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The Contribution of Vocational Education and Training to Innovation and Growth

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Summary

Despite the common view that innovation requires academically educated workers, some countries that strongly emphasize vocational education and training (VET) in their education systems—such as Switzerland and Germany—are highly competitive internationally in terms of innovation. These countries have dual VET programs, i.e., upper-secondary-level apprenticeship programs that combine about three-quarters of workplace training with about one-quarter of vocational schooling, and design them in such a way that their graduates (i.e., dual apprenticeship-graduates) play crucial roles in innovation processes. Regular updates of VET curricula incorporate the latest technological developments into these curricula, thereby ensuring that dual apprenticeship-graduates possess up-to-date, high-level skills in their chosen occupation. This process allows these graduates to contribute to innovation in firms. Moreover, these graduates acquire broad sets of technical and soft skills that enhance their job mobility and flexibility. Therefore, conventional wisdom notwithstanding, dual apprenticeship-graduates in such countries not only have broad skill sets that accelerate innovation in firms, but also willingly participate in innovation because of their high flexibility and employability.

Moreover, Switzerland and Germany have tertiary-level VET institutions that foster innovation. These are Universities of Applied Sciences (UASs), which teach and conduct applied re-

search, thereby helping build a bridge between different types of knowledge (vocational and academic). UAS students have prior vocational knowledge through their dual apprenticeship and acquire applied research skills from UAS professors who usually have both work experience and a doctoral degree from an academic university. Thus UAS graduates combine sound occupational knowledge with applied research knowledge inspired by input from the academic research frontier and from practical research and development (R&D) in firms. Firms employ UAS graduates with their knowledge combination as an important input for R&D. Consequently, regions with a UAS have higher levels of innovation than regions without one. This effect is particularly strong for regions outside major innovation centers and for regions with larger percentages of smaller firms.

Keywords: vocational education and training (VET), innovation, education systems, apprenticeship training, Universities of Applied Sciences, applied research

Introduction

Innovation relies on highly skilled individuals—an undisputed finding of the international literature on the innovation effects of education (e.g., Bianchi & Giorcelli, 2019; Valero & Van Reenen, 2019). However, the literature is divided on what exactly constitutes high skills. The dominant view is that individuals acquire high skills through a tertiary-level academic education (e.g., Aghion, 2008; Aghion & Howitt, 2006). Thus this literature views the skills taught in vocational education and training (VET) programs as low- or mid-level (e.g., Krueger & Kumar, 2004a;b). This view implies that only those countries with high percentages of graduates from tertiary-level academic education institutions will outpace other countries, because they can pro-

duce high-quality innovations at the technology frontier (e.g., Aghion, Akcigit, & Howitt, 2014; Vandenbussche, Aghion, & Meghir, 2006).

Despite this traditional view that high-quality innovation requires academically educated workers, some countries with strong VET systems always appear among the leading innovators in international innovation rankings. For example, Switzerland and Germany often rank among the top five or top ten countries in terms of innovation,[1] thereby surpassing countries that exhibit much higher percentages of students with tertiary-level degrees acquired solely through academic education (e.g., the UK or the US) (Organisation for Economic Co-operation and Development, 2014). About 60 to 70 percent of workers in Germany or Switzerland acquired their skills through VET (Statistisches Bundesamt, 2019b; State Secretariat for Education, Research and Innovation, 2020). These empirical patterns appear puzzling because they contradict the traditional literature's perception that academic education is the key ingredient for an economy to achieve high innovation performance. The question thus arises as to how this puzzle in the international literature can be explained.

In short, the answer is that the strong VET systems in countries such as Switzerland and Germany provide all labor market entrants (and thus not only academic students) with the high skills necessary for participation in outstanding innovation activities. Typically, young adolescents begin a three- or four-year dual VET program after compulsory school ends at the age of 15 or 16 years (State Secretariat for Education, Research and Innovation, 2020). The programs are "dual VET programs" because they feature two core components to ensure the provision of high skills (Backes-Gellner & Pfister, 2019): apprenticeship training at a firm and classroom education at a vocational school. About three-quarters of a dual VET program are carried out in training firms which—according to nationally defined and binding occupational curricula—integrate apprentices into regular work processes to systematically train them in a broad array of skills and

tasks. About one-quarter of a dual VET program is provided by vocational schools, also according to nationally defined and binding curricula. At the vocational schools, apprentices acquire theoretical knowledge that is related—but not limited—to their chosen VET occupation. These two components of dual VET programs ensure that their graduates (i.e., dual apprenticeship-graduates)[2] possess very broad occupation-specific skills, as well as general ones such as social and organizational skills. Thus these programs prepare their graduates to participate in high-quality innovation activities—not least because of the many educational or professional career options that Switzerland and Germany's permeable education systems offer, for example, studying at a University of Applied Sciences (UAS).

A reason for why these occupational skill sets constitute a valuable input for firms' innovation activities is a systematic curriculum updating process that guarantees that VET curricula contain skills in handling the latest technologies (Backes-Gellner & Pfister, 2019). As this curriculum updating process integrates the most innovative firms, those operating at the technology frontier, it ensures future-oriented updates of VET curricula. These skill sets of VET workers strongly complement those of academically educated workers in research and development (R&D), thereby ensuring that inventions more easily and quickly turn into innovative and marketable products (e.g., Backes-Gellner, 1996; Rupietta & Backes-Gellner, 2019b; Rupietta, Meuer, & Backes-Gellner, 2018). Through such mechanisms as important parts of the dual VET system in countries such as Switzerland and Germany, this system with its highly skilled vocationally trained workers contributes to these countries' very successful innovation ecosystems.

Therefore, a strong VET system presents one of several successful national paths for promoting innovation through education (Meuer, Rupietta, & Backes-Gellner, 2015; Toner & Woolley, 2016). This path builds on highly skilled dual apprenticeship-graduates with both the general and occupation-specific skills that enable them to participate in high-quality innovation activities

(Meuer et al., 2015). It also builds on a high-quality tertiary-level academic pillar as a complement to upper-secondary VET. The academic pillar needs to be internationally competitive in research and innovation but not necessarily large in student numbers (Commission of Experts for Research and Innovation, 2014).

However, Backes-Gellner & Pfister (2019) show that for a dual VET system to be successful in promoting innovation, it does require carefully designed and systematically updated training curricula with future-oriented occupational content at the technology frontier. In addition, to achieve a large enough workforce with VET skills, a successful dual VET system also requires that a VET path is an attractive educational choice for young adolescents through both high permeability and strong connections between the vocational and the academic pillars (Backes-Gellner & Pfister, 2019). As a positive secondary effect, this system also fosters social mobility by providing ample opportunities for educational and professional career advancements to apprenticeship graduates. For example, UASs offer dual apprenticeship-graduates the opportunity to acquire tertiary-level vocational knowledge augmented with applied research skills, thereby further promoting innovation through VET. In providing these opportunities, a dual VET system leads to high social and income mobility (as, e.g., shown by Chuard & Grassi, 2020, for Switzerland) and it reduces inequalities stemming from a sole focus on academic credentials (as, e.g., described by Sandel, 2020, as the "Tyranny of Merit").

The requirements that allow VET systems to promote innovation successfully will be outlined further in two sections. The first section "Dual Vocational Education and Training as a Driver of Innovation Activities" focuses on the requirements of upper-secondary-level dual VET programs that contain apprenticeships as their main component. The second section "The Role of Universities of Applied Sciences (UASs) in a VET-based Innovation Ecosystem" focuses on the required tertiary-level VET contributions as taught at UASs. If these two requirements of a dual

VET system are fulfilled, VET strongly contributes to innovation and growth.

Dual Vocational Education and Training as a Driver of Innovation Activities

Unlike economics studies that frequently highlighted only the importance of academically educated workers, an important strand of more qualitative literature has long indicated that innovation requires workers with mid- and high-level vocational skills (e.g., Maurice, Sellier, & Silvestre, 1986; Thurley & Lam, 1990; Toner, 2010; Lewis, 2020). Furthermore, these workers contribute not only to producing incremental innovation but also in transforming radical inventions into high-quality, marketable products, as well as advancing new inventions through participation in R&D activities (Backes-Gellner, 1996; Backes-Gellner & Pfister, 2019; Berger, 2013; Hall & Soskice, 2001; Maurice, Sorge, & Warner, 1980).

However, for vocationally trained workers to make such contributions, a VET system must fulfill three major requirements. First, a systematic VET curriculum design process must ensure that VET workers' skills align with the latest technological developments. Second, the VET programs must impart a mix of general and occupation-specific skills, both of which are essential for innovation. Third, for young adolescents, a VET path must represent an attractive educational choice by offering various occupational and educational career options and a high degree of job mobility.

Systematic Curriculum Design Processes to Guarantee Up-to-Date Occupational Skills

For enabling vocationally trained workers to contribute to firms' innovation activities, the structure and design of dual VET programs must teach apprentices the knowledge and skills that are crucial for innovation processes. These skills need to be embedded in dual VET programs'

two core components as is the case in such programs in Germany and Switzerland; that is, innovative skills need to be taught in the workplace training at the training firm (accounting for about 75 percent of the time) and in the education at the vocational schools (accounting for about 25 percent).[3] Furthermore, these two components are often complemented by inter-company training courses as a very important third component, although it accounts only for a small percentage of the training time. These inter-company training courses teach in particular the novel skills related to innovation activities (Backes-Gellner & Pfister, 2019; Rupietta & Backes-Gellner, 2019b). Therefore, all components of dual VET programs that prepare for innovation, such as those in Germany and Switzerland, adhere to nationally binding VET curricula that regulate the contents and requirements not only of the classroom-based vocational education but also of the workplace-based training and the inter-company training courses (Backes-Gellner & Pfister, 2019; Staatssekretariat für Bildung, Forschung und Innovation, 2017).

However, an important question from an education system perspective is how it can be guaranteed that such curricula are up to date and contain innovative skill sets. In Germany and Switzerland, the solution is a systematic curriculum updating process that involves all stakeholders, but innovative ones in particular for the designing and updating of its dual VET curricula. Thus the updating process involves representatives of all actors taking part in VET, including training experts from (innovative) firms, industry, vocational schools, and government (Backes-Gellner, 2017; Backes-Gellner & Pfister, 2019). As this institutionalized process regulates VET programs at the federal level, all dual apprenticeship-graduates in an occupation possess the same skill sets, independent of regional or firm-specific characteristics (Backes-Gellner & Pfister, 2019; Bundesinstitut für Berufsbildung, 2017). Therefore, the process of designing and regularly updating VET curricula also ensures that all dual apprenticeship-graduates all across Switzerland or Germany (irrespective of whether they received training at a large or small, or an innovative or

traditional firm) have the requisite skills for successfully participating in innovation activities (Backes-Gellner & Pfister, 2019).

Thus, in particular, two elements of the process for defining the VET curricula are crucial to the innovation success of a dual VET system:

- First, all types of stakeholders provide innovative input to the curriculum updating process, that is, training firms, industry experts, worker representatives, organizations of work, government, and vocational teachers contribute their knowledge on current and future developments and challenges (Backes-Gellner, 2017; Backes-Gellner & Pfister, 2019; Bolli, Caves, Renold, & Buergi, 2018a; Busemeyer & Trampusch, 2012). Most important in this process is industry experts' involvement from innovative training firms. They help ensure that VET curricula contain the skills that dual apprenticeship-graduates need to become contributors to innovation activities (Backes-Gellner & Pfister, 2019). All these experts jointly bring their occupational knowledge into the curriculum design process, thereby guaranteeing (a) that VET curricula feature the skills that firms require for production and innovation, (b) that the VET skills in updated curricula can be taught effectively at the respective training locations (firms, vocational schools, and inter-company training courses), and (c) that these skills meet the actual labor demand of employers.
- Second, frequent updates of VET curricula ensure that apprentices acquire knowledge at the technology frontier, enabling them to contribute to innovation upon completion of their dual apprenticeship program. For example, the time interval between curriculum updates for each VET occupation in Switzerland is five years or less (Backes-Gellner & Pfister, 2019). These frequent updates ensure that dual apprenticeship-

graduates as new labor market entrants keep pace with current technological and economic developments (Backes-Gellner & Pfister, 2019).

Furthermore, these elements of the curriculum design process lead to knowledge diffusion through the participation of firms in apprenticeship training, thereby contributing to the innovation performance of an economy. Two historical examples illustrate this contribution. First, Backes-Gellner (1996) shows in a cross-country analysis that updates of the VET curricula for metal-working occupations in the 1980s allowed Computerized Numerical Control (CNC) procedures to spread faster in Germany than in countries without strong VET systems. Second, the creation of new VET programs for IT occupations in the 1990s accelerated digitization by providing German firms with highly skilled IT workers (Backes-Gellner, 2017; Bundesinstitut für Berufsbildung, 2013). A later study by Schultheiss and Backes-Gellner (2020) further finds that implementing new technologies into VET curricula is particularly helpful for diffusing these technologies into small firms not yet operating at the technology frontier. In addition, Rupietta & Backes-Gellner (2019b) show that VET curriculum updates lead to increased innovation outcomes for firms participating in apprenticeship training due to faster diffusion of new technologies.

General and Occupation-Specific Skills in VET Curricula to Provide Innovation-Enabling Skill Mix

While academically educated workers may develop the theoretical bases for new products, vocationally trained workers provide the crucial complementary skills for getting them to market and contributing to new inventions. To acquire such vocational skills, workers need practical, up-to-date on-the-job training, work experience in their occupation, and theoretical occupational education at vocational schools. Furthermore, to have the ability and motivation to partici-

pate in innovation activities successfully, vocationally trained workers need skills to adapt to new technological developments throughout their careers continuously. The general and occupation-specific skill components of each VET curriculum thus must guarantee such bundles of skills.

An emerging literature shows that the type of workplace training implemented in dual VET effectively provides such general and occupation-specific skills (e.g., Bolli & Hof, 2018; Heckman & Kautz, 2012; Hoeschler, Balestra, & Backes-Gellner, 2018). From the very start of their apprenticeship, apprentices acquire organizational skills (e.g., meeting deadlines, organizing projects, and staying within budget) and quality-oriented work habits (e.g., being precise and being goal-oriented) during workplace training because they are integrated into regular work environments and have to perform in these environments (Bierhoff & Prais, 1997; Mühlemann & Wolter, 2014; Ryan, Gospel, & Lewis, 2007). In addition, they acquire general skills such as project planning, good communication, teamwork, and foreign language skills because the curricula for both workplace training and school education contain these skills (Backes-Gellner & Pfister, 2019).

In addition to these general skills, apprentices acquire high-level and broad occupation-specific skill bundles. These skill bundles go far beyond the requirements for performing only one particular job or handling only one particular machine. For example, the mathematical skills for Swiss VET curricula in mechanical occupations (e.g., automotive technicians and electricians) correspond to those taught in tertiary-level engineering courses in the UK (Bierhoff & Prais, 1997). Thus apprentices in dual VET programs acquire high-level general and occupation-specific skills that prepare them for many different R&D tasks. In contrast, while academic university graduates are highly educated in the theoretical foundations of their field of study, they usually receive structured training neither in general skills (such as work habits, communications, or organizational skills) nor in occupation-specific skills (such as those necessary for the applica-

tion of new technology in manufacturing tasks).

The high-level and broad occupational skill bundles of dual apprenticeship-graduates are also an important ingredient in a firm's overall skill mix to achieve high-quality innovation and production outcomes. Empirical studies find that integrating dual apprenticeship-graduates into a firm's skill mix increases innovation outcomes, including radical innovation, and that firms of different sizes benefit from integrating dual apprenticeship-graduates into their workforce (Bolli, Renold, & Wörter, 2018b, Meuer et al., 2015; Rupietta & Backes-Gellner, 2019a; for theoretical explanations see Backes-Gellner & Veen, 2013; Lazear, 1999). This increase in innovation results from spillover effects and reductions in skills gaps between different types of workers. Unlike traditionally assumed, these knowledge spillovers occur not only from academic university graduates to dual apprenticeship graduates but also in the reverse direction (i.e., from apprenticeship graduates to academic university graduates) (Backes-Gellner, Rupietta, & Tuor Sartore, 2017). Because of their broad and high-level occupational skills, dual apprenticeship-graduates close the skill gap between academic university graduates and low-skilled workers. This skill gap otherwise hampers firms' innovation activities and often arises in countries without strong VET systems (Teuber, Backes-Gellner, & Ryan, 2016).

Permeability of Education System to Ensure Occupational Mobility and Attractiveness of Vocational Education

Dual VET programs prepare their students for participating in innovation activities in their current job or firm and lay the foundation for a successful educational and professional career, thus contributing to the dual VET system's attractiveness. Chuard and Grassi (2020) show that the income mobility of Swiss workers who choose the VET path is very high by international standards. This high income mobility results from VET programs preparing students for adapting

their skills to new labor market developments as they arise.

Attractive educational and professional career options constitute an important feature of dual VET because they ensure that many young adolescents are interested in choosing a VET path and that the entire workforce's skill mix fits employers' actual labor demand (Backes-Gellner & Pfister, 2019). Typically, students begin their apprenticeship in a VET occupation after compulsory school ends at the age of 15 or 16 years (State Secretariat for Education, Research and Innovation, 2020). Therefore, it is of utmost importance that dual VET offers these adolescents a variety of future career directions instead of a limited occupational field for their entire professional career. That dual VET is an attractive educational choice for adolescents is reflected in the high numbers of entrants into VET programs. For example, about 50 percent of a post-compulsory school cohort in Germany, and almost 70 percent of Swiss students choose VET as their upper-secondary educational path (Statistisches Bundesamt, 2019a; Bundesamt für Statistik, 2020).

Regarding long-term labor market outcomes, dual VET programs can ensure favorable outcomes for their graduates independent of their degree of specificity. Recent literature applying Lazear's (2009) skill-weights approach to measure the specificity of an occupation assumes that all single skills are general but that the particular combination of single skills in an occupational skill bundle makes this bundle more or less specific. In this approach's framework, a VET program provides its graduates with an occupational skill bundle that differs more or less from the skill bundles provided by other VET programs, thereby making it more or less specific (Mure, 2007; Geel, Mure, & Backes-Gellner, 2011). Thus a VET curriculum determines labor market outcomes and employability through the combination of skills it includes compared to the combinations of skills included in the VET curricula of other occupations and the combinations of skills required in the overall labor market. The empirical literature based on the skill-weights ap-

proach shows that both more specific and more general VET occupations can benefit labor market outcomes; while workers with more specific skill bundles can achieve higher wage returns when they stay in their occupation, workers with more general skill bundles have higher job mobility and face less unemployment risks (Eggenberger, Rinawi, & Backes-Gellner, 2018; Geel et al., 2011).

Dual VET programs are also beneficial to cope with ever-changing technological and economic developments in the labor market. In comparison to countries (a) where no strong VET systems exist and (b) where technological change decreases the demand for workers with mid-level skills, the demand for workers with VET skills remains stable in countries with strong VET systems (e.g., Aepli et al., 2017; Murphy & Oesch, 2018; Rinawi & Backes-Gellner, 2019b). This finding clearly indicates the value of VET workers' mid- and high-level skills for production and innovation. Moreover, VET equips workers with the necessary skills for coping with the changing economic conditions accompanying globalization (Eggenberger, Janssen, & Backes-Gellner, 2020). Given the regular curriculum updates, VET also increasingly provides workers with different types of IT skills, thereby enhancing their employability (Backes-Gellner, 1996; Backes-Gellner & Pfister, 2019; Eggenberger & Backes-Gellner, 2020; Kiener, Gnehm, Clematide, & Backes-Gellner, 2019; Mohrenweiser & Janssen, 2018). Other studies attesting to the positive relationship between VET skills and labor market outcomes include, for example, Mueller and Schweri (2015), Rinawi and Backes-Gellner (2019a), and Schweri, Eymann, and Aepli (2020).

In addition, dual VET programs also guarantee educational career options at the tertiary level and upward mobility. The education systems in countries such as Switzerland and Germany follow the principle that no educational degree should lead to a dead-end (State Secretariat for Education, Research and Innovation, 2020). Graduates from upper-secondary dual VET programs have several tertiary-level educational career options, such as pursuing a tertiary-level profes-

sional education or university education (academic or applied) (State Secretariat for Education, Research and Innovation, 2020). One of the frequently chosen options is studying at a UAS (State Secretariat for Education, Research and Innovation, 2020),[4] where dual apprenticeship-graduates deepen their vocational skills and acquire applied research knowledge. After an apprenticeship, obtaining a tertiary-level vocational education yields additional benefits for labor market outcomes (e.g., income) (Cattaneo, 2011; Pfister, Tuor Sartore, & Backes-Gellner, 2017). The benefits of such tertiary-level vocational education equal, and can even surpass, those of tertiary-level academic education—for example, a lower unemployment risk (Backes-Gellner & Geel, 2014; Balestra & Backes-Gellner, 2017; Wolter & Weber, 1999). Thus permeability as a design feature of the education systems in countries such as Switzerland and Germany makes VET programs an attractive educational choice that results in both employability and occupational mobility.

The Role of Universities of Applied Sciences (UASs) in a VET-based Innovation Ecosystem

While the different types of skills of both vocationally trained workers and academically educated workers might generally be valuable for innovation in firms, these workers' potential cannot be (fully) exploited if the skill gap between the different types of workers is too large to be bridged. Thus an additional education institution aimed at improving the linkage of vocationally trained and academically educated workers can systematically help foster innovation. Such institutions are the UASs in Germany and Switzerland.

UASs target dual apprenticeship-graduates as their students and offer them a tertiary-level educational career option equivalent to studying at an academic university (according to the In-

ternational Standard Classification of Education, ISCED) (Nikolai & Ebner, 2013; Swiss Coordination Centre for Research in Education, 2018).[5] However, UASs differ from academic universities (which focus on theoretical knowledge and basic research skills) by concentrating on vocational knowledge and applied research skills (Commission of Experts for Research and Innovation, 2018; Lepori & Kyvik, 2010). In addition, UASs are legally mandated to provide services to local firms (e.g., joint research projects and continuing education courses) and to collaborate with other research institutions and companies (Commission of Experts for Research and Innovation, 2018; State Secretariat for Education, Research and Innovation, 2019). This mandate means that UASs frequently engage in cooperative research projects (Arvanitis, Kubli, & Woerter, 2008; Beck, Hulfeld, Spescha, & Wörter, 2020; Hachmeister, Duong, & Roessler, 2015).

UASs and their graduates thus play two roles in the education and innovation systems of countries that emphasize VET. First, on the input side, UAS graduates close the gap between vocationally trained and academically educated workers in firms' R&D departments, thereby improving communication and creative problem solving. Thus UAS graduates are essential as bridge builders. Second, on the output side, UASs and their graduates support R&D outcomes (e.g., patenting) because of an influx of fresh ideas and opportunities for innovation projects. In so doing, they foster innovation in regions with a UAS in comparison to regions without one.

UAS Graduates as Bridge Builders in Firms' R&D

UAS graduates are well suited for closing the skill gap between vocationally trained and academically educated workers due to the characteristics of their educational path. When studying at a UAS, dual apprenticeship-graduates augment their previously acquired skills with applied research skills. As UASs often engage in cooperative research projects with (local) firms, UAS students also learn to understand and apply basic research findings. Thus UAS graduates constitute an important link between academically educated specialists in R&D and vocationally

trained specialists in production, manufacturing, or services.

Case studies by Backes-Gellner and Pfister (2019) show that, for example, in prototyping a new high-technology precision motor, UAS graduates played a crucial role in a firm's R&D with their expertise in both conceptual design and production. When prototyping this motor, UAS graduates contributed input to the prototype's technical development and used their vocational skills in the manufacturing of it. By speaking the professional language of both academically educated and vocationally trained specialists, UAS graduates can, for example, incorporate the feedback of VET workers from manufacturing into theoretical engineering processes, thereby creating synergies between different types of workers. Thus, with their sound occupational skills and their knowledge of academic methods, UAS graduates act as bridge builders between workers with vocational and academic educational backgrounds (Backes-Gellner & Pfister, 2019; Schultheiss, Pfister, Backes-Gellner, & Gnehm, 2019).

The Effect of UASs on Patenting Activities

To investigate how UASs affect regional innovation, Pfister, Rinawi Koomen, Harhoff, & Backes-Gellner (2021) exploit quasi-random variation in the location and timing of establishing UAS campuses in Switzerland. They analyze how patenting activities develop in regions with a new UAS campus compared to regions without one.[6] The use of patenting activities as an indicator of innovation allows them to examine both the quantity and the quality of regional innovation outcomes.

Pfister et al.'s (2021) analyses show that UASs significantly increase the patent quantity (the number of priority filings) and patent quality in regions with a new UAS campus. They report that patent quantity grows by about seven percent, and patent quality grows by up to almost ten percent (depending on the patent quality indicator). Furthermore, Pfister et al. (2021) find that

UASs stimulate innovation activities outside major innovation centers; that is, the establishment of UASs induces regional firms to begin engaging in innovation activities. The tertiary-level vocational skills and applied research knowledge that UASs produce thus positively impact regional innovation.

To explore heterogeneity in the UAS effect on innovation, Schlegel, Pfister, Harhoff, & Backes-Gellner (2021) analyze the regional economic preconditions necessary for this effect. They find that UASs must have a prevalence of firms operating in high-tech industries and a large enough regional workforce to affect patenting activities. This finding is in line with the argument that UAS graduates serve as a link between vocationally trained and academically educated workers due to their vocational and applied research skills. However, UAS graduates can function as a link only if a workforce with linkable skill sets exists. Thus, if UASs cannot draw on enough other vocational and academic skill sets necessary for successful innovation activities in a region, the UASs will not serve their purpose (e.g., in very remote regions). However, if those skill sets exist in a region, a UAS will substantially boost that region's innovation strength.

The findings of Lehnert, Pfister, Harhoff, & Backes-Gellner (2020b), who study complementarities between UASs and other public research institutions in Germany, point in the same direction. As the establishment of UAS campuses did not follow a quasi-random pattern in Germany, the study of Lehnert et al. (2020b) first had to solve endogeneity issues; it did so through a novel approach using daytime satellite imagery to model the regional economic characteristics that determine UAS locations. When applying this approach, their results show positive—although in comparison to Switzerland, somewhat lower—causal effects of UASs on patenting activities. In addition, they reveal that knowledge complementarities between UASs and other research institutions—public research organizations performing basic or applied research, such as the Max Planck Society or the Fraunhofer Society—intensify the UAS effect (Lehnert et al.,

2020b). The lower average effect in Germany in comparison to Switzerland might be attributable to German UASs having a less rigid focus on vocational knowledge and applied research than their Swiss counterparts (e.g., in later years, German UASs have also been accepting students who are not dual apprenticeship-graduates) (Enders, 2010; Nikolai & Ebner, 2013). The complementarity effects in Germany indicate that the regional availability of complementary research knowledge is a prerequisite for UASs to increase innovation.

Thus in regional innovation ecosystems, UASs can function as an important producer of complementary research knowledge that other actors in these ecosystems can benefit from. When different types of research knowledge coexist within a region, UASs can constitute the necessary link between these types of knowledge, thereby fostering patenting activities. With their regional focus, UASs also offer a valuable source of applied research knowledge in regions far from major innovation centers such as Silicon Valley or Route 128 (see, e.g., Dorfman, 1983; Jaffe, 1989). Moreover, Lehnert, Pfister, & Backes-Gellner (2020a) find that small firms, likely start-ups, are one of the main beneficiaries of the establishment of UASs.

Mechanisms: R&D Employment and Labor Market Spillover Effects to Non-UAS Graduates

Further analyses of the mechanisms underlying the UAS effect on patenting activities suggest that UASs provide their graduates with skills complementary to those of workers with different educational degrees. Lehnert et al. (2020a) analyze changes in R&D personnel in regions affected by the establishment of a UAS campus in Switzerland. They find that firms located in a UAS campus region both increase the number of employees devoted to R&D tasks by about 15 percent and increase their overall spending on wages for R&D employees by the same percentage. These findings have two implications: First, firms employ UAS graduates for innovation activities. Second, these new employees constitute a valuable input for innovation activities with-

out replacing other types of workers. Otherwise, firms would not be willing to increase their spending on R&D personnel. These findings support the argument that UAS graduates are an important complement to other types of workers and act as bridge builders between them.

The increased supply of UAS graduates in UAS regions also positively affects the labor market outcomes of non-UAS graduates, likely boosting innovation further. Schultheiss et al. (2019) show that the establishment of UASs leads to an upskilling of the tasks of VET workers who have not graduated from a UAS. They find that after establishing a UAS campus in a region, such VET workers subsequently perform more R&D tasks, that is, tasks that require higher-level skills than those they had previously performed. Therefore, the increase in firms' innovation activities results from tertiary-level UAS graduates' direct engagement in innovation activities and spillovers. In other words, these firms increase the involvement of upper-secondary-level dual apprenticeship-graduates in R&D activities. Thus the establishment of UASs has positive spillover effects on other types of workers, "just as a rising tide lifts all boats" (Schultheiss et al., 2019, p. 4).

In addition to the increases in R&D labor supply and patenting activities, Schlegel, Pfister, and Backes-Gellner (2020) find significant increases in regional firm profits after the establishment of UASs in Switzerland, an effect that persists even in the long run. Other studies also attest to further positive outcomes of universities on regional economies, although many do not explicitly differentiate between UASs and academic universities (e.g., Becker & Dietz, 2004; Fritsch & Slavtchev, 2007; Robin & Schubert, 2013). Exceptions that explicitly analyze UASs include Fritsch and Aamoucke (2017), who find that UASs positively affect the regional number of start-ups in technology-intensive industries,[7] and Eberle, Brenner, and Mitze (2020), who find that third-party research funding for UASs contributes more to regional patenting than third-party research funding for academic universities.

Conclusion

Unlike suggestions the mainstream literature, VET can be an important part of a successful national innovation ecosystem if it meets certain requirements. For example, the skills taught in Switzerland's or Germany's dual VET programs are not low-level skills but high-level skills and enable dual apprenticeship-graduates to engage in high-quality innovation activities. These high-quality vocational skills complement those of academic university graduates, together constituting the key ingredients of the skill mix for innovative firms and (regional) economies. Therefore, countries such as Switzerland and Germany achieve high innovation performance internationally, not in spite of but because of their strong emphasis on dual VET. Using the examples of Switzerland and Germany, this article illustrated that a dual VET system needs to fulfill four crucial requirements to ensure this high innovation performance.

First, both parts of a dual VET program—workplace-based training at the training firm and classroom-based training at the vocational school—must follow comprehensive, future-oriented occupational training curricula. These curricula lay a broad foundation of up-to-date occupational skills to ensure that apprentices acquire the general and occupation-specific skills that firms and (regional) economies need for innovation activities at the technology frontier, instead of skills restricted to a narrow job- or firm-specific skill set.

Second, these curricula must receive systematic and frequent updates. In these updates, all stakeholders (e.g., innovative firms, industry training experts, social partners, and government) need to participate to guarantee that the focus on skills stays future-oriented and relevant for labor market outcomes.

Third, dual VET must provide attractive educational career options for young adolescents through giving them (a) the necessary skills for adapting to changing work environments through

lifelong learning and (b) a permeable education system that offers them, as dual apprenticeship-graduates, various options for continuing their educational careers (e.g., professional education or university studies). The provision of these options also increases the willingness of VET workers to engage in implementing innovation.

Fourth, to further boost innovation, tertiary-level education institutions that focus on advanced vocational knowledge and applied research (e.g., UASs) must function as bridge builders between the vocational pillar and the academic pillar of an education system. They support communication, creative problem solving, and the inflow of new ideas into firms' R&D activities.

The success of dual VET in countries such as Switzerland and Germany is based on their VET systems' four characteristics, coupled with well-established links to their general education systems. In recent years, the success of dual VET has also spurred other countries' interest in adopting VET pathways as part of their national education systems (e.g., Bolli, Bolli-Kemper, Parajuli, Renold, & Thapa, 2020; Caves, Renold, & Backes-Gellner, 2018; Gîncu & Moldovanu, 2019; Renold & Oswald-Egg, 2017; Wiemann & Fuchs, 2018). However, due to a dual VET system's complex structure and interconnectedness with other parts of the education and innovation systems, implementing it in existing national institutional frameworks poses a great challenge. Evaluating the innovation performance of new dual VET pathways that other countries establish—in addition to analyzing new developments in countries already emphasizing dual VET—offers a fruitful direction for future research, one that will further improve scholarly understanding of dual VET as a driver of innovation activities.

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Links to Digital Materials

Study on the Contribution of the VPET System to Innovation (Swiss Leading House on Economics of Education, Firm Behaviour and Training Policies, University of Zurich)

Research Papers on Innovation, Vocational Education and Training, and Universities of Applied Sciences (Swiss Leading House on Economics of Education, Firm Behaviour and Training Policies, University of Zurich)

Research Papers on Occupational Specificity and Labor Market Outcomes of Dual VET Graduates (Swiss Leading House on Economics of Education, Firm Behaviour and Training Policies, University of Zurich)

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[1] Such innovation rankings include the Bloomberg Innovation Index (see Jamrisko & Lu, 2020), the World Intellectual Property Organization's Global Innovation Index (see Dutta, Lanvin, & Wunsch-Vincent, 2020), and the European Commission's European Innovation Scoreboard (see European Commission, 2020)

[2] The term "dual apprenticeship-graduate" refers to individuals who have successfully completed a dual VET program and thus received a nationally recognized, upper-secondary-level VET certificate. In contrast, a UAS degree is a tertiary-level degree granted by Universities of Applied Sciences, three-year colleges teaching applied research skills to dual apprenticeship-graduates.

[3] Such dual VET systems differ from entirely or at least more intensively school-based VET programs in other countries (Eichhorst, Rodríguez-Planas, Schmidl, & Zimmermann, 2015; European Commission, 2012)

[4] Other options include, for example, continuing on to a professional education and training college (which do not teach applied research skills) or, upon fulfillment of certain additional requirements, to an academic university (Backes-Gellner & Pfister, 2019; State Secretariat for Education, Research and Innovation, 2020; Swiss Coordination Centre for Research in Education, 2018).

[5] Like academic universities, UASs award bachelor's and master's degrees (but usually not doctoral degrees) (Enders, 2010; Meurer, 2018). Very few research-intensive UASs in Germany have recently started to award doctoral degrees (Meurer, 2018).

[6] While the international literature has extensively investigated the effects of academic universities on innovation and growth (e.g., Andersson, Quigley, & Wilhelmsson, 2009; Toivanen & Väänänen, 2016; Valero & Van Reenen, 2019), research has only recently begun to systematically analyze the causal effects of UASs.

[7] A descriptive analysis by Barjak, Lindeque, Maidl, Blaese, and Morandi (2020) also suggests positive UAS effects on the number of start-ups in industries associated with the humanities and the social sciences.