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Regional Innovation Effects of Applied Research Institutions

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ABSTRACT

We analyze the effect of applied research institutions on regional innovation activity. Exploiting a policy reform that creates tertiary education institutions conducting applied research, the Universities of Applied Sciences (UASs) in Switzerland, we apply difference-in-differences estimations to investigate the effect on innovation quantity and quality. Findings show a 7.7 to 13 percent increase in regional patenting activity (i.e., quantity), and a 1.3 to 11 percent increase in patent family size, and the number of granted patents, claims, and citations per patent (i.e., quality). Findings are robust to various model specifications, suggesting that applied research taught in UASs boosts regional innovation.
I. Introduction

Following Jaffe’s (1989) influential study on “the real effects of academic research,” a study investigating the innovation effects of research in universities, a number of researchers have investigated the role played by major centers of academic research and education, such as those in Silicon Valley or on Route 128, in enhancing a country’s innovation activities (e.g., Audretsch & Stephan, 1996; Mansfield & Lee; 1996, Saxenian, 2000). More recently, some studies have also successfully resolved endogeneity problems and identified causal effects (e.g., Toivanen & Väänanen, 2016; Valero & Van Reenen, 2016).

However, two issues remain unresolved: First, the literature has mainly examined the effect on innovation of universities that predominantly focus on basic research (e.g., Rosenberg & Nelson, 1994). Institutions that conduct and teach applied research have not been studied. Second, regional heterogeneity in innovation activities can be very substantial. Thus what works for the major innovation centers, which often draw upon many top-ranked academic research institutions, might not work for other regions of a state or country. Whether the implementation of applied education institutions can drive innovation activities in regions outside of major centers of commercial innovation remains unknown. But given their focus on applied research and the strong relationships they have to small and medium-sized enterprises (SMEs), such a link appears plausible.

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 (UASs¹). According to their legal mandate, UASs must (a) focus their research and

¹ “Universities of Applied Sciences” is used for Swiss institutions called “Fachhochschulen” or for German institutions called “Fachhochschulen” and more recently “Hochschulen für angewandte Wissenschaften (HAW)”.
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) with 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 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 information which provides us with comprehensive information on the emergence of new technologies, and because patent data are systematically screened and recorded by patent offices (Nagaoka, Motohashi, & Goto, 2010; Giuri et al., 2007). From administrative records of the European Patent Office (EPO) we obtain data on the location of each applicant to determine the geographic origin of patent applications. From these data we compute the number of regional patent applications, grants and citations per year.

We use the abbreviation UASs for Universities of Applied Sciences, plural, and UAS for University of Applied Sciences, singular.
However, not all patents are equally important: some are more valuable, others are less so (van Zeerbroeck, 2011). EPO patent filings are already more valuable than national ones, but are still highly heterogeneous in terms of value. The economic value of patents thus greatly differs (Acs et al., 2002; Giuri et al., 2007; Griliches, 1979, 2007). Estimating the effect of the establishment of UASs on patent quality therefore requires further measures that take into account the value distribution of patents. For our second outcome measure of “regional patenting quality,” we use the following quality indicators provided by the EPO: grant status, forward citations, claims, and patent family size.

Our empirical results show an increase in the quantity and the quality of innovation activities after the establishment of UASs: Depending on the specification of our econometric model, we estimate an increase of 7.7 to 13 percent in regional patenting activity. Depending on the quality indicator we use, we measure an increase of 1.2 to 11 percent in regional patenting quality. Several robustness tests verify that the impact on innovation is highly robust. In the last section, we provide additional empirical analyses of the mechanisms that might underlie the increased innovation activities. Our results indicate that the effects are at least partly due to a change in the labor supply, i.e., UAS graduates who spread out into the treated regions after the UASs were established.

For national or regional innovation policy makers, our results suggest that the establishment of applied research and higher education institutions helps to foster regional innovation by spreading innovation activities to areas outside the 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 II presents the institutional background and outlines the Swiss education system. Section III explains how we created and prepared the data. Section IV describes our empirical strategy, and section V shows the results. Section VI provides number of robustness checks, and section VII discusses the findings and concludes.

II. Institutional Background

Before the UAS reform and the resulting UAS establishment 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 percent of the country’s population, and (b) professional vocational education and training (PVET) institutions for approximately 15 percent 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

\(^2\) 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](http://www.bfs.admin.ch/bfs/portal/de/index/regionen/11/geo/institutionelle_gliederungen/01b.html)).

\(^3\) The Swiss education system has both an academic and a vocational track at the upper secondary and tertiary levels. However, the large majority of Swiss students follow the vocational track completing an apprenticeship and receiving a nationally recognized certificate that gives them access to vocational institutions at the tertiary level: UASs, Professional Education and Training Colleges, and (Advanced) Federal Professional Education and Training Exams (e.g., SCCR\(^5\) 2007, 2010, and 2014). The latter two institutions allow vocational graduates to acquire formal, continuous training, but do not have a legal mandate to conduct research (Bereuter, 2011; EFHK, 2000).

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). The underlying idea was that UASs should provide a steady supply of highly skilled individuals with both practical and scientific knowledge, 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 Botschaft FHSG, 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. In contrast, academic universities perform basic academic 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, or Botschaft FHSG, 1994).

Although fields of study may overlap between universities and UASs—e.g., engineering, business administration, and chemistry—and graduates may end up in almost the same 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 Baccalaureate schools), UAS students usually come from a dual VET system apprenticeship, which involves both classroom education and practical training, including work experience at the training firm. In addition, while students from both the academic university and
the UAS track may study in 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.

To estimate the effect of the UAS reform on innovation quantity and quality, we exploit two sources of variation in the establishment of UAS campuses: location and time. These two sources developed 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. 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 underlying differences in economic, technical, or innovative
factors.\footnote{Pfister (mimeo 2017) provides a detailed analysis of the process through which the establishment of UASs was
determined. Results are available upon request.}

III. Data

A. 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.\footnote{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.} 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 & Väänänen, 2016; Schartinger, Rammer, Fischer, & Fröhlich, 2002). We restrict our analysis to campuses located in 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.\footnote{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). So does the distribution of firms
in these regions.} The German-speaking
UASs constitute two-thirds of the UAS in 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

<table>
<thead>
<tr>
<th>University of Applied Sciences</th>
<th>Location of Campuses</th>
<th>Year of establishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bern University of Applied Sciences</td>
<td>Bern</td>
<td>1997-2003</td>
</tr>
<tr>
<td></td>
<td>Burgdorf</td>
<td>1997</td>
</tr>
<tr>
<td></td>
<td>Biel</td>
<td>1997</td>
</tr>
<tr>
<td>University of Applied Sciences of Eastern Switzerland</td>
<td>St. Gallen</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>Rapperswil</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>Buchs</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>Chur</td>
<td>2000</td>
</tr>
<tr>
<td>University of Applied Sciences of Zurich</td>
<td>Winterthur</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>Wädenswil</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>Zürich</td>
<td>1998</td>
</tr>
<tr>
<td>University of Applied Sciences of Central Switzerland</td>
<td>Horw</td>
<td>1997</td>
</tr>
<tr>
<td>University of Applied Sciences of Northwestern Switzerland</td>
<td>Oensingen</td>
<td>1998-2003</td>
</tr>
<tr>
<td></td>
<td>Olten</td>
<td>2003-2006</td>
</tr>
<tr>
<td></td>
<td>Brugg-Windisch</td>
<td>1998</td>
</tr>
<tr>
<td></td>
<td>Muttenz</td>
<td>1997</td>
</tr>
</tbody>
</table>


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 & Kogler, 2010; Moretti, 2011). 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 & Goldstein, 2007; Liu, 2015). This literature suggests that universities affect regional innovation (and other economic outcomes such as productivity, growth, and entrepreneurial 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.
activity) not only by producing (basic) research, but also by generating direct and indirect spillovers (Liu 2015). 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. Indirect spillovers arise from agglomeration economies, i.e., the benefits or increasing returns accruing from nearby resources, such as firms or skilled people (Feldman & Audretsch 1999; Glaeser, 2010).

Both types of spillovers are sensitive to geographical distance, because proximity implies lower costs (Feldman & Kogler, 2010; Moretti, 2011). Moreover, tacit knowledge—a fundamental driver of these spillovers—is regionally embedded (Feldman & Kogler, 2010; Lundvall & Johnson, 1994; Maskell & 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 & Kogler 2010: 389). This sensitivity to distance 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 supply in the labor market 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

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8 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.
knowledge into practice. Assuming that these UAS graduates have a low mobility (i.e. rarely moving 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 VI (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.\(^9\)

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\(^{10}\), 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

\(^9\)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 (mimeo 2017). The moving 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 & Wolter, 2013; Muehlemann & Wolter, 2011). Thus contamination due to potential UAS students’ moving from the control group to the treatment group is very unlikely.

\(^{10}\)For Switzerland, Muehlemann, 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.
catchment area. 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 percent of employed individuals living in Switzerland commute less than 25 kilometers (approximately 15 miles) from home to work.

We therefore define a municipality as a “treated region” if it is located within 25 kilometers of a UAS campus. 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). This data provides information on the actual travel distance (in car 11 Section VI, 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.

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

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

The mobility and transport microcensus (SFSO/ARE, 2007) shows that 90 percent 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 (mimeo 2017) show that our definition of the UAS catchment area well represents the region in which 90 percent of Swiss people regularly commute.
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.

Figure 1 Catchment area for the campus in St. Gallen and locations of UAS campuses

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

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 beyond the scope of this study. For example, whether interaction between UASs and firms are 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. Consequently, calculating the distance between UASs and firms is not possible.

Nevertheless, we try to investigate these different spillovers separately: In section VI, 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.

B. Patent Data

To measure patenting activity, we use patent data from the “Worldwide Patent Statistical Database – April 2013 Version” from the European Patent Office (EPO). The EPO database, containing more than one million patent applications of Swiss applicants from 1888 through 2013, provides information about the application date and the inventors’ and applicants’ names, affiliations, and addresses. To localize a patent’s geographic origin, we use the applicant’s address. We assign each patent application to its applicant’s municipality, Switzerland’s smallest

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15 UAS’s 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 academic 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).
political unit. Because almost 99 percent of all patent applications have only one applicant, they can be clearly attributed to one specific municipality. For the remaining one percent with multiple applicants from several municipalities, we use fractional counts, i.e., we weight the number of applicants in a particular municipality by its relative number of applicants.

To construct our outcome variable “regional patenting activity,” we take the sum of patent applications by application 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. Our final sample contains information on more than 300,000 patent applications in 1435 regions of which 1043 were treated at some point.

To create our outcome measures for “regional patenting quality,” we use the following set of quality indicators (provided by the European Patent Office) that indicate different aspects of value (e.g., Squicciarini et al., 2013): granted patents, forward citations, number of claims, and patent family size.17

16 Switzerland comprises approximately 2,300 municipalities, 148 districts, and 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). Each municipality generally includes several ZIP codes. Overall, Switzerland has about 3,500 ZIP codes.

17 We link the indicators using the application identifier number appln_id from our database “Worldwide Patent Statistical Database – April 2013 Version.”

As granted patents fulfill the patentability criteria (inventive step, novelty, and industrial applicability), they are technologically and economically more valuable than unsuccessful applications. However, as a large percentage of applications are granted, the indicator is less informative (OECD, 2009; van Zeebroeck, 2011). Forward Citations
The EPO database contains a binary variable indicating whether a patent application was granted. This variable consists of our qualitative indicator granted patents. The indicator forward citations includes the number of citations for each patent application. 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.\footnote{One problem with using forward citations is its timeliness: As the citations that a patent receives appear 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 years, as more than 50\% of citations arise within this years (Gambaradella et al., 2008; Lanjouw & Schankerman, 2004; OECD, 2009; van Zeebroeck, 2011).}

To create the indicator number of claims, we use the number of claims in each patent application in the latest EP publication. 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.

\textit{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 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 & 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 & Shankerman 2001; Schmoch, Grupp, Mannsbart & Schwitalla, 1988).
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.
### Table 2 Descriptive statistics for quantity and quality indicators

<table>
<thead>
<tr>
<th>Variable</th>
<th>Untreated regions</th>
<th>Treated regions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Number of Patent Applications</td>
<td>2.09</td>
<td>13.60</td>
</tr>
<tr>
<td>Number of Granted Patents</td>
<td>0.75</td>
<td>6.14</td>
</tr>
<tr>
<td>Number of Citations per Patent (3 year citation lag)</td>
<td>0.08</td>
<td>0.37</td>
</tr>
<tr>
<td>Number of Citations per Patent (5 year citation lag)</td>
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<td>0.59</td>
</tr>
<tr>
<td>Number of Claims US</td>
<td>1.65</td>
<td>4.91</td>
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<tr>
<td>Number of Claims Europe</td>
<td>1.33</td>
<td>3.82</td>
</tr>
<tr>
<td>Family Size</td>
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<td>2.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Granted Patents</td>
<td>1.00</td>
<td>10.12</td>
</tr>
<tr>
<td>Number of Citations per Patent (3 year citation lag)</td>
<td>0.11</td>
<td>0.73</td>
</tr>
<tr>
<td>Number of Citations per Patent (5 year citation lag)</td>
<td>0.21</td>
<td>0.97</td>
</tr>
<tr>
<td>Number of Claims US</td>
<td>1.86</td>
<td>5.60</td>
</tr>
<tr>
<td>Number of Claims Europe</td>
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<td>4.52</td>
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</tr>
<tr>
<td></td>
<td>392</td>
<td>1043</td>
</tr>
</tbody>
</table>


---

20 Descriptive statistics show averages per municipality (not per applicant). 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 differences before and after the establishment and between the treatment and control groups, i.e. the DID effect, is positive and significant.
## Table 3 Descriptive statistics for quantity and quality indicators – Trends

<table>
<thead>
<tr>
<th>Variable</th>
<th>Untreated regions</th>
<th>Treated regions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average trend in percent</td>
<td>Std. Err.</td>
</tr>
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<td>Number of Patent Applications</td>
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</tr>
<tr>
<td>Number of Granted Patents</td>
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<td>(0.003)</td>
</tr>
<tr>
<td>Number of Citations per Patent (3 year citation lag)</td>
<td>0.004***</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Number of Citations per Patent (5 year citation lag)</td>
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<td>(0.002)</td>
</tr>
<tr>
<td>Number of Claims US</td>
<td>0.013**</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Number of Claims Europe</td>
<td>0.011**</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Family Size</td>
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<td>(0.004)</td>
</tr>
<tr>
<td>Number of Municipalities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: EPO Worldwide Patent Statistical Database – April 2013 Version. Given that the distribution of the outcome variables is skewed to the right, we transform the outcome variables to receive approximate normal distributions. A regression of the variable ln(number of patents) and of the variables indicating patent quality on the continuous year variable (1990 to 1997 for the period before the reform and 1998 to 2008 for the period after the reform) provides the average changes in the outcome variable for the treatment and the control groups and for the period before and after the reform. The trends of the treatment and the control groups before the reform do not show a statistically significant difference.
IV. Empirical Framework

A. Difference-in-Differences Estimation

To analyze the effect of the establishment of UASs on regional patenting quantity and quality, we use a DiD\textsuperscript{21} approach and estimate the following equation:

\begin{equation}
Y = \alpha + \beta \text{Treatment}_{jt} + \gamma_t + \delta T G_j + \lambda_k + \varepsilon_{jt}
\end{equation}

Our dependent variable $Y$ includes our set of indicators for patent quantity and quality in municipality $j$ in year $t+3$. The variable $\ln(\text{Number of patents}_{jt+3})$, our quantitative measure, refers to the natural logarithm\textsuperscript{22} of the number of patent applications three years after the 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.\textsuperscript{23}

\textsuperscript{21} 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) might lead to misleading estimation outcomes. However, as these factors equally affect both the treatment and control groups, they do not distort our results.

\textsuperscript{22} To transform the variable $\text{Number of patents}$, we add 1 to all patent counts.

\textsuperscript{23} 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
Our measures of innovation quality include
- the number of granted patents $\ln(Granted_{jt+3})$,
- the citations each patent receives within three years and within five years $^{24} \ln(\text{Citations per patent}_{jt+3})$
- the number of claims, $\ln(\text{Claims US}_{jt+3})$, and in the latest EP publication, $\ln(\text{Claims EP}_{jt+3})$
- the number of jurisdictions in which an invention is protected (international patent family), $\ln(\text{Family size}_{jt+3})$

The explanatory variables on the right-hand side of (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 $\gamma$ represents the common non-linear time trend of the treatment and the control groups and includes year dummies. To control for unobservable time-constant effects on the district level, we include the variable $\lambda_k$, which comprises district dummies. $^{25} \epsilon_{jt}$ is the error term.

Our main variable of interest, $\text{Treatment}_{jt}$, is a dummy variable indicating whether municipality $j$ has a UAS campus in year $t$. The coefficient $\beta$ in the equations shows the effect of UAS establishment on a region’s patenting activity, assuming that the treated regions would have effects may become stronger over time, we use short time lag (three years) to make our test stronger and underestimate the effect size.

$^{24}$ For those patent applications having no citations, we add a constant of 1 before transforming into $\ln(\text{Citations per patent}_{jt+3})$

$^{25}$ 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.
had the same trends as the untreated regions had the policy reform not happened. We test this assumption (and others) in Section B.

**B. Identification**

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

Figure 2 shows the natural logarithm of the number of patents per municipality from 1990 through 2008 for the treatment and the control groups. The curves show a common underlying trend before the establishment of the UAS campuses in 1997. After the establishment, a deviation from this common trend takes place.\(^{26}\)

\(^{26}\) Figures showing the trends for the qualitative indicators are available in Pfister (mimeo 2017)
Figure 2 ln(Number of Patents) for treatment and control group, before and after the UAS establishment

Source: EPO Worldwide Patent Statistical Database – April 2013 Version; 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 UAS establishment or whether they show a statistically significant difference, we proceed as follows: We regress the quantitative and qualitative innovation indicators on the years 1990 to 1997, the period preceding the UAS creation\textsuperscript{27}, thereby differentiating between the pre-treatment trend for the control group (the variable $Year$) and the pre-treatment trend for the treatment group (the variable $Year \times TG$). If the interaction $Year \times TG$ shows a statistically significant effect, the treatment group would have a significantly different trend from the control group.

\textsuperscript{27} 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.
Table 4 shows the results with a linear time trend, and Table 5 shows the same results for possible non-linear trends by including dummies for each year. Both tables show no statistically significant difference in pre-treatment trends (variable Year x TG) between the treatment and control groups. Therefore, we find no indication of a violation of the parallel trends assumption.28

The second key assumption of our empirical strategy concerns the mobility of graduates. To estimate the unbiased effect of UASs on regional patenting activities, we assume that UAS graduates have stable mobility and commuting behavior.29 However, although we showed that 90 percent of employed individuals commute less than 25 kilometers to work, the remaining ten percent 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 VI, showing that these effects are very small and negligible.

28 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.

29 The second form of direct spillovers (interaction between UASs and firms) and indirect spillovers are less prone to these mobility concerns, because UAS’s, firms and cities are less mobile than graduates are.
Table 4 Parallel trends assumption quantitative and qualitative Indicators – linear trend

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<thead>
<tr>
<th></th>
<th>ln(Number of Patents)</th>
<th>ln(Granted)</th>
<th>ln(Citations, 3-year lag)</th>
<th>ln(Citations, 5-year lag)</th>
<th>ln(Claims US)</th>
<th>ln(Claims EP)</th>
<th>ln(Family Size)</th>
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<tbody>
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<td>0.0025</td>
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</table>

Source: EPO Worldwide Patent Statistical Database – April 2013 Version. Clustered Standard errors on the municipality level are reported 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 – year dummies

<table>
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<tr>
<th>Year</th>
<th>ln(Number of Patents)</th>
<th>ln( Granted)</th>
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<th>ln(Citations, 5-year lag)</th>
<th>ln(Claims US)</th>
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<table>
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<tr>
<th>Year x Treatment Group</th>
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</thead>
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<td>1994</td>
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<td>1995</td>
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<tr>
<td></td>
</tr>
<tr>
<td>1997</td>
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<td></td>
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</tbody>
</table>

Source: EPO Worldwide Patent Statistical Database – April 2013 Version. Clustered Standard errors on the municipality level are reported 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 0.9393 for ln(Number of Patents), 0.7508 for ln(Granted), 0.6693 for ln( Citations, 3-year lag), 0.2281 for ln( Citations, 5-year lag), 0.9096 for ln( Claims US), 0.9522 for ln( Claims EP), and 0.7353 for ln(Family Size) (Prob. > F).
V. Results

To estimate the effect of UAS on regional patenting activity, we estimate (1) using a DiD estimator. Table 6 shows the results of the estimations using the our quantity and quality indicators: The first column displays the results for the number of patent applications. The $Treatment_{jt}$ coefficient equals 12.23 (13 percent) and is statistically significant at the one percent level. The UAS establishment thus led to a significant and economically important increase in innovation quantity.

The second column shows the results for our first quality indicator, the number of granted patents per municipality. This quality indicator tells us whether quality of patent applications in terms of the patentability criteria—Inventive step, novelty, and industrial applicability—changes after the establishment of UASs. The coefficient of the variable $Treatment_{jt}$ equals 7.5 and is statistically significant at the one percent level. In other words, the number of granted patent applications increases by 7.8 percent more in municipalities located in treated areas than those municipalities located in untreated areas. This increase in the number granted patents thus parallels the increase in the number of patent applications.\(^\text{30}\) The establishment of UAS therefore does not lead to an increase in the number of patent applications that are low quality and thus never lead to patents. In contrast, the increase in innovation quantity is also an increase in innovation quality.

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

\(^{30}\) The effect on the number of granted patents per patent applications, i.e., the change in ratio of granted patents relative to the number of patent applications, equals 0.4 percent and is statistically insignificant.
patent application. Together, these two indicators are relative quality measures showing the change in average citations for each patent application. The effect of UAS on forward citations with a three-year citation lag equals 1.3 percent; with a five-year lag, 3.0 percent. Both coefficients are statistically significant (at the ten and the one percent level).

This effect in the two quality indicators has three implications. First, as forward citations reflect the importance of the patented technology for the patent holder, the establishment of UASs increased the private economic value of patents for their owners. Second, citations mirror the social value of an invention, i.e., its economic externalities: A large number of forward citations implies that the invention is important for those not holding the patent. UASs thus increased not only the private value of patents but also their social value. Third, an increase in the number of citations with a short citation lag implies that the invention is rapidly recognized. The positive effect in the number of citations with a three-year lag thus show that UAS increase the technological value of patents.

The fifth and sixth columns show that the number of claims increased in both the U.S. and Europe. These two indicators show the boundaries of the property rights that the patent protects. More claims, i.e., the broader the scope of a patent, imply a broader legally protected technological area and, consequently, higher economic value for the patent holder. In our DiD framework, the coefficient of the variable Treatment, shows the percentage change in the number of claims in patents in the treatment group compared to that in the control group. The two indicators thus measure whether the average scope of a patent—and its economic value—in the treatment group increased more than that of patents in the control group. For the U.S., the effect amounts to 10.6 percent; for Europe, 9.3 percent. The average number of claims per patent thus increased by almost 11 percent in the U.S., and by 9 percent in Europe. These results demonstrate
that the establishment of UASs led to a significant increase in the average patent scope and, consequently, to an increase in the average economic value of the patents.

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 several countries. In regions that received a UAS, the average patent family size increased by 6.8 percent more than in non-UAS regions. Thus patents in treated regions are protected in 6.8 percent more countries than those in untreated regions, corroborating the increase in the economic value of patents due to the establishment of UAS.
<table>
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<th>yes</th>
<th>yes</th>
<th>yes</th>
</tr>
</thead>
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<td>0.025</td>
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<td>(0.061)</td>
<td>(0.046)</td>
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<td></td>
</tr>
</tbody>
</table>

Source: EPO Worldwide Patent Statistical Database – April 2013 Version. Clustered Standard errors at the municipality level are reported in parentheses; * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.
VI. Robustness Checks

In our 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.

The first possible cause of contamination is UAS graduates’ commuting behavior across the regional boundaries that we previously defined.\textsuperscript{31} 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 most likely be contaminated in both directions.

The first column in Table 7 shows the results of the DiD regression of (1) with the reduced sample. The coefficient of $Treatment_{it}$ is slightly, but not significantly higher than that in the baseline model (0.132 (0.028) vs. 0.122 (0.027)). 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 moving across the regional boundaries. To analyze the moving 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 percent of UAS graduates from engineering, IT, chemistry, and the life sciences still live in the same UAS catchment area in which they graduated. Thus moving 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 this form of contamination effects.

\textsuperscript{31} Pfister (mimeo 2017) provides an extensive description of the data and the methods for analyzing potential contamination effects.
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 downwardly biased; 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.\footnote{The results would imply a downward bias.} For 80 percent 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 the graduates are distributed evenly across the regions.

Although all forms of mobility—commuting or moving—might lead to contamination of the treatment and control groups, these issues cause only very limited problems in our Swiss data. Therefore, studying this policy reform in Switzerland provides an almost ideal setting for analyzing the causal effects of applied research on innovation. However, even if mobility were an empirical concern, 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.

Second, we focus on the economic background of the smallest regional entities municipalities, including municipality fixed effects, in our baseline estimation equation. By so doing, we are able to control for unobservable time-constant characteristics at the lowest possible level.\footnote{See Pfister (mimeo 2017, chapter 2.6.2).} Column two of Table 7 displays the results of the estimation. As the coefficient $\beta$ 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.\textsuperscript{34} However, the effect still equals 7.7 percent and is statistically significant at the one percent level. The effect, though smaller, remains robust to the inclusion of municipality fixed effects. Our result indicate that it is not induced by the municipalities’ underlying unobservable time-constant characteristics.

Third, we deal with the question of whether the expansion of higher academic education could also potentially drive our results.\textsuperscript{35} In 1990, for example, 86,000 students were enrolled in an academic university; by 2008, the number had increased to 120,000.\textsuperscript{36} This expansion of academic graduates constitutes a change in the labor supply, a change that may also substantially affect innovation in our regions. To compare the importance of the two different supply changes of highly skilled workers—the increase in UAS graduates due to the establishment of UASs and the increase in academic university graduates—we use data from the “Schweizer Hochschulinformationssystem” (SHIS), provided by the Swiss Federal Statistical Office. In other words, we model the change in the labor supply of UAS graduates and of academic university graduates in each municipality and in each year to investigate their relative importance for regional patenting activity.

Column three of Table 7 includes the variables for two supply changes. It shows a large and statistically significant effect for the UAS graduates; the effect for the academic university graduates

\textsuperscript{34} 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).

\textsuperscript{35} Chapter 2.6.4 Confounding Effects: Education Expansion of Academic Universities provides an extensive description of the data and the methods to analyze the potential impact of a change in the supply of academic university graduates (Pfister, mimeo 2017).

\textsuperscript{36} See SFSO, SHIS, at http://www.bfs.admin.ch/bfs/portal/de/index/infothek/erhebungen__quellen/blank/blank/sash/01.html.
graduates is six times smaller and insignificant. The coefficient of the variable \(\text{Treatment}_{jt}\) decreases substantially compared to the same coefficient in the baseline specification. This portion of the innovation effect is attributable to UAS graduates entering the labor market, remaining in it, and enhancing its quality. The remaining innovation effect relates to the other forms of spillovers—collaboration between UAS and firms, and agglomeration economies—or merely UAS professors producing patents.

Fourth, we examine timing issues.\(^{37}\) As the baseline model shows only the average effect of the establishment of UAS on innovation over the entire observation period, we now investigate how the effect develops over years, i.e., in the first, second, third, and further years after UAS establishment. Column four of Table 7 shows the innovation effect from the third to the eleventh year after UAS establishment.\(^{38}\) The effect equals 4 percent in \(t+3\) and increases to more than 13 percent in later years. Thus the results clearly show that, first, the innovation effect takes time to manifest after the establishment of UAS; a time lag of three years therefore seems adequate to estimate the effect of the UAS on innovation in our baseline model. Second, the results show that the innovation effect increases over time.

\(^{37}\) See Pfister (mimeo 2017) for a detailed description on the method to analyze how the innovation effect develops in post-treatment year.

\(^{38}\) 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 & Pischke, 2008). In other words, an increase in patenting activities before the reform 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.
Fifth, we investigate whether rural areas profit from the establishment of UASs.\textsuperscript{39} The literature shows vast empirical evidence that rural areas have less highly educated workers, weaker economic growth rates, higher poverty, and lower innovative performance (e.g., Abel et al., 2014; Partridge, Rickman, Ali, & Olfert, 2009; Partridge & 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 4.7, i.e., 4.8 percent, which is statistically significant at the five percent level. Thus, compared to rural municipalities not located near a UAS campus, rural municipalities near a UAS campus show a 5 percent increase in patenting activities, i.e., a smaller than average effect. The UAS establishment thus had a positive effect on rural areas and improved their innovative performance.\textsuperscript{40}

\textsuperscript{39} 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 mimeo 2017).

\textsuperscript{40} Estimating the effect of UAS on agglomeration municipalities reveals an 18 percent 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.
Table 7 OLS Results – Robustness Checks

<table>
<thead>
<tr>
<th>Year</th>
<th>Contamination Analysis</th>
<th>Municipality Fixed Effects</th>
<th>Academic Education Expansion</th>
<th>Innovation Effect over Time</th>
<th>Rural Areas</th>
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<td>yes excluded (0.068)</td>
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<td>0.064** (0.030)</td>
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<td>t+2 0.023 (0.028)</td>
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<td>University Graduates</td>
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<td>0.005 (0.015)</td>
<td>t+3 0.039 (0.028)</td>
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Notes: Authors’ calculations, based on EPO Worldwide Patent Statistical Database – April 2013 Version. Clustered standard errors on the municipality level are reported in parentheses; the regression includes district fixed effects; * statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.
VII. Conclusion

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 vocational training degree. To study their effect on innovation, we exploit the staggered establishment of these UAS in the mid-1990s. To measure their impact on innovation, we employ a difference-in-differences approach and rely on patent data provided by the European Patent Office. As a quantitative measure of innovation activities, we use the number of patent applications. Our results show that the establishment of UAS led to an increase of approximately 7.7 to 13 percent in regional patenting activity. To estimate the effect on innovation quality, we use a set of quality indicators from the EPO database. All indicators show a positive and statistically significant effect.

We provide extensive 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, because (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.
The results of our other robustness tests show that differences between the regions (municipality fixed effects) do not change our results and that the effect is not driven by an overall educational expansion.

The results of our robustness tests also provide insights into the potential mechanisms underlying this innovation effect. By modeling the innovation effect in each year following UAS establishment, we find that it develops over time. While the first two years show hardly any effect, from year three onward the effect becomes 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 take hold several years after the establishment of a UAS, because that is when the first graduates enter the labor market, following which will be a steady stream of new graduates.

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 three years because of application and funding processes), this second form of direct spillovers would also be consistent with an innovation effect taking hold after about three years.

Furthermore, the results of our robustness tests provide some evidence for the relative importance of different mechanisms. They show that a considerable portion of the effect is related to UAS graduates entering the labor market. Future research should use employer data to investigate how firms adapt their personnel decisions to the newly created labor supply in the respective regions. The remaining innovation effect might be attributed to cooperation between UAS and firms, collaboration between UAS and other research institutes, or UAS professors producing patents. We plan to investigate the relevance of these mechanisms in future research.
Our analysis thus shows strong evidence that the establishment of UASs whose primary purpose is conducting and teaching applied research has a causal quantitative and qualitative effect on innovation activities in the regions where they have been established, even when these regions are outside major centers of commercial innovation. These properties should make UAS an interesting instrument of economic and regional policy.
Bibliography


