provides the respective trends. To obtain the trend results in Table 3, the variables were transformed to logarithms and regressed on a continuous year variable. The DID effect of the share of municipalities having a patent—the difference before and after the establishment and

---

patent value positively correlates with the *number of claims* in a patent application. For valuable inventions, patent attorneys will attempt to have patent protection on multiple aspects of the inventions, which is reflected in a larger number of claims (e.g., Lanjouw and Schankerman, 2004). Finally, we consider *patent family size*, i.e., the number of countries in which the applicant seeks protection for the invention (Harhoff et al., 2003; Lanjouw and Schankerman, 2001; Schmoch, Grupp, Mannsbart, and Schwitalla, 1988; Putnam 1996).

[29] One problem with using *forward citations* is the timeliness of the measure. As the citations that a patent receives occur over time, the indicator is censored to the right. Limiting the citation lag to a specific number of years solves the problem of timeliness (OECD, 2009). Most studies usually use a lag of five year, as more than 50% of citations arise within this period (Gambardella et al., 2008; Lanjouw and Schankerman, 2004; OECD, 2009).

between the treatment and control groups—is positive and significant. We analyze the trends further in section 4.2.

Table 2 Descriptive statistics for quantity and quality indicators

		Untreated regions				Treated regions			
	Variable	Mean	SD	Min.	Max	Mean	SD	Min.	Max
Before the UAS establishment	no of priority filings	0.65	2.87	0.00	43.17	2.19	16.73	0.00	503.33
	av. grant rate	0.10	0.23	0.00	1.00	0.17	0.28	0.00	1.00
	av. citations (3 year citation lag)	0.08	0.50	0.00	20.00	0.15	0.58	0.00	25.00
	av. citations (5 year citation lag)	0.17	0.97	0.00	43.00	0.31	0.97	0.00	31.00
	av. claims USPTO	1.21	5.54	0.00	171.00	2.17	5.68	0.00	95.61
	av. claims EPO	1.29	3.77	0.00	35.00	2.45	5.17	0.00	89.00
	av. family size	0.81	2.27	0.00	44.00	1.50	2.88	0.00	61.00
After the UAS establishment	no of priority filings	0.95	4.09	0.00	62.00	3.32	23.61	0.00	785.76
	av. grant rate	0.09	0.20	0.00	1.00	0.15	0.24	0.00	1.00
	av. citations (3 year citation lag)	0.14	0.61	0.00	15.00	0.25	0.75	0.00	14.00
	av. citations (5 year citation lag)	0.27	1.01	0.00	22.00	0.50	1.39	0.00	36.00
	av. claims USPTO	1.25	4.52	0.00	50.87	2.40	5.78	0.00	78.00
	av. claims EPO	1.77	4.72	0.00	49.00	3.10	5.77	0.00	85.00
	av. family size	0.96	2.51	0.00	43.00	1.84	3.15	0.00	41.00
	Number of Municipalities	392				1043			

Note: Descriptive statistics show values at the municipality level. The share of municipalities having at least one patent in the control group equals 17.95% before and 18.62% after the establishment of UASs; the share in the treatment group equals 30.12% before and 31.89% after the establishment. The DID effect of the establishment of UASs on the share of municipalities having at least one patent—i.e., the differences before and after the establishment and between the treatment and control groups—is positive and significant.

Table 3 Descriptive statistics for quantity and quality indicators – average trends

		Untreated regions		Treated regions	
	Variable	Average trend in percent	Std. Err.	Average trend in percent	Std. Err.
Before the UAS establishment	no of priority filings	0.0141***	(0.0029)	0.0179***	(0.0022)
	av. grant ratio	0.0027**	(0.0011)	0.0032***	(0.0008)
	av. citations (3 year citation lag)	0.0033**	(0.0015)	0.0063***	(0.0012)
	av. citations (5 year citation lag)	0.0062***	(0.0022)	0.0106***	(0.0017)
	av. claims USPTO	0.0134***	(0.0048)	0.0146***	(0.0040)
	av. claims EPO	0.0073	(0.0056)	0.0183***	(0.0041)
	av. family size	0.0099**	(0.0042)	0.0142***	(0.0031)
After the UAS establishment	no of priority filings	0.0035*	(0.0019)	0.0068***	(0.0016)
	av. grant ratio	-0.0004	(0.0007)	-0.0011**	(0.0005)
	av. citations (3 year citation lag)	0.0041***	(0.0012)	0.0066***	(0.0010)
	av. citations (5 year citation lag)	0.0054***	(0.0016)	0.0109***	(0.0013)
	av. claims USPTO	-0.0006	(0.0033)	0.0038	(0.0025)
	av. claims EPO	-0.0020	(0.0036)	0.0051*	(0.0027)
	av. family size	0.0022	(0.0025)	0.0077***	(0.0020)
	Number of Municipalities	392		1043	

Note: * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level. Regressions of ln(1+outcome variable) on the continuous year variable yield the average changes for the treatment and the control groups and for the periods before and after the UAS creation. The trends of the treatment and the control groups before the reform do not show a statistically significant difference (see section 4).

4. Empirical Framework

4.1. Difference-in-Differences Estimation

To analyze the effect of the establishment of UASs on regional patenting quantity and quality, we use a DiD[31] approach and estimate the following equation:

$$(1) \qquad Y_{jt} = \alpha + \beta Treatment_{jt} + \gamma_t + \delta TG_j + \lambda_k + \varepsilon_{jt}$$

Our dependent variable *Y* includes our set of indicators for patent quantity and quality in municipality *j* in year *t+3*. First, the variable $ln(1+no\ of\ priority\ filings_{jt+3})$, our quantitative measure, refers to the natural logarithm[32] of the number of patent applications three years after the

[31] The DiD technique is particularly appropriate for measuring changes in patent quantity and quality, for two reasons. First, finding a correct and meaningful benchmark, a problem usually found in studies analyzing effects on patent indicators, is not an issue in our study (Squicciarini et al., 2013; OECD, 2009). The DiD approach estimates changes in patent quantity and quality in the treatment group relative to the control group. As the results show changes relative to the control group, the interpretation is therefore straightforward. Second, estimating changes in patent indicators over time might lead to biased results: Factors unrelated to inventive or economic characteristics (e.g., changes in patent legislation or changes in the measurement technique of the indicators; see, e.g., Harhoff, 2016) might lead to misleading estimation outcomes. However, as these factors equally affect both the treatment and control groups, they do not distort our results.

[32] We use an alternative estimator—Poisson pseudo-maximum likelihood (PPML)—without transforming the number of patent applications. In doing so we follow Balestra and Backes-Gellner (2017), who refer to Santos, Silva, J. M. C. and Tenreyro (2006) and Wooldridge (1999) and argue that log-linearized models also lead to biased estimates in presence of heteroscedasticity. We round the number of patent applications to receive integer numbers. The coefficient of the PPML estimation is 0.109 (11.5%) and is statistically significant at the one percent level, i.e., slightly higher than the results of our log-linear estimations.

establishment of a UAS campus (*t+3*) in municipality *j*. We use a time lag of three years because we assume that UAS have no immediate impact on innovation, given that potential channels for innovation take time to evolve.[33]

Second, our measures of patent quality include the

- average grant rate computed as $granted\ patents_{jt+3}/total\ no\ of\ filings$,

- average number of citations patents in the region receive within three years and within five years $ln(1+ av.\ citations_{jt+3})$

- average number of claims in the latest USPTO publication, $ln(1+ av.\ claims\ USPTO_{jt+3})$, and in the latest EPO publication, $ln(1+ av.\ claims\ EPO_{jt+3})$

- average number of jurisdictions in which an invention is protected (size of the international patent family), $ln(1 + av.\ family\ size_{jt+3})$.

Given that our quality indicators for claims, citations, and number of jurisdictions measure changes per patent, an increase in these indicators implies a rise in quality (and a decrease in the indicator a reduction in quality).

The explanatory variables on the right-hand side of equation(1) include the variable TG_j, a dummy that indicates whether a municipality belongs to the treatment group. TG_j equals one when a municipality j is located within a 25 km radius to a UAS campus. The term γ represents the common non-linear time trend of the treatment and the control groups and includes year dummies.

[33] Such direct and indirect channels could be, e.g., UAS graduates or joint research projects between UAS's and firms. Acquiring a Bachelor's degree at a UAS takes three years, and establishing research cooperation and finishing a typical project generally takes at least three years. Although many of the processes may take longer and innovation effects may become stronger over time, we use short time lag (three years) to make our test stronger and underestimate the effect size.

To control for unobservable time-constant effects on the district level, we include the variable λ_k, which comprises district dummies.[34] ε_{jt} is the error term.

Our main variable of interest, $Treatment_{jt}$, is a dummy variable indicating whether municipality j has a UAS campus in year t. The coefficient β in the equations shows the effect of UAS establishment on a region's patenting activity, assuming that the treated regions would have had the same trends as the untreated regions had the policy reform not happened. We test this assumption (and others) in Section 4.2.

4.2. Identification

Our identification relies on two key assumptions -parallel trends and no contamination assumption. We test these assumptions in the following.

Parallel trends assumption

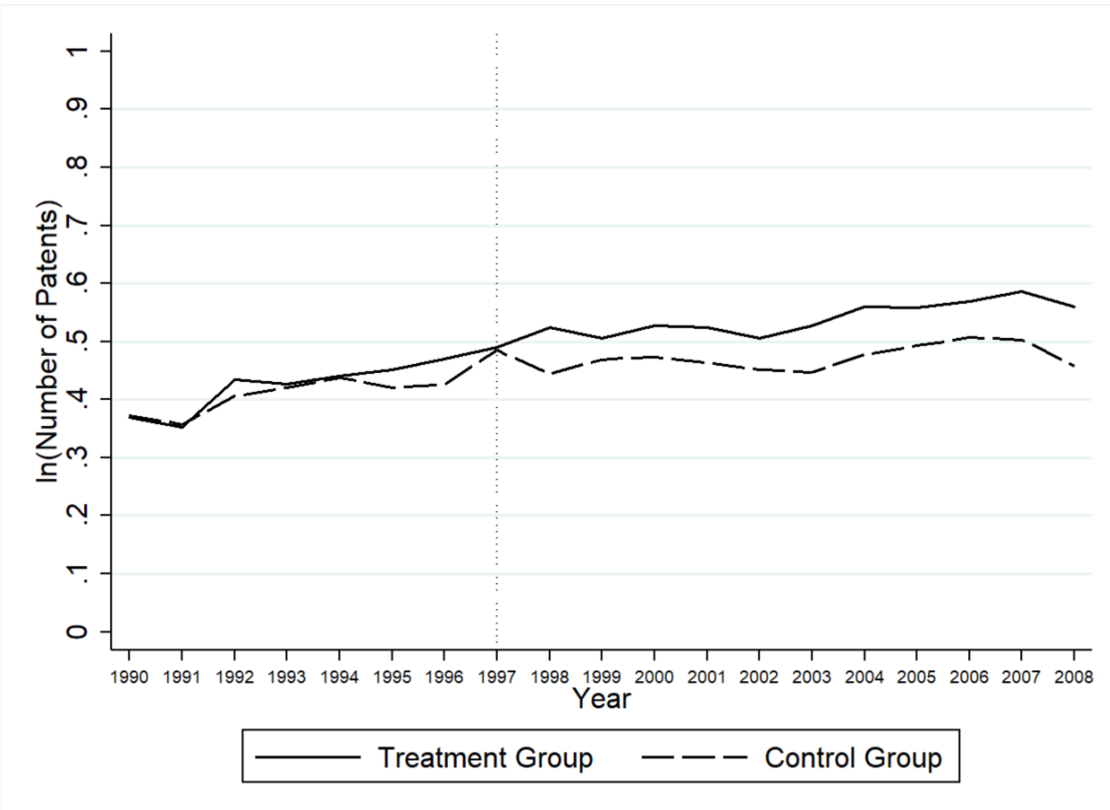
The most important assumption for estimating causal effects of UAS in a difference-in-differences model is the parallel trends assumption, i.e., treated regions (the treatment group) and untreated regions (the control group) have parallel trends in the absence of the UAS reform (e.g., Angrist and Pischke, 2008). Because our data contains information on multiple years before and after the creation of UAS, we can investigate this parallel trends assumption.

Summary information is presented in Table 3. Figure 2 shows the natural logarithm of the number of patents per municipality from 1990 through 2008 for the treatment and the control

[34] We control for districts because they could potentially affect the results as follows: Although unrelated to UAS establishment, the economic background of a region (e.g., industry structure or tax regime) may have an effect on our innovation outcomes. To control for differences in economic background even in the absence of a full set of observable or unobservable characteristics, we include dummy variables for all districts.

groups. The curves show a common underlying trend before the establishment of the first UAS campuses in 1997. After the establishment, a deviation from this common trend starts to take place.[35]

Figure 2 Priority filings for treatment and control group, before and after the UAS establishment



Note: Control group curve shifted to the initial level of treatment group curve.

To test whether the trends of the treatment and the control groups were parallel before the UASs were established or whether they show a statistically significant difference, we proceed as follows. In a first test we regress the quantitative and qualitative innovation indicators on the years 1990 to

[35] Figures showing the trends for the qualitative indicators are available in Pfister (2017).

1997, the period preceding the UAS creation[36], thereby differentiating between the pre-treatment trend for the control group (the linear variable *Year*) and the pre-treatment trend for the treatment group (the variable *Year* × *TG*)[37]. If the interaction term *Year x TG* shows a statistically significant effect, the treatment group would have a significantly different trend from the control group.

Table 4 shows the results when estimating a linear time trend, and Table 5 shows the results when estimating non-linear trends by including dummies for each year. Both tables show no statistically significant difference in pre-treatment trends (variable *Year* × *TG)* between the treatment and control groups. Therefore, we find no indication of a violation of the parallel trends assumption.[38]

In a second test of the parallel trends assumption, we take into consideration that in some catchment areas the UASs were not established right after the legal mandate took effect in 1997 but only in later years, which may have created anticipation effects in the regions that got their UAS later than 1997. To do so, we look for each catchment area at its last years before the UAS was actually established (-1, -2, -3, etc.) and after it was established (+1, +2, +3, etc). This specification helps to detect potential contamination or anticipation effects that appear in catchment areas that in 1997 did not yet have a UAS but would later get one. The results of these estimations

[36] This parallel trends assumption focuses on the years 1990 through 1997—i.e., the observation period before the establishment of the earliest UAS campus—to capture the overall impact of the policy intervention that was set in motion in 1997 by the new law on UAS, i.e. on the period before the policy intervention started to take its first effects.

[37] The variable *Treatment Group (TG)* shows the difference in the log of the number of patents between the treatment and the control groups in 1990.

[38] One explanation for these parallel trends between the treatment and the control groups are the political environment and the multiple and coalition building processes surrounding the establishment of the different UAS campuses.

are presented in Table A2 in the appendix (column 1 showing how the number of patents develop before the treatment takes place and column 2 afterwards). As expected, there are no statistically significant positive effects in the years before the UASs had been established (column 1). This confirms that anticipation effects are not a problem in our data set. Moreover, the results in column 2 show that the estimates for the first few years after the treatment are not significant but only become significant from the sixth year on. This also supports our assumption that anticipation effects are not a problem because the patenting effects did not kick in faster in areas that got their UAS later than 1997, rather the effect took equally long to kick in as in the baseline estimations.

In a third test of the parallel trends assumption we re-estimate our baseline specification by including catchment-area-specific trends to see whether different pre-treatment trends across catchment areas may drive our main results. If potential differences in pre-treatment trends across catchment areas were the drivers of our main treatment effect, the inclusion of such catchment-area-fixed effects would kill our main treatment effect. Results of this estimation are provided in Table A3 in the appendix of the paper. The table shows that the results for the treatment variable remain unchanged. This indicates that our main treatment effect is not driven by differing catchment-area-specific pre-treatment trends and that the parallel trends assumption holds even with specifications that are more detailed.

No-contamination assumption

The second key assumption for our identification strategy is that there is no contamination between treated and untreated regions, i.e., no change in mobility of graduates. To argue that we estimate an unbiased effect of UASs on regional patenting activities, we have to assume that UAS graduates have stable mobility and commuting behaviors.[39] However, although we showed that 90% of employed individuals commute less than 25 kilometers to work, the remaining 10% may commute from a non-treated area into a treated area and vice versa. In addition, graduates might still live in the catchment area in which they graduated, while commuting to a firm located in the non-treated region. Moreover, after finishing their studies, UAS graduates could move from a treated to a non-treated area and start working there. Such contamination of treatment and control groups could lead to biased results. Although such movement works against our hypothesis and thus makes our test stronger, we nevertheless provide a detailed analysis of the possible contamination effects in Section 6, showing that these effects are very small and negligible.

[39] The second form of direct spillovers (interaction between UASs and firms) and indirect spillovers are less prone to these mobility concerns, because UASs, firms and cities are less mobile than graduates are.

Table 4 Parallel trends assumption quantitative and qualitative Indicators – estimations with linear trends

	Dependent Variable						
	ln(priority filings)	ln(grant rate)	ln(citations 3-yr lag)	ln(citations 5-yr lag)	ln(claims USPTO)	ln(claims EPO)	ln(family size)
Year	0.014***	0.003**	0.003**	0.006***	0.013***	0.007	0.010**
	(0.003)	(0.001)	(0.001)	(0.002)	(0.005)	(0.006)	(0.004)
Year × Treatment Group	0.004	0.001	0.003	0.004	0.001	0.011	0.004
	(0.004)	(0.001)	(0.002)	(0.003)	(0.006)	(0.007)	(0.005)
Treatment Group	0.196***	0.054***	0.033***	0.060***	0.230***	0.235***	0.222***
	(0.030)	(0.008)	(0.008)	(0.012)	(0.035)	(0.040)	(0.033)
Constant	0.172***	0.065***	0.038***	0.069***	0.194***	0.281***	0.257***
	(0.022)	(0.007)	(0.006)	(0.009)	(0.027)	(0.031)	(0.025)
AR2	0.0193	0.0161	0.0089	0.0125	0.0145	0.0175	0.0208
R2	0.0195	0.0164	0.0091	0.0127	0.0148	0.0178	0.0211
n	11480	11480	11480	11480	11480	11480	11480
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level

Table 5 Parallel trends assumption quantitative and qualitative indicators – estimations with year dummies

	Dependent Variable						
	ln(priority filings)	ln(grant rate)	ln(citations 3-yr lag)	ln(citations 5-yr lag)	ln(claims USPTO)	ln(claims EPO)	ln(family size)
Year							
1990	Base Group	Base Group	Base Group	Base Group	Base Group	Base Group	Base Group
1991	-0.015	0.008	0.019*	0.016	0.039	0.040	0.042
	(0.018)	(0.009)	(0.011)	(0.017)	(0.035)	(0.043)	(0.031)
1992	0.033*	0.025***	0.019*	0.031*	0.108***	0.015	0.081**
	(0.020)	(0.010)	(0.011)	(0.017)	(0.041)	(0.043)	(0.033)
1993	0.048**	0.033***	0.016	0.021	0.035	0.031	0.096***
	(0.021)	(0.010)	(0.011)	(0.016)	(0.037)	(0.045)	(0.034)
1994	0.065***	0.035***	0.029**	0.028	0.090**	0.047	0.080**
	(0.023)	(0.010)	(0.014)	(0.018)	(0.043)	(0.047)	(0.034)
1995	0.048**	0.018**	0.023*	0.042**	0.071*	-0.022	0.058*
	(0.020)	(0.009)	(0.012)	(0.019)	(0.038)	(0.044)	(0.032)
1996	0.053**	0.020**	0.021**	0.029*	0.114***	0.039	0.066**
	(0.021)	(0.009)	(0.010)	(0.015)	(0.042)	(0.047)	(0.032)
1997	0.112***	0.026***	0.035***	0.060***	0.116***	0.102**	0.113***
	(0.024)	(0.010)	(0.012)	(0.019)	(0.042)	(0.049)	(0.035)
Year × Treatment Group							
1990	Base Group	Base Group	Base Group	Base Group	Base Group	Base Group	Base Group
1991	-0.002	-0.017	0.004	0.016	-0.063	-0.017	-0.050
	(0.023)	(0.011)	(0.014)	(0.021)	(0.046)	(0.052)	(0.040)
1992	0.032	-0.009	-0.002	0.017	-0.069	0.076	-0.030
	(0.025)	(0.012)	(0.014)	(0.021)	(0.052)	(0.053)	(0.041)
1993	0.009	-0.005	0.008	0.024	-0.058	0.023	-0.076*
	(0.027)	(0.012)	(0.014)	(0.020)	(0.048)	(0.055)	(0.042)

1994	0.006	-0.002	0.011	0.032	-0.088	-0.011	-0.035
	(0.028)	(0.013)	(0.017)	(0.023)	(0.053)	(0.057)	(0.043)
1995	0.034	0.009	0.003	0.015	-0.026	0.119**	0.022
	(0.026)	(0.012)	(0.015)	(0.023)	(0.050)	(0.056)	(0.042)
1996	0.048*	-0.008	0.037**	0.057***	-0.058	0.052	0.012
	(0.027)	(0.012)	(0.014)	(0.021)	(0.054)	(0.058)	(0.041)
1997	0.009	-0.009	0.010	0.024	-0.004	0.069	-0.020
	(0.030)	(0.012)	(0.016)	(0.024)	(0.054)	(0.061)	(0.044)
Treatment Group	0.192***	0.061***	0.034***	0.052***	0.280***	0.235***	0.259***
	(0.034)	(0.010)	(0.009)	(0.015)	(0.042)	(0.048)	(0.037)
Constant	0.178***	0.053***	0.030***	0.063***	0.169***	0.276***	0.225***
	(0.025)	(0.008)	(0.007)	(0.012)	(0.031)	(0.038)	(0.028)
AR2	0.0188	0.0179	0.0089	0.0121	0.0144	0.0174	0.0203
R2	0.0201	0.0192	0.0102	0.0133	0.0157	0.0187	0.0216
N	11480	11480	11480	11480	11480	11480	11480
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level. Results of the joint F-test for the interaction between the year dummies and the variable TG equal 0.5010 for ln(priority filings), 0.5167 for ln(grant rate), 0.3237 for ln(citations, 3-year lag), 0.2947 for ln(citations, 5-year lag), 0.6403 for ln(claims USPTO), 0.2104 for ln(claims EPO), and 0.3304 for ln(family Size) (Prob. > F).

5. Results

To estimate the effect of UAS on regional patenting activity, we estimate equation(1) using a DiD estimator. Table 6 shows the estimation results using our quantity and quality indicators: The first column displays the results for the number of patent applications. The estimate for the $Treatment_{jt}$ coefficient is 0.068 and is statistically significant at the one percent level (SE 0.016). The UAS establishment thus led to a statistically significant and economically sizable increase in regional patenting activities of about 7% in the treated regions.

The second column shows the results for our first quality indicator, the average grant rate of patents in the respective municipality. The treatment coefficient is 0.005 (SE 0.004) so that we cannot reject the hypothesis that the establishment of UASs has not affected the overall grant rate. However, we also find no evidence that the expansion of patent quantity has come at the price of fewer granted patents. We note that grant rates should be viewed with some caution given that they may reflect idiosyncratic differences between patent office practices.

Citations, claims and size of the international patent family are widely acknowledged as (noisy) correlates of the monetary value of patents. The third and the fourth columns of Table 6 show the results for our two forward citation indicators (the third column refers to the three-year citation lag; the fourth, to the five-year lag). While the variable for granted patents shows the absolute number of granted patent applications for each municipality, our forward citation indicators show the number of citations for each patent application. Together, these two indicators are relative quality measures showing the change in average citations for each patent application. The treatment effect of UAS on forward citations with a three-year citation lag is estimated to be 0.024 (SE 0.007), and with a five-year lag 0.049 (SE 0.010). Both coefficients are statistically significant (at the one percent level).

This effect in the coefficient of the citation indicators has two implications. First, as forward citations reflect the importance of the patented technology, the establishment of UASs increased the private economic value of patents for their owners. Second, according to Trajtenberg (1990) citations also mirror the social value of an invention, i.e., its economic externalities. UASs thus increased not only the private value of patented inventions but also their social value. We argue that both results are due to the improved availability of technical knowledge in the treated regions.

The fifth and sixth columns show that in treated regions, the number of claims increased in US and in EPO patent filings related to the priority applications more strongly than in untreated regions. Empirical tests have demonstrated that the number of claims is positively related to the monetary value of patents (e.g., Harhoff et al., 2003; Lanjouw and Schankerman, 2004). In our DiD framework, the treatment coefficient shows the approximate percentage change in the number of claims of patents in the treatment group compared to patents originating in the control group of regions. For the average number of US claims, there is an increase of 4.8%, for claims in EPO applications of about 9.7%. These results suggest that the establishment of UASs led to a significant increase in the average economic value of patents in the respective regions.

The seventh column shows the change in the average patent family size, i.e., the number of countries in which a patent is protected. Given that filing and enforcing an invention in different jurisdictions is costly, only patents of high expected value have protection in multiple countries. In regions that received a UAS, the estimated treatment effect is 0.082 (SE 0.019). This corroborates our finding of an increase in the economic value of patents due to the establishment of UAS to which applicants apparently react with an international expansion of their patenting strategies.

Table 6 OLS Results for Patent Quantity and Quality

	Dependent Variable						
	ln(priority filings)	ln(grant rate)	ln(citations 3-yr lag)	ln(citations 5-yr lag)	ln(claims USPTO)	ln(claims EPO)	ln(family size)
Year	yes	yes	yes	yes	yes	yes	yes
TG_j	0.060	0.021*	0.009	0.016	0.070	0.084*	0.086**
	(0.047)	(0.011)	(0.010)	(0.017)	(0.047)	(0.051)	(0.042)
$Treatment_{jt}$	0.068***	0.005	0.024***	0.049***	0.048**	0.097***	0.082***
	(0.016)	(0.004)	(0.007)	(0.010)	(0.022)	(0.024)	(0.019)
Constant	0.328***	0.111***	0.070***	0.128***	0.315***	0.433***	0.392***
	(0.038)	(0.009)	(0.009)	(0.015)	(0.040)	(0.043)	(0.036)
AR2	0.283	0.134	0.103	0.129	0.155	0.147	0.189
R2	0.286	0.138	0.108	0.134	0.160	0.151	0.193
N	22960	22960	22960	22960	22960	22960	22960
p-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

6. Robustness Checks

To check the robustness of our results and tackle additional questions that our results may raise, we perform additional analyses with additional data sets that we present in the following.

a) Relative Importance of Applied Research Universities vs. Traditional Universities

To tackle the question of how strong the measured innovation effect of applied research universities (UASs) is in comparison to that of traditional universities (focusing on basic academic research), we can use the expansion of students in the 1990s in Switzerland.[40] Throughout this period, there was a substantial and uneven growth in the number of graduates from traditional universities across regions and time. While in 1990s the number of students at traditional universities was 86,000 it had grown to 120,000 in 2008, i.e. by approximately 40% in less than two decades.[41] This educational expansion provides an opportunity to investigate at the intensive margin the relative effect of an expansion of the newly established UAS in comparison to the traditional research universities. We were able to use disaggregated data from the Swiss Federal Statistical Office (from the "Schweizer Hochschulinformationssystem" (SHIS) on graduates in each municipality and each year in the respective time period. With these data we are able to use the change in the number of graduates from UASs and from academic universities in treated and untreated regions to investigate their relative importance for patenting activity.

The first column of table 7 shows the results of this comparison. The column shows that the effect of an increase in UAS students is much larger than the effect of an increase in traditional

[40] Pfister (2017) provides an extensive description of the data that we use here to analyze the potential impact of traditional research universities (cf. Chapter 2.6.4).

[41] See SFSO, SHIS, at https://www.bfs.admin.ch/bfs/de/home/statistiken/bildung-wissenschaft/personen-ausbildung/tertiaerstufe-hochschulen/universitaere.assetdetail.12327692.html.

university students. While controlling for the UAS-establishment effect, the coefficient of an increase in UAS students is 0.021 and statistically highly significant. In contrast, the coefficient of traditional university students is only 0.007 and statistically insignificant. The difference between the two estimates is highly significant ($p<0.01$). Thus, the effect on innovation of an increase in UAS students is about three times higher than the effect of an increase in graduates from traditional universities.

Since we cannot be completely sure that the increase in students is exogenous, these results are not a solid proof of a stronger effect of UAS in comparison to traditional universities, but they may nevertheless give a first indication of the relative importance of applied research universities in comparison to traditional universities focusing on basic academic research. They point to an important potential feature for higher education policy, i.e., to a complementary innovation effect of UAS. It may be efficient to complement existing research universities with additional research institutions that are strongly focused on applied research and on combining high quality vocational knowledge with applied research knowledge, rather than continuously increasing the number of traditional university students (for a theoretical explanation cf. Schultheiss et al., 2019). In the case of Switzerland, our results indicate that such an extension of the higher education sector seems to have benefited innovation activities.

b) Further Robustness Checks

In our further robustness checks, we first tackle the potential bias arising from contamination of the treatment and the control groups focusing on three forms of mobility of UAS graduates.

1. Contamination

The first possible cause of contamination is UAS graduates' commuting behavior across the regional boundaries that we previously defined.[42] To reduce this potential contamination, we redefine our catchment areas and exclude a belt of municipalities located just at the boundaries of our treatment regions. In other words, we exclude the outer limits of our original area from the analysis, because those are the areas where the treatment and control groups could be contaminated in both directions.

Column 2 in Table 7 shows the results of the DiD regression of equation(1) with the reduced sample. The treatment coefficient is slightly, but not significantly higher than that in the baseline model (0.082 (0.018) vs. 0.068 (0.016)). As the increase in the coefficient is very small, the contamination of the baseline model appears only marginal.

The second form of mobility that may cause contamination is UAS graduates not commuting but instead relocating across the regional boundaries. To analyze the relocating behavior of UAS graduates, we use a representative survey for Switzerland, the Survey of Higher Education Graduates (EHA), provided by the Swiss Federal Statistical Office. This survey shows that five years after graduation, about 75% of UAS graduates from engineering, IT, chemistry, and the life sciences still live in the same UAS catchment area in which they graduated. Thus relocating across the boundaries of our regions is a restricted problem.

The third form of mobility that may cause contamination is graduates commuting to another catchment area than the one they graduated in. As an indicator of the extent of contamination, we take the net fluctuations between the catchment areas for the following reasons: If graduates from a UAS catchment area start working in a control group area, our estimation results would be biased

[42] Pfister (2017) provides an extensive description of the data and the methods for analyzing potential contamination effects.

downwards. Conversely, if graduates are evenly distributed across the areas, i.e., if the net fluctuations between the different UAS catchment areas are low, contamination is low and our results would be only marginally affected.[43] For 80% of the UAS catchment areas, the net fluctuations equal at most one percentage point, meaning that incoming and outgoing UAS graduates cancel one another out across treated regions. Even in the regions with the largest net fluctuation, the problem remains insignificant because the great majority of graduates are distributed evenly across the regions.

Although all forms of mobility—commuting or relocating—might lead to contamination of the treatment and control groups, these issues cause only very limited problems in our Swiss data.[44] Therefore, studying this policy reform in Switzerland provides an almost ideal setting for analyzing the causal effects of applied research on innovation. With its low mobility, the country provides a particularly clean treatment and control group. In contrast, in countries where mobility patterns are less restricted there may be large contamination effects such that treatment effects might not be statistically verifiable. This does, however, not mean that in countries with higher mobility a comparable UAS reform would not have similar innovation effects – it would just be more spread out and difficult to measure.

2. Unobservable time-constant characteristics

Second, we focus on unobservable (economic) background of our regions (municipalities),[45] and include municipality fixed effects in our baseline estimation equation. By so doing, we are able

[43] The results would imply a downward bias.

[44] However, even if mobility were an empirical concern in Switzerland, the resulting contamination effect would lower the effect sizes and potential significance—and therefore make our test stronger—and the true effect size is likely to be even higher.

[45] See Pfister (2017, chapter 2.6.2).

to control for unobservable time-constant characteristics at the lowest possible regional disaggregation level.[46] Column three of Table 7 displays the results of the estimation. As the coefficient β shows a lower effect than the baseline model, the municipality fixed effects erode part of the innovation effect. Given that they control for unobservable time-constant characteristics at a much lower level than the district fixed effects, this decrease in the innovation effect is in line with our expectations.[47] However, the effect still equals 3.8% and is statistically significant at the one percent level. The effect, though smaller, remains robust to the inclusion of municipality fixed effects. This indicates that our results not induced by the municipalities' underlying unobservable time-constant characteristics.

3. Timing of Effect

Third, we examine how the innovation effect develops over time, i.e., in the first, second, third, and further years after the UAS establishments.[48] While the baseline model shows only the average effect of the establishment of UAS on innovation over the entire observation period, column four of Table 7 shows the innovation effect separately for each year from the third to the eleventh year after a UAS establishment.[49] The effect equals 2.0% in $t+5$ and increases to more than 5% in later

---

[46] In all the robustness tests, our results remain stable if we include municipality fixed effects (results are available upon request).

[47] Switzerland consists of approximately 2,300 municipalities and 148 districts (see http://www.bfs.admin.ch/bfs/portal/de/index/regionen/11/geo/institutionelle_gliederungen/01b.html).

[48] See Pfister (2017) for a detailed description on the method to analyze how the innovation effect develops in post-treatment year.

[49] In addition, we find no statistically significant effect in the periods preceding UAS establishment. A positive effect in this period, particularly in the years close to $t=0$, would indicate that the assignment of the treatment was endogenous (e.g., Angrist and Pischke, 2008). In other words, an increase in patenting activities before the reform

years. Thus, the results indicate that the innovation effect increases over time and that the innovation effect takes time to manifest after the establishment of a UAS—also confirming that a time lag of three years is adequate to estimate the effect of a UAS on innovation in our baseline model.

4. Innovation effects in rural areas

Fourth, we investigate whether rural areas profit from the establishment of UASs.[50] The literature shows vast empirical evidence that rural areas have less highly educated workers, weaker economic growth rates, higher poverty, and lower innovative performance compared to urban areas (e.g., Abel et al., 2014; Partridge, Rickman, Ali, and Olfert, 2009; Partridge and Rickman, 2008; Usai, 2011). To test whether the establishment of UASs had a positive effect on the regional patenting activities of rural areas, we restrict our sample to rural municipalities and estimate our basic estimation equation. Column five of Table 7 shows an effect of 1.7% which is, however, not statistically significant, probably due to a lack of statistical power (p=0.138). Taken together, these results suggest that the economic effect is larger in cities than in rural areas. Given that knowledge

would indicate that the location and timing of the establishment of UAS campuses were related to innovative, technical, or economic factors. However, as expected, we find no effects for these years in the pretreatment period.

[50] The definition of rural municipalities relies on federal population census data from the year 2000. The SFSO differentiates between nucleated cities, agglomeration municipalities, isolated cities, and rural municipalities; this differentiation takes into account the municipalities' demography (and demographic development), structurally spatial context, employment share, economic structure, and their commuter flows to core areas. For further information, see Schuler, Dessemontet, Joye, Perlik, and Geiser (2005). Chapter 4.3 The Effect of UAS on Rural Areas contains a detailed analysis of the impact of the establishment of UAS's on rural municipalities (Pfister, 2017).

exchange and creative work depend on having creative individuals for discussions around, the result is not suprising.[51]

5. Role of economically important city regions

In a fifth robustness check we examine whether the increased patent output stems mostly from powerful economic regions, which may have influenced the establishment decision in their favor. To do so, we identify the ten largest cities in our sample, assuming that they could all have such strong local economies and lobbying power. We successively exclude these cities from our estimation sample. Table A4 shows the estimation results. Column (1) repeats our baseline results, Column (2) shows results excluding the city of Zurich, the largest and economically strongest city of Switzerland. Further columns exclude the next larger cities, i.e., Column (3) excludes the city of Bern, Column (4) Basel, Column (5) Winterthur, etc. Finally, Column (12) shows the estimation results without any of the 10 largest cities in the German-speaking part of Switzerland. Throughout all these additional specifications, the estimate of the treatment effect remains unchanged. These results clearly indicate that the local economic or innovative strength of the UAS regions do not explain our effects. This provides additional support for our assumption that the location decision of UAS campuses is not dependent on the power or economic strength of the respective regions, but rather a quasi-random process independent of economic strength.

6. Role of large R&D-intensive firms

---

[51] Estimating the effect of UAS on agglomeration municipalities reveals a 7% increase in patenting activities. Although comparing the effect of UAS on agglomeration municipalities with the effect on rural municipalities can lead to misleading conclusions (because the results of the two estimations are based on different subsamples), the differing sizes of the effects indicate that rural municipalities profit less from the UAS establishment than do agglomeration municipalities.

In a sixth robustness check we investigate whether the establishment of UASs might have been driven by large, R&D-intensive firms that may have succeeded absorbing the lion's share of the benefits of having the new educational institutions in their proximity. To shed light on this concern, we eliminate the effect that stems from large, R&D-intensive firms in our estimations. Unfortunately, none of our datasets provides information on firm size. Therefore, we proxy large R&D performers by the number of patents an applicant has filed in our data set (as suggested by Pfister 2017). We rank all applicants according to the number of their patent applications and thus to their ownership share of patent filings. Manual inspection shows that this procedure does indeed select the large Swiss chemicals, pharma and engineering firms.

We then perform several re-estimations of our baseline model excluding more and more of the frequent applicants from the sample. First, we re-estimate our model excluding the applicants in the upper first percentile of the portfolio size distribution[52] (Table A5, column 2). Then, we exclude applicants in the upper fifth percentile (Table A5, column 3), and finally those in the upper decile (Table A5, column 4). Our estimation results show that the innovation effect of the UAS establishment remains statistically and economically significant throughout all the specifications.[53] Although the effect size is smaller than in the baseline estimations, the effect persists even when we exclude the entire upper decile of the frequent applicants from the data. Thus, it seems safe to

[52] The top percentile of applicants in the ownership distribution possess 23.1% of priority filings, the 5th percentile of applicants 31. 9%, the top decile of applicants 41.2%.

[53] "The results in Table A5 show that excluding the top 10% of patenting firms results in a smaller, yet highly significant coefficient estimate of 4.2% (instead of 6.8% for the whole sample). We leave the analysis of this form of heterogeneity to further research, but suggest that larger firms may simply be better positioned to profit from spillovers and the additional labor supply provided by UASs."

conclude that the innovation effect of the establishment of UASs was not concentrated among the large and R&D-intensive companies.

Table 7 OLS Results – Robustness Checks

	Dependent Variable: ln(priority filings)					
	Academic Education Expansion	Contamination Analysis	Municipality Fixed Effects	Innovation Effect over Time		Rural Areas
Year	yes	yes	yes	yes		yes
TG_j	0.071	0.124*	excluded	excluded		0.096**
	(0.045)	(0.064)				(0.038)
$Treatment_{jt}$	0.020	0.082***	0.038***	t+1	-0.025	0.017
	(0.019)	(0.018)	(0.009)		(0.020)	(0.015)
UAS Graduates	0.021***			t+2	0.003	
	(0.005)				(0.021)	
University Graduates	0.007			t+3	-0.003	
	(0.012)				(0.022)	
				t+4	-0.004	
					(0.023)	
				t+5	0.022	
					(0.023)	
				t+6	0.053**	
					(0.024)	
				t+7	0.047*	
					(0.026)	
				t+8	0.021	
					(0.028)	
				t+9	0.037	
					(0.032)	
				t+10	0.048	
					(0.034)	
				t+11	0.061	
					(0.040)	
Constant	0.320***	0.299***	0.372***	0.335***		0.108***
	(0.036)	(0.043)	(0.012)	(0.041)		(0.028)
AR2	0.342	0.282	0.771	0.2967		0.1742
R2	0.346	0.287	0.786	0.3007		0.1802
n	22960	17744	22960	23902		14320
p-Value	0.000	0.000	0.000	0.0000		0.0022

Note: standard errors clustered at the municipality level in parentheses. The regressions include district fixed effects in (1, 2, 4 and 5) and municipality fixed effects in (3). * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

7. Role of first-time applicants

In a seventh robustness check, we analyze whether the establishment of UASs also had an effect at the extensive margin of patent applicants, i.e., the number of first-time applicants, or only at the intensive margin, i.e., the number of inventors with already existing patents. To estimate this effect, we build a proxy for first-time applicants by counting the number of applicants that appear for the first time in each year in each region. We then re-estimate our baseline model by using first-time applicants, i.e. $ln(number\ of\ first\text{-}time\ applicants_{jt+3})$ as our dependent variable. The estimation results are provided in Table A6 in the appendix. They show that the establishment of UASs increases first-time applicants by more than 3 percent in the treated regions compared to the untreated regions. Thus, the establishment of UASs had a significantly positive effect on the emergence of new patent applicants. Thus, the innovation effect we measure in our baseline specification does not solely derive from inventors with a record of patenting activity or from already R&D-intensive firms, but also from inventors patenting for the first time.

8. Exploiting variation in timing across treated regions

In an eighth robustness check we exploit solely the quasi-random variation in the timing of UAS campuses in the treated regions, thus eliminating potentially existing structural differences (in observable or unobservable factors) between treatment and control group. We thus only use the treated regions, exclude the control group, and re-estimate all our models. Table A7 in the appendix presents all results. The table shows that all results from our main specifications remain basically unchanged.

7. Conclusions

Our study investigates the impact of Swiss Universities of Applied Sciences on regional innovation activities. These institutions were explicitly created and funded to conduct applied research and to train individuals with a previous vocational training degree. To study their effect on innovation, we exploit the staggered establishment of these UAS in the mid-1990s. To characterize regional innovation activities, we use the number of priority patent filings and various characteristics of patents. We employ a difference-in-differences approach to measure their impact of the establishment of UASs on inventive activity. Our results show that the establishment of UAS led to an increase of up to 6.8% in regional patenting activity. To estimate the effect on innovation quality, we use a set of proven correlates of patent value (claims, citations, family size) and find positive and statistically significant effects on patent quality as well.

We provide detailed analyses of the key assumptions of the model, and our results strongly suggest that the increase in innovation quantity is indeed a causal effect of the establishment of UAS. First, we find no evidence for a violation of the first key assumption of the DiD model, the common trends assumption. Second, we find that the contamination of the treatment and control groups—the second key assumption of our model—affects our results only marginally, if at all. The reason is that (a) there is almost no net fluctuation in UAS graduates across our regions and (b) when we exclude a belt of municipalities at the outer border of our treated regions, the results become only stronger. Moreover, if contamination were a problem, the true effect would be even higher, because UAS graduates would raise the patent number in the control group instead of the treatment group, and our results would then underestimate the size of the effect. Thus, we are confident that our results indeed measure the causal effect of the establishment of UAS on regional innovation activities.

In further robustness tests, we also tackle the question of the relative importance of applied research universities in comparison to traditional research universities. We use an expansion at the intensive margin, i.e., the increase in the number of students at the traditionally existing research universities in comparison to the growing number of students at the newly established UASs. Results indicate that the innovation effect of growing numbers of UAS students is significantly (about three times) larger than the effect of an increase in graduates from traditional research universities. These results offer an intriguing idea for higher education policies. Even if there is a foundation of well-established research universities in a country, it appears worthwhile complementing them with UAS-type institutions that combine strong vocational competences with applied research and teaching rather than simply expanding the classical university sector. In any case, our results show that in the case of Switzerland, complementing research universities with applied research universities has been an effective means to increase innovation output.

Our results and our robustness checks also provide insights into the potential and manifold mechanisms underlying this innovation effect. One important mechanism is an increased flow of human capital into the regional economy, i.e. additional Bachelor graduates from UAS who combine professional with advanced research skills (a combination that did not exist before). By modeling the innovation effect in each year following UAS establishment, we find that it develops over time. While the first few years show hardly any effect, from year six onward the effect becomes significant and increasingly larger. This time pattern is in line with our theoretical expectations of direct spillovers: First, UAS graduates entering the labor market are bringing new knowledge to firms and help them boost innovation. Thus, the effect should therefore only materialize several years after the establishment of a UAS, because that is when the first graduates have entered the labor market and start bringing in their new expertise. This mechanism is supported by results of Lehnert et al. (2020) who show that firms in regions with a UAS start employing more people in R&D than firms outside the range of a UAS a few years after the establishment of UAS.

Second, the establishment of UAS may affect patenting because of direct research cooperation between UAS professors or students with public or private firms in each respective region. Because establishing, funding, and carrying out R&D cooperation projects takes time (often at least a few years because of application and funding processes), this second form of direct spillovers would also be consistent with an innovation effect starting a few years after the establishment of UASs. Unfortunately, there is no data to test this mechanism, but anecdotal evidence suggests that for example bachelor thesis projects in which students, professors, and local firms work together are quite frequent and that such projects are thus likely to be part of the mechanism underlying the effect.

Third, another mechanism could be additional funding for which UASs together with local firms apply. As Switzerland has a particular funding agency (CTI, today InnoSuisse) that only provides money for cooperation projects in which higher education institutions cooperate with firms, it is likely that this mechanism also supports the effect. However, data to test this mechanism is not available. Additional mechanisms could be direct cooperation between UAS and firms, collaboration between UAS and other research institutes, or UAS professors producing patents. Future research should tackle these questions.

To summarize, our analysis provides strong evidence that the establishment of Swiss UASs whose primary purpose is conducting and teaching applied research to graduates with vocational education degrees had a positive quantitative and qualitative effect on innovation activities in the regions where they were established. Our results also suggest that the establishment of such applied research institutions helps fostering innovation outside major innovation centers by spreading innovation activities to such areas, often through more traditional and small or medium-sized firms, who intensify their applied research by employing UAS graduates who combine thorough vocational knowledge (acquired through mandatory pre-UAS apprenticeships) with applied research skills. These properties should make UASs an interesting instrument for regional economic policy.

Bibliography

Abel, J. R., Gabe, T. M. and Stolarick, K. (2014). Skills across the Urban-Rural Hierarchy. *Growth and Change*, *45*(4), 499–517.

Acs, Z. J., Anselin, L. and Varga, A. (2002). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy*, *31*(7), 1069–1085.

Andersson, F., Burgess, S.M. and Lane, J. (2007). Cities, matching and productivity gains of agglomeration. *Journal of Urban Economics, 61*(1), 442–448.

Andersson, R., Quigley, J.M. and Wilhelmsson, M. (2009). Urbanization, productivity, and innovation: Evidence from investment in higher education. *Journal of Urban Economics, 66*(1), 2–15.

Angrist, J. and Pischke, J. S. (2008). *Mostly harmless econometrics: An empiricist's companion.* Princeton, NJ: Princeton University Press.

Anselin, L., Varga, A. and Acs, Z. (1997). Local geographic spillovers between university and high technology innovations. *Journal of Urban Economics, 42*(3), 442–448.

Audretsch, D.B. and Feldman, M.P. (1996). R&D spillover and the geography of innovation and production. *American Economic Review, 86*(3), 630–640

Audretsch, D. B. and Stephan, P. E. (1996). Company-Scientist Locational Links: The Case of Biotechnology. *American Economic Review*, *86*(3), 641-652.

Backes-Gellner, U., Rupietta, C. and Tuor Sartore, S. N. (2017). Reverse educational spillovers at the firm level. *Evidence-based HRM: a Global Forum for Empirical Scholarship*, *5*(1), 80–106.

Balestra, S. and Backes-Gellner, U. (2017). When a Door Closes, a Window Opens? Long-Term Labor Market Effects of Involuntary Separations. *German Economic Review 18*(1), 1-21.

Belenzon, S. and Schankerman, M. (2013). Spreading the Word: Geography, Policy, and Knowledge Spillovers. *The Review of Economics and Statistics, 95*(3), 884–903.

Bereuter, R. (2011). *Beurteilung von Trägerschaftsstrukturmodellen von Fachhochschulen anhand ausgewählter Beurteilungskriterien. Beispielhafter Vergleich der Zürcher Fachhochschule, der Fachhochschule Nordwestschweiz und der Fachhochschule Ostschweiz* (Zertifikatsarbeit CeMaP). University of Bern, Bern.

Bonander, C., Jakobsson, N., Podest, F. and Svensson, M. (2016). Universities as engines for regional growth?: Using the synthetic control method to analyze the effects of research universities. *Regional Science and Urban Economics*, *60*, 198–207.

Bundesgesetz über die Fachhochschulen (Fachhochschulgesetz, FHSG) vom 6. Oktober 1995, SR/RS 414.71 (2011).

Bundesgesetz über die Förderung der Hochschulen und die Koordination im schweizerischen Hochschulbereich (Hochschulförderungs- und -koordinationsgesetz, HFKG) vom 30. September 2011, SR 414.20 (2011).

Carlino, G. A., Chatterjee, S. and Hunt, R. M. (2007). Urban density and the rate of invention. *Journal of Urban Economics*, *61*(3), 389–419.

Chatterji, A., Glaeser, E. and Kerr, W. (2013). Clusters of Entrepreneurship and Innovation. In J. Lerner and S. Stern (Eds.), *Innovation policy and the economy* (Vol. 14, pp. 129-166). Chicago, IL: University of Chicago Press.

Che, Y. and Zhang, L. (2018). Human Capital, Technology Adoption and Firm Performance: Impacts of China's Higher Education Expansion in the Late 1990s. *The Economic Journal* *128*(614), 2282-2320.

Cowan, R. and Zinovyeva, N. (2013). University effects on regional innovation. *Research Policy,* *42*(3), 788–800.

Commission of Experts for Research and Innovation (2017). Research, Innovation and Technological Performance in Germany. Berlin, EFI 2017.

Drucker, J. and Goldstein, H. (2007). Assessing the Regional Economic Development Impacts of Universities: A Review of Current Approaches. *International Regional Science Review*, *30*(1), 20–46.

Eidgenössische Fachhochschulkommission (EFHK). (2000). *Zwischenbericht über die Schaffung der Fachhochschulen – Stand der Aufbauarbeiten und Erfüllungsgrad der Auflagen des Bundesrates.* Bern, Switzerland: EFHK.

Eidgenössische Fachhochschulkommission (EFHK). (2002). *Fachhochschulbericht 2002, Bericht über die Schaffung der Schweizer Hochschulen*. Bern, Switzerland: EFHK.

Eugster, B., Lalive, R., Steinhauer, A. and Zweimüller, J. (2011). The demand for social insurance: does culture matter?. *The Economic Journal*, *121*(556).

Federal Office for Professional Education and Technology (OPET). (2009). *Die Schweizer Fachhochschulen.* Bern, Switzerland: OPET.

Feldman, M. P. and Audretsch, D. B. (1999). Innovation in cities: Science-based diversity, specialization and localized competition. *European Economic Review*, *43*(2), 409–429.

Feldman, M. P. and Kogler, D. F. (2010). Stylized facts in the geography of innovation. *Handbook of the Economics of Innovation*, *1*, 381-410.

Forman, C., Goldfarb, A. and Greenstein, S. (2016). Agglomeration of invention in the Bay Area: not just ICT. *American Economic Review*, *106*(5), 146-51.

Funk, P. and Gathmann, C. (2013). How do electoral systems affect fiscal policy? Evidence from cantonal parliaments, 1890-2000. *Journal of the European Economic Association, 11*(5), 1178–1203.

Gambardella, A., Harhoff, D. and Verspagen, B. (2008). The value of European patents. *European Management Review*, *5*(2), 69–84.

Giuri, P., Mariani, M., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., … Verspagen, B. (2007). Inventors and Invention Processes in Europe: Results From the PatVal-EU Survey. *Research Policy, 36*(8), 1107–1127.

Glaeser, E. L. (Ed.). (2010). *Agglomeration economics*. Chicago: University of Chicago Press.

Glaeser, E. L., Scheinkman, J. A. and Sacerdote, B. I. (2003). The social multiplier. *Journal of the European Economic Association, 1*(2–3), 345–353.

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics*, *10*(1), 92–116.

Griliches, Z. (1990). Patent statistics as economic indicators: a survey. *Journal of Economic Literature*, 28, 1661–1707

Hall, B. H., Jaffe, A. B. and Trajtenberg, M. (2005). Market Value and Patent Citations. *The RAND Journal of Economics*, *36*(1), 16–38.

Harhoff, D. (2016). Patent quality and examination in Europe. *American Economic Review*, *106*(5), 193-97.

Harhoff, D., Narin, F., Scherer, F. M. and Vopel, K. (1999). Citation Frequency and the Value of Patented Inventions. *The Review of Economics and Statistics*, *81*(3), 511–515.

Harhoff, D., Scherer, F. M. and Vopel, K. (2003). Citations, family size, opposition and the value of patent rights. *Research Policy*, *32*(8), 1343–1363.

Helmers, C. and Overman, H. G. (2017). My Precious! The Location and Diffusion of Scientific Research: Evidence from the Synchrotron Diamond Light Source. *The Economic Journal* *127*(604), 2006-2040.

Hotz-Hart, B. (2010). F&E-Zusammenarbeit von Hochschulen und Unternehmen. *Die Volkswirtschaft, 1,* 50-53.

Jaffe, A. B. (1989). Real Effects of Academic Research. *American Economic Review, 79*(5), 957-970.

Jaffe, A. B., Trajtenberg, M. and Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics*, *108*(3), 577–598.

Kiener, U. (2013). Die Fachhochschule als Missverständnis. Reform, Identität, Selbstbeschreibung. *Swiss Journal of Sociology, 39*(2), 341–360.

Lanjouw, J. O. and Schankerman, M. (2001). Characteristics of Patent Litigation: A Window on Competition. *The RAND Journal of Economics*, *32*(1), 129–151.

Lanjouw, J. O. and Schankerman, M. (2004). Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. *The Economic Journal*, *114*, 441–465.

Liu, S. (2015). Spillovers from universities: Evidence from the land-grant program. *Journal of Urban Economics*, *87*, 25–41.

Lehnert, P., Pfister, C. and Backes-Gellner, U. (2020). Employment of R&D personnel after an educational supply shock: Effects of the introduction of Universities of Applied Sciences in Switzerland. *Labour Economics,* 66 (10). https://doi.org/10.1016/j.labeco.2020.101883

Lundvall, B.A. and Johnson, B. (1994). The Learning Economy. London: Routledge.

Mansfield, E. and Lee, J.-Y. (1996). The modern university: contributor to industrial innovation and recipient of industrial R&D support. *Research Policy*, *25*(7), 1047–1058.

Maskell, P. and Malmberg, A. (1999). Localised Learning and Industrial Competitiveness. *Cambridge Journal for Economics*, 23, 167–186.

Moretti, E. (2011). Local labor markets. *Handbook of labor economics*, *4*, 1237-1313.

Muehlemann, S., Ryan, P. and Wolter, S. C. (2013). Monopsony Power, Pay Structure, and Training. *Industrial Labor Relations Review, 66*(5), 1097–1114.

Muehlemann, S. and Wolter, S. C. (2011). Firm-sponsored training and poaching externalities in regional labor markets. *Regional Science and Urban Economics, 41*(6), 560–570.

Nagaoka, S., Motohashi, K. and Goto, A. (2010). Patent Statistics as an Innovation Indicator. In B. H. Hall and N. Rosenberg (Eds.), *Handbook of the Economics of Innovation* (Vol. 2, pp. 1083–1127). Oxford, England: Elsevier B.V.

OECD. (2009). *OECD Patent Statistics Manual*. Paris, France: OECD Publishing.

Partridge, M. D. and Rickman, D. S. (2008). Distance from Urban Agglomeration Economies and Rural Poverty. *Journal of Regional Science*, *48*(2), 285–310.

Partridge, M. D., Rickman, D. S., Ali, K. and Olfert, M. R. (2009). Do New Economic Geography agglomeration shadows underlie current population dynamics across the urban hierarchy? *Papers in Regional Science*, *88*(2), 445–466.

Pfister, C. (mimeo 2017) *Different Educational Structures and their Economic Impact on Individuals and the Economy*. Dissertation, University of Zurich, mimeo October 2017.

Projektgruppe Bund-Kantone Hochschullandschaft 2008. (2004). *Bericht über die Neuordnung der schweizerischen Hochschullandschaft*. Bern, Switzerland: Staatssekretariat für Wissenschaft und Forschung / Bundesamt für Bildung und Wissenschaft.

Putnam, J., 1996. The value of international patent rights. Ph.D. Thesis. Yale University, Yale.

Rosenberg, N. and Nelson, R. R. (1994). American universities and technical advance in industry. *Research Policy*, *23*(3), 323–348.

Rosenthal, S. S. and Strange, W.C. (2008). The attenuation of human capital spillovers. *Journal of Urban Economics, 64*(2), 373–389.

Rosenthal, S. S. and Strange, W.C. (2001). The determinants of agglomeration. *Journal of Urban Economics, 50*(2), 191–229.

Salinas, P. and Solé-Ollé, A. (2018). Partial fiscal decentralization reforms and educational outcomes: A difference-in-differences analysis for Spain. *Journal of Urban Economics, 107*(2018), 31–46.

Santos, Silva, J. M. C. and Tenreyro, S. (2006). The Log of Gravity. *The Review of Economics and Statistics*, *88*(4), 641–658.

Saxenian, A. (2000). *Regional advantage: Culture and competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.

Schartinger, D., Rammer, C., Fischer, M. M. and Fröhlich, J. (2002). Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. *Research Policy, 31*(3), 303–328.

Scherer, F.M. (1965). Firm size, market structure, opportunity, and the output of patented inventions. *American Economic Review,* 55, 1097–1125.

Scherer, F.M. and Harhoff, D. (2000). Policy implications for a world with skew-distributed returns to innovation. *Research Policy*, 29, 559–566.

Schmoch, U., Grupp, H., Mannsbart, W. and Schwitalla, B. (1988). *Technikprognosen mit Patentindikatoren*. Cologne, Germany: Verlag TÜV Rheinland.

Schlegel, T., Pfister, C., Harhoff, D. and Backes-Gellner, U. (2019). *Heterogeneous Regional Innovation Spillovers of Universities of Applied Sciences. Zurich: Economics of Education Working Paper Series 0161.*

Schuler, M., Dessemontet, P., Joye, D., Perlik, M. and Geiser, A. (2005). *Die Raumgliederungen der Schweiz*. *Eidgenössische Volkszählung 2000.* Neuchâtel, Switzerland: Vertrieb Bundesamt für Statistik.

Schultheiss, T., Pfister, C., Backes-Gellner, U. and Gnehm, A. (2019). Tertiary education expansion and task demand: Does a rising tide lift all boats? Zurich: Economics of Education Working Paper Series 0154.

Schweizerischer Bundesrat. (1994). Botschaft zu einem Bundesgesetz über die Fachhochschulen (Fachhochschulgesetz, FHSG) vom 30. Mai 1994. *Bundesblatt, 3*(29), 789-875.

Schweizerischer Bundesrat. (2009). Botschaft zum Bundesgesetz über die Förderung der Hochschulen und die Koordination im schweizerischen Hochschulbereich (HFKG) vom 29. Mai 2009, *Bundesblatt, 26*, 4561-4686.

Squicciarini, M., Dernis, H. and Criscuolo, C. (2013). *Measuring Patent Quality: Indicators of Technological and Economic Value* (OECD Science, Technology and Industry Working Papers No. 2013/03). Paris, France: OECD Publishing.

Staatssekretariat für Bildung, Forschung und Innovation (SBFI). (2015). *Hochschulen und Forschung in der Schweiz*. Bern, Switzerland: SBFI.

Swiss Coordination Centre for Research in Education (SCCRE). (2007). *Swiss Education Report 2006.* Aarau, Switzerland: SCCRE.

Swiss Coordination Centre for Research in Education (SCCRE). (2010). *Swiss Education Report 2010*. Aarau, Switzerland: SCCRE.

Swiss Coordination Centre for Research in Education (SCCRE). (2014). *Swiss Education Report 2014*. Aarau, Switzerland: SCCRE.

SFSO (1997) (Swiss Federal Statistical Office 1997). *Pendlermobilität in der Schweiz*. Bern, Switzerland: Vertrieb Bundesamt für Statistik.

SFSO-ARE (2007) (Swiss Federal Statistical Office, Bundesamt für Raumentwicklung 2007). *Mobilität in der Schweiz. Ergebnisse des Mikrozensus 2005 zum Verkehrsverhalten.* Bern, Switzerland: Vertrieb Bundesamt für Statistik.

Swiss Science and Technology Council (2010). *Forschung an Fachhochschulen in der Schweiz* (SWTR Schrift 2/2010). Bern: SWTR.

Toivanen, O. and Väänänen, L. (2016). Education and Invention. *Review of Economics and Statistics, 98*(2), 382–396.

Trajtenberg, M. (1990). A Penny for Your Quotes: Patent Citations and the Value of Innovations. *The RAND Journal of Economics*, *21*(1), 172–187.

Usai, S. (2011). The Geography of Inventive Activity in OECD Regions. *Regional Studies*, *45*(6), 711–731.

Valero, A. and Van Reenen, J. (2016). *The Economic Impact of Universities: Evidence From Across the Globe* (NBER Working Paper 22501). Cambridge, MA: National Bureau of Economic Research.

Weber, K. and Tremel, P. (2010). *Programmatik und Entwicklung der Schweizer Fachhochschulen*. Bern, Switzerland: Zentrum für Universitäre Weiterbildung ZUW.

Wooldridge, J. M. (1999). Distribution-free estimation of some nonlinear panel data models. *Journal of Econometrics, 90*(1), 77-97.

Appendix:

Illustrative Case Study Evidence on UAS Establishment Process

The federal government set the general conditions that determined where and when the establishment of a new UAS was granted. It not only imposed the legal mandates—such as teaching and conducting applied R&D—but also required an equal geographical distribution of UAS campuses across Switzerland. Moreover, the federal government decided on whether to confer accreditation to a UAS, a UAS campus or a UAS study program. As a result, cantons had to collaborate and coordinate across (and even within) cantonal borders to meet the accreditation requirements. This setup provoked heated debates among policymakers both across and within cantons, but also between cantons and the federal government.54

The UAS establishment process was thus multi-layered, comprising a large number of different players with different policy priorities (not only focusing on innovation or economic topics, but on a wide variety of cantonal and federal policy topics). It included repeated interactions and renegotiations, constantly changing coalition building and disruptions of coalitions, changes in the number of UAS (campus) applications, UAS campus relocations, package deals, and historical coincidences. This complex process made the final outcome, i.e., where and when a UAS was established, highly unpredictable.

Pfister (2017) has extensively researched and documented the process of each UAS establishment and shows how the complexities of the processes and decision makings lead to quasi-random results from an economic or innovation perspective. As an illustrative example we provide an abbreviated narration of the process that led to the establishment of the different campuses of the "University of Applied Sciences Bern", with the city of Bern being the capital of Switzerland.

> The University of Applied Sciences Bern applied for accreditation with a STEM campus each in the small towns of Biel, Burgdorf, and the city of Bern (i.e., the geographical middle of Biel and Burgdorf). However, it only received conditional accreditation in 1997 and the federal government required the consolidation of the STEM campuses in one location for final accreditation. As can be expected, a large number of powerful economic, political, and UAS representatives tried to emphasize the economic importance of the city of Bern and argued for establishing the STEM campus in Bern. However, they did not succeed. Instead,

[54] The Swiss political system is a federalist system. The federal government grants autonomy to the cantons in all areas that are not explicitly regulated by the federal constitution. The cantons are political entities that are geographically very small but highly independent irrespective of their economic strength.

> it was finally decided that the provisional STEM campus in the city of Bern had to be closed and relocated. After further heated political debate, the STEM campus in Bern finally closed its doors in 2003 and was relocated to the campuses of the rural cities of Burgdorf and Biel. As a concession for the loss of the STEM campus, the study programs in social work, arts and business administration became concentrated in the city of Bern.

Our main assumption, that the outcome of such processes is quasi-random from economic or political power play, is also supported by additional descriptive evidence from Lehnert et al. (2020). Table A1 shows the economic conditions measured by employment (fulltime equivalents, depicted in column 1) and by number of resident firms (column 2) for the catchment areas in the city of Bern, in Burgdorf, and in Biel. The table shows that the city of Bern, who did not succeed with establishing a UAS, was clearly and much more economically powerful than Burgdorf or Biel, who succeeded with a UAS. This comparison indicates that the location decision of STEM campuses was not related to the economic potential of a region or the lobbying of powerful R&D corporations. Rather, it was determined by the federal requirement of an equal geographical distribution of campuses across regions.

A similarly complex establishment processes is for example observed for the "Northwestern University of Applied Sciences" as shown in the historical policy analysis by Pfister (2017) and by descriptive results in Table A1. These results for the "Northwestern UAS" also confirm our previous conclusions: the two regions that did not succeed with a UAS STEM campus had higher shares of employees and firms than the region who actually did succeed with a UAS STEM campus, i.e., Brugg-Windisch.

Table A1 Number of employees and firms in regions that succeeded with application for UAS-STEM-campus in comparison to regions that did not succeed

	(1) Fulltime equivalents / hectare	(2) Firms / hectare
University of Applied Sciences Bern		
Region not successful with STEM campus		
Catchment Area STEM-Campus City of Bern, relocated in 2003 to Burgdorf and Biel	*17.237*	*1.732*
Region successful with STEM campuses		
Catchment Area Burgdorf	6.195	0.924
Catchment Area Biel	9.435	1.195
UAS of Northwestern Switzerland		
Region not successful with STEM campuses		
Catchment Area of Olten: relocated in 2003	*9.972*	*1.180*
Catchment Area of Oensingen: relocated in 2006	*9.251*	*1.142*
Region successful with STEM campus		
Catchment Area of Brugg-Windisch	9.146	1.128

Note: Table based on Lehnert et al. (2020), data are from SFSO, Business Census, waves 1995 and 1998.

Table A2 Additional analyses of parallel trends

	Dependent Variable: ln(priority filings)			
	(1) pre-treatment period		(2) post-treatment period	
Year			yes	
TG_j			excluded	
$Treatment_{jt}$				
	t-11	-0.264*	t+1	-0.025
		(0.147)		(0.020)
	t-10	-0.188***	t+2	0.003
		(0.064)		(0.021)
	t-9	-0.093	t+3	-0.003
		(0.060)		(0.022)
	t-8	-0.113***	t+4	-0.004
		(0.034)		(0.023)
	t-7	-0.076***	t+5	0.022
		(0.028)		(0.023)
	t-6	-0.064**	t+6	0.053**
		(0.026)		(0.024)
	t-5	-0.063**	t+7	0.047*
		(0.025)		(0.026)
	t-4	-0.081***	t+8	0.021
		(0.025)		(0.028)
	t-3	-0.054**	t+9	0.037
		(0.023)		(0.032)
	t-2	-0.017	t+10	0.048
		(0.023)		(0.034)
	t-1	-0.015	t+11	0.061
		(0.020)		(0.040)
	t 0	Baseline		
Constant		0.335***		
		(0.041)		
AR2		0.2967		
R2		0.3007		
n		23902		
p-Value		0.0000		

Note: standard errors clustered at the municipality level in parentheses. The regression includes municipality fixed effects. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A3 Estimation results including catchment-area-fixed-effects and catchment area linear trends

	Dependent Variable ln(priority filings)		
	(1) Baseline	(2) Levels	(3) Levels and trends
Year	yes	yes	yes
Catchment area-specific levels		yes	yes
Catchment area-specific linear trends			yes
TG_j	0.060	excluded	excluded
	(0.047)		
$Treatment_{jt}$	0.068***	0.061***	0.055***
	(0.016)	(0.015)	(0.020)
Constant	0.328***	0.310***	0.311***
	(0.038)	(0.040)	(0.039)
AR2	0.2826	0.2906	0.2912
R2	0.2862	0.2946	0.2957
N	22960	22960	22960
p-Value	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A4 Estimation results without the 10 largest cities

	Dependent Variable ln(priority filings)											
	(1) Baseline	(2) without Zurich	(3) without Bern	(4) without Basel	(5) without Winterthur	(6) without Lucerne	(7) without St. Gallen	(8) without Biel	(9) without Thun	(10) without Köniz	(11) without Schaffhausen	(12) without the 10 largest cities
Year	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TG_j	0.060	0.060	0.057	0.060	0.060	0.060	0.060	0.060	0.064	0.058	0.067	0.066
	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.046)	(0.046)
$Treatment_{jt}$	0.068***	0.068***	0.070***	0.068***	0.068***	0.068***	0.068***	0.068***	0.068***	0.069***	0.069***	0.072***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Constant	0.328***	0.325***	0.328***	0.324***	0.325***	0.326***	0.326***	0.326***	0.324***	0.328***	0.321***	0.300***
	(0.038)	(0.038)	(0.038)	(0.037)	(0.037)	(0.038)	(0.038)	(0.037)	(0.037)	(0.038)	(0.037)	(0.036)
AR2	0.2826	0.2609	0.2889	0.2750	0.2882	0.2781	0.2828	0.2857	0.2855	0.2848	0.2813	0.2657
R2	0.2862	0.2646	0.2925	0.2787	0.2918	0.2817	0.2864	0.2893	0.2891	0.2884	0.2850	0.2694
N	22960	22944	22944	22944	22944	22944	22944	22944	22944	22944	22944	22800
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A5 Estimation results excluding frequent applicants

	Dependent Variable ln(priority filings)			
	(1) Baseline Model	(2) Without upper 1st percentile	(3) Without upper 5th percentiles	(3) Without upper 10th percentiles
Year	Yes	yes	Yes	yes
TG_j	0.060	0.056	0.041	0.026
	(0.047)	(0.034)	(0.025)	(0.020)
$Treatment_{jt}$	0.068***	0.063***	0.050***	0.042***
	(0.016)	(0.013)	(0.010)	(0.009)
Constant	0.328***	0.270***	0.221***	0.162***
	(0.038)	(0.028)	(0.021)	(0.016)
AR2	0.283	0.2870	0.2787	0.2605
R2	0.286	0.2906	0.2823	0.2642
n	22960	22960	22960	22960
p-Value	0.000	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A6 Estimation results for first-time applicants

	Dependent Variable ln(Number of first-time Applicants)
Year	yes
TG_j	0.030
	(0.019)
$Treatment_{jt}$	0.031***
	(0.008)
Constant	0.125***
	(0.016)
AR2	0.2310
R2	0.2349
n	22960
p-Value	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A7 Estimation results exploiting only timing of UAS-establishments in treated regions (without control groups)

	Dependent Variable						
	ln(priority filings)	ln(grant rate)	ln(citations 3-yr lag)	ln(citations 5-yr lag)	ln(claims USPTO)	ln(claims EPO)	ln(family size)
Year	yes	yes	yes	yes	yes	yes	yes
TG_j	excluded	excluded	excluded	excluded	excluded	excluded	excluded
$Treatment_{jt}$	0.075***	0.016**	0.024**	0.055***	0.053	0.132***	0.099***
	(0.026)	(0.007)	(0.011)	(0.015)	(0.035)	(0.038)	(0.030)
Constant	0.426***	0.142***	0.088***	0.160***	0.426***	0.564***	0.504***
	(0.021)	(0.007)	(0.007)	(0.011)	(0.025)	(0.029)	(0.021)
AR2	0.2719	0.1183	0.0998	0.1227	0.1514	0.1310	0.1721
R2	0.2763	0.1236	0.1052	0.1280	0.1565	0.1362	0.1771
N	16688	16688	16688	16688	16688	16688	16688
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A8 Estimation results based on inventor location data

	Dependent Variable						
	ln(priority filings)	ln(grant rate)	ln(citations 3-yr lag)	ln(citations 5-yr lag)	ln(claims USPTO)	ln(claims EPO)	ln(family size)
Year	yes	yes	Yes	yes	yes	yes	yes
TG_j	0.078*	0.043***	0.028**	0.045**	0.138**	0.184***	0.168***
	(0.045)	(0.011)	(0.014)	(0.021)	(0.055)	(0.060)	(0.050)
$Treatment_{jt}$	0.088***	0.009*	0.047***	0.088***	0.106***	0.138***	0.115***
	(0.016)	(0.005)	(0.010)	(0.013)	(0.026)	(0.027)	(0.021)
Constant	0.464***	0.148***	0.114***	0.197***	0.545***	0.668***	0.585***
	(0.036)	(0.009)	(0.012)	(0.018)	(0.046)	(0.050)	(0.041)
AR2	0.364	0.152	0.119	0.148	0.175	0.176	0.209
R2	0.368	0.156	0.123	0.152	0.180	0.180	0.213
N	22960	22960	22960	22960	22960	22960	22960
p-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: standard errors clustered at the municipality level in parentheses. * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.