The influence of vocational education and training on innovation

The case of Germany

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Chapter I

Introduction and Summary

My dissertation aims at analyzing the relevance of vocational education and training (VET) on firm innovation in Germany. It makes a twofold contribution to the innovation literature:

Firstly, it complements studies on the effect of conducting initial VET on firm innovation. In doing so, it identifies indirect moderation and mediation effects of participating in VET in combination with learning capacity in SMEs, particularly microenterprises. Secondly, the dissertation supplements the research literature on VET graduates' participation in innovation as well as literature on the effects of educational diversity among employees on innovation: It determines the active participation of VET graduates and advanced VETs (masters, technicians) in (non-)R&D-invention and in implementation in comparison to university graduates.

In the course of this, it underlines that the dual system in Germany contributes to the country's innovativeness twofold: On the one hand indirectly by interacting with and fostering learning capacity of microenterprises and on the other hand by educating skilled workers, who subsequently innovate. Taken as a whole, conducting VET can be seen as one distinct (low-level) means, which contributes to paving the way to innovation in (small) German firms as well as to participating in the innovation system.

Innovation then again is key driver of economic growth (Kremer, 1993; Rodríguez-Pose & Crescenzi, 2008; Solow, 1956) with internal resources, the external environment and technological trajectory (Malerba, 2002; Nooteboom, 1994; Pavitt, 1984; Rosenberg, 1982) fostering company innovativeness. Internal resources include R&D departments, employees and their human capital, accumulated experience, the organizations' way of learning, their competence to shape products and processes as well as their technological equipment. The external environment as innovation driver is constituted by the interrelation of companies and employees with external actors, i.e. universities, research and other educational institutions, suppliers, costumers, users and competitors as well as the institutional system. Finally, the technological trajectory in which firms operate in depends on their respective economic sector and market developments, which constitute a third innovation driver. This diversity in innovation drivers leads to multifaceted patterns of company innovativeness, which differ for each company, the respective economic sector and the region where a firm is located (Asheim & Gertler, 2005; Malerba, 2002; Malerba & Orsenigo, 1997; Pavitt, 1984).

For the German case, the VET system has already been found to constitute an essential pillar of the national innovation system (Philip Cooke & Morgan, 1994; EFI, 2014; Porter, 1991). It is attributed particular importance for smaller companies as these rely on skills beyond academic qualification as well as innovation activities apart from R&D (Brunet Icart & Rodríguez-Soler, 2017; Lund & Karlsen, 2020; Thomä, 2017). However, explicit research for the German case on the one hand concerning the direct and indirect effects of conducting VET for firm innovation is lacking. On the other hand, analyses on the participation of VET graduates and advanced VETs (masters, technicians) to different innovation phases in comparison to university graduates remain scarce, as well.

At the same time, the German innovation system is currently under pressure. According to the OECD, Germany needs – among others – "to boost investment in […] knowledge-based capital, […] and address skills bottlenecks" (OECD, 2021) due to demographic changes with shrinking and ageing work population (Thomas Deissinger & Breuing, 2014; Frosch, 2011). The lack of skilled employees such as (vocationally trained) technicians, in turn, decreases firm capacity to integrate new technologies and hence to innovate (Lewis, 2020).

The dual VET system as guarantor of a skilled workforce faces thereby not only demographic changes but also specific issues, which go beyond demographic developments. These issues subsequently challenge the VET systems' function in the innovation system at least in terms of securing a skilled labor force. According to the National Educational Report 2022 (Autor:innengruppe Bildungsberichterstattung, 2022), these issues are that supply of and demand for training places are decreasing with simultaneously increasing mismatch. Particularly integrating certain social groups (Seeber & Seifried, 2019), problems of small companies with hiring apprentices and premature cancellation of contract (Eckelt, Mohr, Gerhards, & Burkard, 2020; Pahnke, Icks, & Brink, 2020) are contributing to these current issues. Accordingly, particularly smaller firms as crucial element of the German "Mittelstand", the backbone of the economy (Kirner, Kinkel, & Jaeger, 2009; Kirner & Som, 2015; Thomä, 2017), and correspondingly their innovativeness, which relies on both, VET system and VET participation respectively, face specific challenges concerning their competitiveness.

Against this backdrop, it is essential to facilitate a deeper understanding of the means by which the VET system and VET activity contribute to innovation. These have been identified as educating skilled employees, fostering learning capacity and organizational changes, promoting knowledge transfer and access to state-of-the art technology along technological trajectory (Barabasch & Keller, 2020; Hodge & Smith, 2019; Lund & Karlsen, 2020; Proeger, 2020; Rupietta & Backes-Gellner, 2019; Rupietta, Meuer, & Backes-Gellner, 2021; Schultheiss & Backes-Gellner, 2022).

Hence laying the foundation for the analyses conducted during the course of my dissertation, the following sections elaborate on the role of skilled employees for innovation, knowledge transfers in regional innovation systems as well as the concept of organizational learning and its interrelation with innovativeness. These innovation drivers subsequently constitute the theoretical foundation for analyzing the influence of the dual VET system and participating in it on company innovation. Chapters II-V contain the empirical results of the conducted analyses.

Skills and innovation

Employee, owner and management skills are essential elements of internal resources for innovation. They contribute to absorptive capacities (Cohen & Levinthal, 1989), are complementary to R&D activities and foster knowledge creation and dissemination in organizations (Iansiti & Clark, 1994; Kline & Rosenberg, 1986; Rothwell et al., 1974; Warner, 1996). Therefore, innovation research is increasingly interested in examining factors such as employee skills (Leiponen, 2005; Siepel, Camerani, & Masucci, 2021).

Recent studies suggest that not only university graduates but also vocationally educated employees foster innovativeness, particularly in smaller companies (Albizu, Olazaran, Lavía, & Otero, 2017; Brunet Icart & Rodríguez-Soler, 2017; Freel, 2005; Toner, 2010). When differentiating innovation processes into invention and implementation phases, academic and upper intermediate skills are perceived to be beneficial for inventing, while implementation also benefits from the intermediate qualifications of VET graduates (Bolli, Renold, & Wörter, 2018; Mason, Rincon-Aznar, & Venturini, 2020).

VET graduates' contributions to innovation, particularly on the shop floor, are stimulated by their theoretical and practical knowledge acquired during vocational education and while working (Thomas; Deissinger, 2015; Flåten, Isaksen, & Karlsen, 2015). These competences enable VET graduates to engage in creative problem-solving and to deal with complex tasks as well as unpredictability on shop floor (Pfeiffer, 2018). With their experience-based knowledge, they particularly contribute to process and product innovation. Nevertheless, VET graduates participate in R&D, prototyping and construction as well (Brunet Icart & Rodríguez-Soler, 2017; Flåten et al., 2015; Pfeiffer, 2016; Thomä, 2017; Toner, 2010). These insights indicate that the VET system, which educates a skilled workforce and provides foundation for upper intermediate skills, subsequently builds one essential pillar for company innovation. Knowledge transfers and stimuli for organizational changes and learning capacity complement this education function. The following sections take a closer look at their link to company innovation.

Knowledge transfer in regional innovation systems

The innovation systems approach builds upon an understanding of innovation as complex, interactive, and cumulative learning processes with a focus on the interaction among firms, universities, education and research institutions, regulatory and policy actors and authorities, financial institutions and intermediaries. Regional innovation systems (RIS) are a core concept in innovation research due to regional proximity being established as a driver of knowledge transfer and hence innovation (Autio, 1998; P. Cooke, 2001; Philip Cooke, Gomez Uranga, & Etxebarria, 1997).

The actors in RIS contribute to generating and diffusing knowledge embedded in specific regional socio-economic, institutional, and cultural environment. SMEs particularly benefit from regional innovation systems as collaboration and external knowledge are important drivers of small firm innovation, especially when companies conduct less or no R&D and have limited financial and personnel resources (Hervás-Oliver, Parrilli, Rodríguez-Pose, & Sempere-Ripoll, 2021; Rammer, Czarnitzki, & Spielkamp, 2009).

Even though universities and research institutions are perceived as main driver of producing and transferring knowledge, the VET system constitutes an important element as well, particularly for smaller firms. It educates a skilled workforce and constitutes a source of knowledge facilitating technology transfer (Albizu et al., 2017; Lund & Karlsen, 2020; Porto Gómez, Zabala-Iturriagagoitia, & Aguirre Larrakoetxea, 2018; Toner, 2010). The latter indicates an indirect contribution of VET participation to innovation beyond the education function. Stimuli for organizational changes and learning capacity, which contribute to organizational learning, complement this indirect function of conducting VET.

Organizational learning, organizational changes and (non-R&D-) innovation

Organizational learning (OL) is a framework in which learning constitutes a process with strategic renewal as product (Crossan, Lane, & White, 1999; Crossan, Maurer, & White, 2011) subsequently laying the foundation for innovation and corporate success (Jiménez-Jiménez & Sanz-Valle, 2011). The process of OL is iterative and interactive, occurring at different but intensively related levels (Jerez-Gómez, Céspedes-Lorente, & Valle-Cabrera, 2005), which are connected with feedback and feedforward processes (Crossan et al., 1999, 2011). The framework itself includes individuals, teams and organizations as three learning levels as well as four learning processes, the so called 4-I-processes: Intuiting, interpreting, integrating and institutionalizing (Crossan et al., 1999, 2011). Through these processes, individual knowledge is transformed into organizational knowledge. This requires the skills and knowledge of groups and individual employees to be embedded in companies' organizational practices, which subsequently improves innovativeness and business performance (Jiménez-Jiménez & Sanz-Valle, 2011; Santos-Vijande, López-Sánchez, & Trespalacios, 2012).

A plethora of theoretical models focuses on the interrelation of organizational learning and innovation, explaining learning processes, knowledge creation, transfer and transformation on the firm level (Lam, 2005). In this regard, the resource-based view constitutes one approach, which focuses on a firm's competitive environment and its strategic resources such as employees' skills to explain future performance (Barney, 1991). The resource-based view of the firm is recently employed to analyze SME innovation (De Massis, Audretsch, Uhlaner, & Kammerlander, 2018; Terziovski, 2010) as well as employee involvement in SME innovation (Andries & Czarnitzki, 2014). Empirical studies thereby reveal contributions of all employees to innovation, while organizational learning is of particular relevance for innovation and performance of SMEs (Jiménez-Jiménez & Sanz-Valle, 2011).

In the literature on innovation modes, where different means of organizational learning constitute a crucial element, recent publications differentiate two innovation modes: A science and technology-driven innovation (STI) and a doing, using and interacting (DUI) mode of innovation (Jensen, Johnson, Lorenz, & Lundvall, 2007). The former relies on codified knowledge, science and technology, while the latter is associated with tacit knowledge, learning environment, and learning from experience, internal and external interaction and problem-solving (Alhusen et al., 2021; Jensen et al., 2007), which is why the VET system and DUI mode learning are often seen as related (Thomä, 2017; Toner, 2010). Moreover, the opportunities for learning and organizational changes, which are stimulated by conducting initial VET, are determinants of DUI mode learning and innovation as well (Jensen et al., 2007; Parrilli, Balavac, & Radicic, 2020; Parrilli & Radicic, 2021; Thomä, 2017). This similarity points to the contributions of VET to an environment conducive to learning and thus organizational learning and innovation, as well. However, research on direct contributions of VET to organizational learning remains scarce.

Notwithstanding and building upon the contributions of VET participation to organizational changes and learning capacity (Barabasch & Keller, 2020; Hodge & Smith, 2019), as well as considering the essential role of VETs in educating a skilled workforce and DUI mode learning, the organizational learning framework suggests that VET participation might contribute to innovation. These contributions hold particularly true for smaller companies.

In conclusion, the current challenges faced by the German national innovation system and particularly by the dual VET system, combined with scarce empirical analysis of the interplay between VET and firm-level innovation, underline the need for research into the influence of vocational education and training on innovation activity. Building upon these aspects, I analyzed the relation of VET participation and innovation, as well as the participation of VET graduates and advanced VETs in innovation, over the course of my dissertation. The next sections provide an overview of the contributions made by my coauthors and myself to this field.

Summary Chapter II

This chapter analyzes the correlation between the participation of firms in initial vocational education (VET) and their innovation activities. Departing from preceding studies on the innovation contributions of initial VET on firm-level (Lund & Karlsen, 2020; Porto Gómez et al., 2018; Rodríguez-Soler & Icart, 2018; Rupietta & Backes-Gellner, 2019; Rupietta et al., 2021), the paper firstly elaborates theoretically on the link between vocational education and training. It examines the interrelation of VET and the doing, using and interacting (DUI) mode of innovation, the role of VET in organizational learning and provides an overview of empirical studies analyzing the contributions of VET to innovation.

Based on two seminal contributions in the research strand on VET and innovation, namely the theoretical considerations of Toner (2010) and the empirical analysis of Rupietta & Backes-Gellner (2019), we secondly employ data from the IAB establishment panel (EP) for a cross-sectional analysis of the correlation between VET participation of firms in Germany and their innovation activity. The results based on linear probability models and entropy balancing show that VET has no association with radical innovation. However, we find a positive correlation between VET activities and incremental product or process innovation in the case of microenterprises with fewer than 10 employees.

We subsequently deduce policy implications for the VET system and VET institutions concerning knowledge transfer, educating skilled youth, and company engagement in conducting VET. These implications are complemented by further research needs in the fields of identification strategy as well as the understanding of the links between VET, organizational learning, knowledge transfer, and innovation. This paper and the related research needs constitute the point of departure for further analyzing the influence of vocational education and training on innovation in Germany.

Summary Chapter III

The influence of VET participation on firm innovation is believed to be most significant for SMEs, although certain aspects have not been fully understood. While Rupietta & Backes-Gellner (2019) found that the effects on product innovation were stronger for smaller enterprises, our first study also identified an association with process innovation, with effects being particularly noticeable for microenterprises (Matthies, Haverkamp, Thomä, & Bizer, 2022). However, despite these quantitative analyses, Hodge & Smith (2019) found only indirect effects of apprentices and accompanying VET participation, with their findings referring to full-time, school-based vocational training systems with company practice periods being constrained to temporarily limited work placements. Nevertheless, they argue that VET fosters innovation indirectly through knowledge diffusion and organizational learning.

Against this backdrop, and based on the findings on the relevance of VET institutions for RIS (Brunet Icart & Rodríguez-Soler, 2017; Philip Cooke & Morgan, 1994; Lund & Karlsen, 2020; Porto Gómez et al., 2018), of which SMEs are probably benefiting most (Lund & Karlsen, 2020; Parrilli & Radicic, 2021), this paper investigates the interrelation of VET, organizational learning, and technological innovation for SMEs employing IAB EP panel waves for 2009-2019. By estimating interaction effects between VET activities and organizational changes, we found that a training firm's initial VET activities are associated with product innovation but not with process innovation. However, for microenterprises, we identified that initial VET is associated with a higher probability of (local) new-to-market product innovation if it is accompanied by changes in organizational processes that support individual learning and knowledge creation.

Based on these findings, we suggest implications for education and innovation policy regarding VET and its potential to foster innovativeness of microenterprises in interaction with organizational learning. These findings also suggest further research opportunities in understanding the interplay between organizational learning, VET, and innovation in more detail, as well as improved identification strategies concerning the chain of effects and reverse causality.

Summary Chapter IV

The third paper builds upon the findings of the first two and complements them by analyzing a mediation effect. The authors depart from qualitative studies that suggest a chain of effects beyond simple interaction: Initial VET participation enhances learning capacity and organizational changes, which in turn boost technological innovation in microenterprises (Barabasch & Keller, 2020; Hodge & Smith, 2019; Schultheiss & Backes-Gellner, 2022). This perspective posits that initial VET indirectly promotes firm-level innovativeness by strengthening a microenterprise's knowledge base and learning capacity, facilitating learning and innovation in the less-R&D-intensive DUI-mode of innovation, which is especially relevant for smaller companies (Thomä & Bizer, 2021). Using German panel data (IAB EP) for the years 2011-2019, with a focus on microenterprises, the authors quantitatively analyze this chain of effects. They discuss their findings against the backdrop of the persistent decline in initial VET participation in the German microenterprise sector.

Against the backdrop of declining VET activities among microenterprises due to difficulties in finding apprentices and premature cancellation of training contracts, the paper finds primarily indirect effects of VET activity on innovativeness, mediated by an organizational work environment conducive to learning. The paper underscores the innovation relevance of microenterprises' initial VET activities and is, therefore, in accordance with Matthies, Thomä, & Bizer (2022) while the results are in contrast to the findings of Matthies, Haverkamp, Thomä, & Bizer (2022) and Rupietta & Backes-Gellner (2019) at first glance. However, as both studies employ cross-sectional data and do not account for mediation effects, their observation of direct contributions can be explained by mediated effects, which our study reveals. In conclusion, and based on the learning capacity-stimulating character of initial VET, this paper deduces policy implications on means by which the learning environment can be fostered and measures to support microenterprises in finding apprentices and conducting VET.

Education, labor market and innovation policy should endeavor to promote the beneficial interplay of conducting initial VET, learning culture and capacity, and innovation. To facilitate continuous training participation and hence the maintenance of channels for transferring knowledge as well technologies, microenterprises need support in finding and hiring apprentices. Therefore, currently available support measures need to be promoted more intensely (Eckelt et al., 2020), and training and learning alliances need to be furthered (Schmierl, 2012). Premature cancellation of training contracts should be prevented, and monetary incentives for apprentices could be introduced (Pahnke et al., 2020).

Moreover, to secure innovativeness, the learning climate and culture of training companies should be promoted. Training as an essential element of company culture (Pilz, 2008), integrated learning along company processes to foster apprentices' professional acting competence and their contributions to organizational changes (Ebbinghaus, 2016; Hodge & Smith, 2019; INAP Commission 'Architecture Apprenticeship,' 2013; Pfeiffer, Ritter, Schütt, & Hillebrand-Brem, 2017), quality standards in terms of available resources and conditions, as well as their assessment, constitute crucial elements of such a learning environment (Guellali, 2017). This environment, in turn, is a seedbed for learning and innovating without R&D based on the „Learning by Doing, Using, Interacting (DUI)" mode, which is particularly relevant for the competitiveness of the German Mittelstand (Thomä & Bizer, 2021). Innovation policy for the German Mittelstand should therefore consider initial VET as a means of promoting the entry of the 'smallest' in the corporate landscape into the innovation system.

Summary Chapter V

The first three studies have provided evidence for the interrelation of VET activities, an organizational work environment conducive to learning, and firm innovativeness, underlining the contributions of apprentices, VET institutions, knowledge transfer and learning atmosphere to innovation. Therefore, the VET system fosters innovation activities indirectly and educates skilled workers who are subsequently engaged in improvement activities and in developing new products and processes.

Departing from the educational function, the engagement of VET graduates and advanced VETs such as masters or technicians, who conducted further training after completing dual education, is the subject matter of the fourth article. By conflating literature on the participation of VET graduates in

SME innovation (Albizu et al., 2017; Brunet Icart & Rodríguez-Soler, 2017) and the strand on the effect of diversity in terms of educational background on innovation (Bolli et al., 2018; Mason et al., 2020), the authors firstly argue theoretically why and how VET personnel contributes to different stages in the innovation process. Subsequently, the article presents results for participation in invention and implementation based on BIBB/BAuA Employment Surveys from Germany for 2006, 2012 and 2018, differentiated by company size classes and in comparison to university graduates.

Independently of firm size, university graduates dominate R&D inputs for inventions, while advanced VETs also contribute to R&D, but to a lesser extent. For inputs without conducting R&D, the latter show comparable likelihoods with university graduates while VET graduates also conduct non-R&D-inputs, which is somehow surprising. During implementation, university graduates focus on organizational, digital, and service innovation, while VET graduates are occupied with technological (process) innovation. Advanced VETs act as all-rounders. For both phases, the labor division is found to increase with firm size, suggesting positive effects of diversity in terms of complementarity for larger firms and between innovation phases. It is particularly here that future research on explicit complementarities should build upon, while management should consider VET as well as university qualifications in innovation processes.

Simultaneously, policy is well-advised to acknowledge the VET system as an essential pillar of the German innovation system and hence to support companies in conducting high-quality VET, apprentices to find the appropriate training places, and to consider and implement political measures on the VET system in both, educational and innovation policy. In concrete terms, idea competitions for employees could leverage employee driven innovation, which should be complemented by intrapreneurship and entrepreneurship education in initial VET to lay the foundation for VET workforce participation in innovation.

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Chapter II

Does initial vocational training foster innovativeness at the company level? Evidence from German establishment data

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Does initial vocational training foster innovativeness at the company level? Evidence from German establishment data

Abstract
While an increasing number of conceptual studies postulate that vocational education and training (VET) activities have a positive impact on firm-level innovation, empirical evidence on the subject remains scarce. This study exploits establishment data from a representative survey of German companies to estimate the association between firms' participation in initial VET and their innovation outcomes. The results based on linear probability models and entropy balancing show that the relationship between VET activity and innovation are more ambiguous than often postulated. Overall, the participation in initial VET has virtually no effect on radical product innovation. However, a positive association between VET activities and incremental product innovation or process innovation is found in the case of microenterprises with fewer than 10 employees. From this, we conclude that participation in the VET system primarily promotes the innovation and learning conditions of very small training enterprises. The paper concludes with implications for policy and research.

Keywords
Vocational education; apprenticeship training; modes of innovation; innovation without R&D; SMEs

1. Introduction
Over decades, scholars of innovation highlighted formal research and development (R&D) activities of firms as the critical source of innovation and the engine of technological change (Hall, Mairesse, & Mohnen, 2010; Rammer, Czarnitzki, & Spielkamp, 2009; Shefer & Frenkel, 2005; Smith, 2005). They conceptualized innovation as a production process based on codified scientific and technical knowledge developed either at scientific institutes or by a company's R&D department (Aghion & Howitt, 2006; R. Locke & Wellhausen, 2014). In this tradition, vocational education and training (VET) below the academic level was not expected to provide any significant impetus for firm-level innovation. By contrast, recent approaches conceptualize the innovativeness of companies as an interactive learning process that is strongly based on informal exchanges within and outside of the firm (Asheim & Parrilli, 2012a; Fitjar & Rodríguez-Pose, 2013; Mario Davide Parrilli, Fitjar, & Rodríguez-Pose, 2016). These approaches emphasize the importance of incremental and process innovation linked to manufacturing activities (Hervas-Oliver, Sempere-Ripoll, & Boronat-Moll, 2014; Trippl, 2011; Trott & Simms, 2017) and accentuate the role of vocationally trained workers (as opposed to scientific personnel) in this process (Albizu et al., 2017; Brunet Icart & Rodríguez-Soler, 2017; Thomä, 2017). These insights have recently prompted the emergence of a number of studies arguing that the participation of businesses in the VET system fosters firm-level innovativeness (Lund & Karlsen, 2020; Porto Gómez et al., 2018; Rodríguez-Soler & Icart, 2018; Rupietta & Backes-Gellner, 2019; Rupietta et al., 2021). The example of VET with its strong emphasis on person-embodied knowhow and experience-based learning therefore vividly illustrates how important tacit skills continue to be in the knowledge economy (Balconi 2002; Thomä 2017).

While these contributions provide well-founded conceptual arguments for the importance of VET for innovation, the empirical evidence remains sparse. The studies to date either remain conceptual (Thomas Deissinger, 2012; Harris & Deissinger, 2003; Toner, 2010) or rely upon a qualitative research design (Alhusen & Bennat, 2021; Barabasch & Keller, 2020; Hodge & Smith, 2019; Lund & Karlsen, 2020; Porto Gómez et al., 2018). These studies reveal that the following key dimensions of the a knowledge economy's competitiveness (see OECD 2004; Powell and Snellman 2004) are potentially fostered by conducting VET: knowledge diffusion, organizational learning and management innovation as well as the built-up of experience-base knowledge, which enables workers to contribute to complex problem-solving. Hence, firms in knowledge economies with strongly embedded VET systems such as Germany, Switzerland or Norway are expected to benefit from companies' VET activities in terms of innovation and competiveness (Cooke & Morgan, 1994; Hirsch-Kreinsen, 2008; Lund & Karlsen, 2020; Porter, 1991; Rupietta & Backes-Gellner, 2019; Rupietta et al., 2021).

However, quantitative testing of the empirical relationship between initial VET and firm-level innovation remains scarce in the literature. In this context, the study of Rupietta and Backes-Gellner (2019) has a pioneering character. Using company-level data for 2,870 firms from Switzerland (with larger companies being overrepresented in the sample), Rupietta and Backes-Gellner (2019) show that firms participating in apprenticeship training have higher innovation outcomes. The authors establish that the effect follows an inverted u-shape along the firm size, i.e. the effects are stronger for smaller enterprises. They also report stronger effects for product rather than process innovations.

Our study aims to shed further light on this. We review and synthesize arguments in favor of the positive impact of VET on firm-level innovativeness and examine them using a representative sample of German companies. Here, we draw on an extensive survey of the Research Institute of the German Federal Employment Agency (the IAB EP dataset), which provides comprehensive information on companies' innovation activities and vocational training. We start the analysis by replicating the seminal contribution of the Swiss study of Rupietta and Backes-Gellner (2019) to directly address the question whether the results obtained by the authors should be treated as country-specific only. Since we observe correlations of increased magnitude as reported by the Swiss study, we conclude that the study of subject deserves further attention. In the next step, we extend the set of controls and examine the sensibility of the estimated coefficients to the inclusion of additional indicators. Most importantly, we include indicators on in-house R&D as well as continuing training, which were missing in the Swiss study and hence may induce omitted variable bias. As expected, we observe a sharp reduction in the measures of associations. For the purpose of robustness testing, we perform estimations based on entropy balancing.

Overall, our results indicate that the association of initial VET with firm-level innovation is more ambiguous than often postulated. For the total population of observed German companies, we find no effect of VET on radical innovation but a positive correlation between VET and incremental product innovation and process innovation. Since VET is often assumed to hold particular relevance for smaller enterprises (Alhusen & Bennat, 2021; Porto Gómez et al., 2018; Rupietta & Backes-Gellner, 2019; Thomä, 2017), we also focus on the effects of VET on innovation for different firm size groups. The corresponding results imply that the association between initial VET and firm-level innovation is in fact strongest in the group of microenterprises with less than 10 employees.

On the one hand, our study thus corroborates the conclusions of previous research on the positive link between VET and innovation. However, we also show that this association is weaker than often postulated as it mainly holds only for the group of microenterprises. We therefore conclude that participation in the VET system increases the innovative capacity of very small firms in knowledge-based economies through organizational learning routines, knowledge diffusion and the built-up of tacit know-how. This finding holds certain implications for policy-makers. At present, innovation policy still tends to neglect non-R&D related sources of innovation such as VET (Hall & Jaffe, 2018; Lay & Som, 2015). As a result, policy support measures are still strongly oriented towards the science-push model of innovation, with its emphasis on promoting in-house R&D (Hirsch-Kreinsen, 2008; Kirner & Som, 2015; Thomä & Zimmermann, 2020). As such, they tend to overlook the body of empirical evidence showing that large shares of innovating companies do not report any formal R&D (Arundel et al. 2008;

Hervas-Oliver et al. 2011; Thomä and Bizer 2013), and still do not differ in productivity levels (Kirner, Kinkel, & Jaeger, 2009; Som, 2012) or growth rates from R&D active companies (Rammer et al., 2009; Thomä & Zimmermann, 2020). Thus, with their traditional focus on R&D-intensive firms and high-tech start-ups, innovation policies may disregard the growth potential of large parts of the SME sector. Furthermore, overlooking the group of non-R&D innovators, they are unable to identify and promote those institutions that facilitate and support less-R&D-oriented modes of innovation at the company level. Our results therefore suggest that promoting a company's engagement in the VET system should not only be regarded by policy-makers as a tool to foster the smooth integration of youth into the regular labor market and secure a supply of skilled workers, but also as a measure of innovation policy towards the small enterprise sector. Similarly, the technological upgrade of vocational schools and training centers should not only be considered as a tool of modern education policy, but also as an integral part of innovation policy in the knowledge economy.

The remainder of the paper is structured as follows. In the following section, we review and synthesize arguments from the conceptual and empirical studies analyzing how initial VET contributes to knowledge transfer, learning and innovation (Section 2). Here, we derive our central arguments on the potential association between VET and different patterns of firm-level innovation. In the next sections, we introduce the dataset (Section 3), discuss the estimation strategy (Section 4) and present the main results both from baseline specifications (Section 5.1) and extended models (Sections 5.2-5.3). The paper concludes with implications for policy and further research.

2. The link between vocational education and innovation

2.1. VET and the DUI mode of innovation

Traditionally, researchers have conceptualized innovation as the production and use of codified scientific and technical knowledge, as a process based on scientific principles and formal R&D practices (Jensen, Johnson, Lorenz, & Lundvall, 2007). Knowledge production has been assumed to take place in scientific institutions or formal R&D departments of industrial leaders and build on prior knowledge and skills of scientific personnel (Aghion, 2008; Aghion & Howitt, 2006). In this context, the human capital of academically-trained personnel (e.g. employees with a PhD or master in natural sciences or engineering) has been seen as the main precondition for a company's ability to absorb valuable knowledge inputs from outside the firm (Cohen & Levinthal, 1989, 1990). Unsurprisingly, this research tradition did not assume that VET-based qualifications below academic levels holds much relevance for technological progress and firm-level innovation.

The more recent literature takes a rather holistic approach to innovation, emphasizing the role of experience-based, locally-embedded tacit knowledge (Grillitsch & Rekers, 2016; Pittaway, Robertson, Munir, Denyer, & Neely, 2004; Thompson, 2010) and interactive learning within and external to the firm (Fagerberg, Fosaas, & Sapprasert, 2012; Lundvall, 1985; Pittaway et al., 2004) for innovation. This approach closely relates to Jensen et al.'s (2007) conceptual differentiation between two distinctive modes of innovation. The first one – labeled the STI mode – resembles the traditional understanding of the innovation process. It is based on learning by science, technology and innovation (STI) and is characterized by the production and use of explicit, codified and scientific knowledge. The second mode is based on learning by doing, using and interacting (DUI) and relies upon the interactive use of experience-based know-how, which is often highly localized and of an implicit nature. The DUI approach builds on the concepts of learning-by-doing (Arrow, 1962), learning-by-using (Rosenberg, 1982) and learning-by-interacting (Lundvall & Johnson, 1994), which imply that not only formalized R&D activities but also practical experience in production and customer relations result in competence building and knowledge flows, which in turn facilitates innovation outcomes. Within the DUI mode, practical problem-solving skills developed in production-related environments hold paramount importance for innovation. Moreover, organizational learning and creating a corresponding business culture are the internal foundation of DUI mode learning in innovating firms (Asheim & Parrilli, 2012b). As a result, some studies in the literature on DUI mode innovation stress the importance of vocational qualifications as an important input into the business innovation process (Thomä, 2017; Thomä & Zimmermann, 2020).

STI and DUI modes of innovation are often associated with different innovation outcomes. The science-driven STI mode is expected to produce more radical, market-shaping, disruptive innovation. By contrast, incremental innovations that involve only minor modifications and improvements of existing technologies, products and services are primarily associated with DUI processes (Nunes & Lopes, 2015). Incremental product modifications are assumed to be mainly customer-driven, and they result from the adaptation and improvement of existing products and services to specific needs of individual consumers (Kirner & Som, 2015). Incremental process innovations in terms of continuous improvements, optimization and the cost efficiency of business processes arise as a result of cumulative learning among employees (Dutton & Thomas, 1984; Matthews, MacCarthy, & Braziotis, 2017). According to Toner (2010), VET trained workers play a critical role in such incremental innovation activities. Similarly, Thomä (2017) and Thomä and Zimmermann (2020) argue that DUI mode learning, the introduction of incremental innovation and the relevance of VET-based qualifications are closely intertwined with DUI-mode learning constituting an important element of small firm innovation (see also Thomä and Zimmermann 2013; Runst and Thomä 2022). An essential prerequisite for DUI innovation in smaller firms to succeed – and thus a key starting point for policy support – is effective knowledge diffusion. On this basis, DUI-oriented SMEs often receive the necessary impetus to engage in innovation. Hence, measures to increase the capacity of smaller firms to absorb external knowledge by including a broad set of institutions that affect learning and innovation (particularity at the regional level), the integration of small and medium-sized enterprises (SMEs) in regional innovation systems and the upgrade workforce skills in SMEs to enable their participation in DUI mode innovation are vital in this context (Isaksen and Karlsen 2011; Hervás-Oliver et al. 2021; Hewitt-Dundas 2006; OECD 2010; Rammer et al. 2009; Thomä 2017; Bennat 2021). All of these mechanisms can be expected to be facilitated by the VET system (Brunet Icart & Rodríguez-Soler, 2017; Hodge & Smith, 2019; Lund & Karlsen, 2020; Porto Gómez et al., 2018; Rupietta & Backes-Gellner, 2019; Rupietta et al., 2021).

According to Jensen et al. (2007: 684), DUI-based workplace learning may occur as an “unintended by-product”, but it can also be intentionally fostered by building organizational structures, which enhance knowledge exchange and informal learning. While previous literature on organizational learning focused on the role of flexible organizational practices like task groups (Argote & Miron-Spektor, 2011), quality circles or task rotation (Wood, 1999), recent literature starts to devote attention to more established and continuous forms of organizational learning, like the initial or continuing training of skilled workers (Barba Aragón, Jiménez Jiménez, & Sanz Valle, 2014; Bauernschuster, Falck, & Heblich, 2009; Jaw & Liu, 2003). Thus, training activities such as those occurring in the VET system are increasingly acknowledged as an essential element of DUI mode learning and innovation (Alhusen & Bennat, 2021; Apanasovich, 2016).

2.2. The role of VET in organizational learning

In Germany, initial VET is often associated with a distinct learning and training culture (Thomas; Deissinger, 2015; Thomas Deissinger, 2012; Harris & Deissinger, 2003; Pilz, 2008; Wiemann & Pilz, 2020). However, only a few recent studies explicitly conceptualize the VET system as an institutional mechanism for organizational learning and knowledge spillover and a driver of smaller firms' absorptive capacities (Barabasch & Keller, 2020; Proeger, 2020; Rupietta et al., 2021). Generally, the concept of organizational learning refers to the transformation of individual knowledge into organizational knowledge and the establishment of organizational routines that sustainably promote knowledge creation and dissemination (Argyris & Schon, 1978; Popper & Lipshitz, 2000). Organizational learning as a multilevel process occurs when the knowledge and skills of individual workers and groups become embedded in the organization's practices (Crossan et al., 2011) and thus improve business performance and innovativeness (Jiménez-Jiménez & Sanz-Valle, 2011; Santos-Vijande, López-Sánchez, & Trespalacios, 2012). Gaining experience is crucial for growing knowledge stocks (Argote & Miron-Spektor, 2011; Fiol & Lyles, 1985).

In accordance with this concept, Barabasch and Keller (2020) argue that companies participating in the VET system not only support and encourage independent learning of their apprentices, but they also introduce "innovative structural practices" that shape the learning culture of the whole enterprise. Similarly, Harris and Deissinger (2003) note that apprenticeship training involves not only the "picking up of skills", but also assimilating the tacit knowledge of the corresponding profession, along with its cultural values, ways of interacting and manufacturing standards by means of "learning-by-immersion". Alhusen and Bennat (2021) argue that participation in the VET system helps to develop a new organizational culture that promotes "learning-by-training". According to Thomä (2017), the strength of the VET system is associated with the interactive character of dual training, enabling VET graduates to solve complex problems and interact with engineers and scientists in innovation projects.

All of these studies suggest that the innovative impact of the VET system stems from both internal knowledge creation and external knowledge transfer (Nonaka, 1994), namely from the combination of endogenous and exogenous learning. Endogenous learning occurs within the firm and is associated with localized skill enhancement (Dutton & Thomas, 1984). While conducting initial VET, tacit knowledge is transferred from experienced practitioners to apprentices. The internal knowledge transfer is seen as a comprehensive process that is not reduced to "teaching skills" but rather conceptualized as a complex process of trade-based socialization (Harris & Deissinger, 2003) and complemented by experience-based practical expertise (Thomä, 2017). Exogenous learning is associated with the acquisition and absorption of new information from external resources (Dutton & Thomas, 1984), like VET colleges (Lund & Karlsen, 2020; Wieland, 2015). In this view, apprentices act as "hybrid agents", integrate external knowledge and moderate organizational change (Rupietta et al., 2021). The VET system helps companies to institutionalize such internal and external forms of learning (Thomas; Deissinger, 2015; Wieland, 2015) and ensures a constant flow of knowledge within the organization (i.e. between employees) and across organizational boundaries from the institutions of the VET system to individual business establishments (Hodge & Smith, 2019; Lund & Karlsen, 2020; Porto Gómez et al., 2018; Rodríguez-Soler & Icart, 2018; Rupietta & Backes-Gellner, 2019; Rupietta et al., 2021). Hence, VET in knowledge economies such as Germany, Norway or Switzerland fosters knowledge dissemination and related innovation activities at the company level (Powell & Snellman, 2004; Proeger, 2020).

2.3. Empirical evidence

To our knowledge, Toner (2010) was the first to discuss the role of vocational training in innovation in more detail. His study focuses on the patterns of innovation activity in Australia, which he describes as being concentrated on a range of low and medium technology sectors and non-R&D-intensive firms that heavily rely on technology sourcing rather than own research activities (i.e. a pattern of DUI mode innovation). The author argues that the effectiveness and efficiency of innovation activities in this less

R&D intensive knowledge environment critically depend on the capacity of the production workforce to engage creatively in problem-solving. The VET system is seen as crucial for this process. According to Toner (2010), it plays a critical role in skills creation, knowledge diffusion and the development of the workforce's absorptive capacity. He also stresses the importance of vocational education institutions, which are highly responsive to the particular needs of local industries, offer customized training programs, serve as intermediaries between equipment producers and local businesses and present new technologies to their customers. Building on the arguments of Rosenfeld (1998), this study recapitulates that all of these functions are especially vital for SMEs, which often lack the resources and competences to scout the newest knowledge and technologies. Taken together, Toner (2010) conceptualizes the VET system as an institutional learning environment that promotes localized skill enhancement and technology diffusion through initial VET.

The role of vocational education institutions for the functioning of regional innovation systems is further examined in the Spanish studies of Porto Gómez et al. (2018) as well as Rodríguez-Soler and Icart (2018) and the Norwegian study of Lund and Karlsen (2020). Porto Gómez et al. (2018) use a survey design to analyze the role of VET training centers as agents of knowledge exchange and dissemination in the Basque country. They conclude that for many local firms, VET centers represent the main source of knowledge and hence play a "pivotal role" in the innovation processes of these companies. Rodríguez-Soler and Icart (2018) establish that geographical proximity is crucial for knowledge exchange networks between VET institutions and SMEs. In this way, VET institutions can be a driving force of regional innovation systems in terms of knowledge diffusion. Again, VET institutions are described as "a key node" (p. 13) in the knowledge network of DUI-oriented SMEs. Lund and Karlsen (2020) conduct nineteen in-depth, semi-structured interviews in two Norwegian manufacturing regions and re-establish the result of the Spanish studies, concluding that vocational colleges are important sources of knowledge for local firms. Similar to Toner (2010), they report the high responsiveness of vocational institutions to the needs of the local business sector, show how industrial actors and vocational schools cooperate in developing educational programs and demonstrate how the manufacturing industry and vocational education institutions co-evolve with new technological developments. Thus, the studies stress that the participation in initial VET contributes to establishing continuous knowledge flows between VET institutions and local business establishments.

The recent Swiss study of Rupietta and Backes-Gellner (2019) goes a step beyond these considerations and analyzes in detail how participation in the VET system promotes technology diffusion and innovation. They describe the Swiss dual system of apprenticeship training and highlight the role of institutionalized curriculum development and updating processes as a central channel of knowledge diffusion, and hence as major driver of DUI mode learning in training companies. In Switzerland (as in Germany), vocational training is based on nationally-binding, occupation-specific training curricula, which ensure a high level and transferability of vocational skills (Mueller & Schweri, 2015; Wolter & Ryan, 2011). These curricula are regularly updated to not only cover widespread knowledge and well-established technologies, but also to provide information about specialized technologies or new technological developments that are not generally used in the day-to-day operations of an individual company. Lund and Karlsen (2020) also illustrate this process, which is based on collaboration between VET institutions and industry actors, for manufacturing regions in Norway.

In the model of Rupietta and Backes-Gellner (2019) the involvement of the leading-edge companies in this institutionalized curricula-updating process fosters the distribution of new knowledge and technologies across the broad range of training companies and therefore enhances their innovation capacities. According to the authors, companies participating in initial VET are confronted with new technologies of the industry leaders, learn about them and – because of this – have competitive advantages over firms that do not participate in apprenticeship training. While large companies are primarily those that provide the innovative input into the curricula-updating process, SMEs are expected to profit most from this knowledge diffusion and the subsequent adaptation of new knowledge inputs to their individual needs. Consequently, Rupietta and Backes-Gellner (2019) expect the innovation effects of participation in the VET system to be stronger for smaller companies.

2.4. Synthesis: the potential impact of initial VET on innovation

Taken together, the existing studies argue that participation in the VET system enables individual companies to enhance their technical competences, raise their absorptive capacity and – even more importantly – establish organizational structures that strengthen the continuous inflow of new knowledge into training firms and foster a viable learning climate at the company level. At the same time, we expect several dimensions of the competitiveness of knowledge-based economies to be promoted through the VET system. These are knowledge diffusion, organizational learning and management innovation as well as the built-up of experience-based know-how. In sum, the innovativeness of training companies should therefore be higher than for non-participants. Moreover, the potential positive impact of initial VET on innovation should therefore result from a complementary relationship between a top-down approach (driven by management) and a bottom-up approach (driven by the trainees) to innovation in training firms (Hodge and Smith 2018).

Moreover, the skill enhancement associated with initial VET should result in incremental innovation rather than radical, market-shaping outcomes. In terms of product innovation, this should relate to minor changes and improvements to existing products. Something similar can be expected with regard to process innovation, where a firm’s involvement in initial VET can contribute to the continuous improvement, optimization and cost reduction of materials and components (Toner 2010). In this context, the empirical results of Rupietta and Backes-Gellner (2019) suggest that initial VET activities have a stronger impact on product innovation activities than for process innovation. Finally, the potential role of VET institutions – training centers as well as training curricula and their continuous updating – should be considered as well. Previous research further stresses their importance as a main channel of technology transfer from technological leaders and technology enablers to technology followers. In this context, participation in the VET system should have the strongest impact on innovation in smaller firms, which are not at the technological frontier of their industry and often lack necessary resources and competencies for technology sourcing.

3. Data

To investigate the link between VET and innovation, we use data from an extensive survey of the German Federal Employment Agency: the IAB EP dataset. The IAB EP is an employer survey that is representative of all industries and firm size groups in Germany. The sampling frame in the IAB EP survey is the Establishment File of the Federal Employment Agency, which contains all business units with at least one employee covered by social security. Thus, one-person establishments or establishments with marginal employees (i.e. employees who are not subject to social security provisions) are not included in the target sample. This limitation does not affect our study because VET trainees are treated as regular employees in German social security schemes. Companies providing initial VET are therefore fully covered by the sampling scheme. Ellguth et al. (2014) provide further details on the sampling of the IAB EP dataset and the overall design of the survey.

Table 1. Descriptive statistics

		All companies		Training companies		Non-training companies	
	Description	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Dependent variables							
General innovation	1 if firm conducted product and/or process innovation	0.43	0.50	0.53	0.50	0.35	0.48
Product innovation	1 if firm conducted product innovation	0.42	0.49	0.51	0.50	0.34	0.47
Process innovation	1 if firm conducted process innovation	0.16	0.37	0.22	0.41	0.11	0.31
Radical product innovation	1 if firm conducted new-to-market product innovations	0.07	0.26	0.09	0.29	0.06	0.23
Incremental product innovation	1 if firm conducted product innovation which is not new to the market	0.36	0.48	0.44	0.50	0.28	0.45
Explanatory variable							
Training company	1 if firm employs VET trainees	0.46	0.50	1.00	0.00	0.00	0.00
Control variables (step 1: replication)							
Company size	Total number of employees	114.30	858.34	215.06	1,257.90	29.81	110.03
Share of workers with vocational qualification	Employees with completed vocational training in total employment (%)	0.55	0.29	0.63	0.24	0.49	0.30
Share of workers with university degree	Employees with higher education in total employment (%)	0.09	0.18	0.09	0.16	0.08	0.19
Competitive pressure	1 for medium / substantial competitive pressure	0.69	0.46	0.74	0.44	0.66	0.47
Demand expectation	1 if company expects increasing business volume next year	0.26	0.44	0.30	0.46	0.24	0.43
Foreign company	1 if company is foreign owned	0.06	0.24	0.07	0.26	0.06	0.23
Shortage of skilled workers	1 if a company reports lack of skilled workers	0.25	0.43	0.34	0.47	0.17	0.38
Extended set of controls (step 2: further controls)							
Continuing training	1 if a company provides continuing training to their employees	0.67	0.47	0.86	0.35	0.51	0.50
R&D activities	1 if a company conducts in-house R&D	0.10	0.31	0.16	0.37	0.06	0.23
Investment activities	1 if a company made investments in 2016	0.61	0.49	0.74	0.44	0.50	0.50
Technical equipment	State of a company's technical equipment (1 "state-of-the-art" – 4 "out of date")	2.75	0.76	2.80	0.74	2.71	0.78
Export activities	1 for exporting companies	0.22	0.41	0.30	0.46	0.15	0.36
Broadband connection	1 if a company has high-speed internet access	0.78	0.41	0.83	0.38	0.74	0.44
Family business	1 if a company is family-controlled	0.77	0.42	0.67	0.47	0.84	0.37

Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution (Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB), 2017). DOI: 10.5164/IAB.IABBP9317.de.en.v1.

We analyze data for 2017, which we access via a remote data execution system (JoSuA) of the Research Data Centre (FDZ) of the German Federal Employment Agency. The dataset includes information on 15,421 establishments, 43.5% of which report innovation outcomes and 45.6% report VET activities. A full description of all variables and the respective descriptive statistics by VET status is given in Table

1. Our main variables of interest are indicators for innovation outcomes and initial VET. The IAB survey asks respondents a number of questions on innovation activities that we can use to construct our dependent variables. Following Rupietta and Backes-Gellner (2019), we distinguish between general, product and process innovation. In contrast to their study, we also differentiate between radical and incremental product innovation.

The underlying survey questions fully comply with the Oslo Manual guidelines on measuring firm-level innovation (OECD/Eurostat, 2018)[1]. Contrary to Rupietta and Backes-Gellner (2019), we do not have any information on the companies' patenting strategy, so we cannot use an indicator for patent applications in our research setting. However, in contrast to Rupietta and Backes-Gellner (2019) we can control for a firm's R&D activity.

The survey further gathers extensive information concerning VET activities of individual companies. We construct our primary variable of interest – the binary training indicator "training company" – based on information in the IAB survey on whether a company employs VET trainees (i.e. apprentices) or not. In addition, we also use the comprehensive information on the qualification structure of the company's workforce provided in the dataset. Here, we construct a metric variable describing the share of workers with different qualification levels.

We divide the sample by VET status and report descriptive statistics for training companies and non-trainers in Table 1. We observe that training companies outperform other firms in a number of dimensions. First of all, training companies more often report innovation outcomes than non-training ones. Thus, based on descriptive statistics, we would expect the training status to be associated with firm-level innovativeness. However, training companies are also larger on average, face fiercer competition and have stronger propensities to invest in equipment, provide continuing training and conduct R&D themselves (Table 1).

Hence, the distribution of the covariates is strongly unbalanced and we should consider this in our estimation strategy. To address this issue, we use a large number of control variables in our estimation models. Most importantly – and in contrast to Rupietta and Backes-Gellner (2019) – we include indicators for R&D, continuing training and investment in the extended control strategy. To improve the precision of the estimates of the association between VET and innovation and to test for robustness of our results, we also perform estimations based on balanced data. We explain the motivation for the usage of the estimation strategy and the associated problems in more detail in the following section.

4. Estimation strategy

We start our analysis by estimating models with different specifications and sets of controls using standard ordinary least square estimators. Our dependent variable is an indicator, so we refer to the estimations as linear probability models (LPMs) (Angrist & Pischke, 2008). In analogy to the Swiss study of Rupietta and Backes-Gellner (2019), we rely on LPMs rather than probit or logit models for consistency. Generally, the choice of the estimation model will hardly affect the results, given that LPMs and non-linear models based on link functions are known to deliver similar results (Angrist & Pischke, 2008).

[1] The questions asked in the IAB survey 2017 were: "In the last business year of 2016, did your establishment improve or further develop a product or service which had previously been part of your portfolio?" (*product innovation*); "In the last business year of 2016, did your establishment start to offer a product/service that had been available on the market before?" (*new-to-the-firm product innovation*); "Have you started to offer a completely new product or service in the last business year of 2016 for which a new market had to be created?" (*radical product innovation*); "Did you develop or implement procedures in the last business year of 2016 which have noticeably improved production processes or services?" (*process innovation*).

Our basic estimation model is thus given by:

$$INNO_j = \gamma_0 + \gamma_1 VET_j + \sum_{k=1}^{K} \gamma_k x_{kj} + e_j$$

where *INNO* denotes the innovation indicator (equal 1 for innovating companies, and 0 otherwise), *VET* takes the value of 1 if the firm is currently engaged in initial VET activities, *k* denotes the number of control variables, *j* denotes the number of companies and *e* is the error term.

We begin our analysis with the replication of the models estimated by Rupietta and Backes-Gellner (2019). Their set of controls include firm size, the educational composition of a firm's workforce, competition measures, an indicator for a shortage of skilled workers and indicators for foreign-owned firms, economic sector, year and region. For the educational composition, we include information on the share of vocationally and academically trained employees. In contrast to Rupietta and Backes-Gellner (2019), we leave out an additional indicator for the share of unqualified workers due to collinearity. Based on our dataset, we are able to construct a comparable set of controls with some minor differences in the scaling of some variables (see Table 1). First, our workforce qualification variable includes four categories rather than five. Second, our competition measures do not refer to price and non-price competition, but rather a question asking survey respondents to assess the pressure of competition in their market (1 for medium or substantial pressure). Third, as an alternative to the control variable on demand changes in the Swiss study, we use information on the business volume expectation (1 if a company expects increasing business volume in the next year). Like Rupietta and Backes-Gellner (2019), we are also able to control for economic sector, firm size, a shortage of skilled workers, foreign ownership and regional dummies.

In the second step of our analysis, we extend the set of controls in the estimated models. Most importantly, Rupietta and Backes-Gellner (2019) are unable to control for in-house R&D in their study. This is an important limitation, because formal and institutionalized R&D activities are known to be a major input to the innovation process at the company level, especially in companies following the STI mode of innovation (Hall & Jaffe, 2018; Jensen et al., 2007). Due to the wide scope of the IAB EP survey, we are able to include the R&D indicator and additionally an indicator for continuing training. We assume that both R&D and continuing training activities increase the knowledge stock of companies and affect their knowledge flows, both of which should have a positive impact on firm-level innovativeness, in particular regarding product innovation (Bauernschuster et al., 2009; Fagerberg, Srholec, & Verspagen, 2010).

Further, we consider indicators on investment and the technical state of equipment as further important inputs into the knowledge production process. The technical state of equipment reflects a firm's technological endowment and its ability to convert resources into innovative outputs. Investments in new production facilities, plants or equipment increase this stock and capabilities (Barney, 1991; Heidenreich, 2009). The literature shows that investment activities may be inversely related to R&D: firms may substitute their own technology development with technology sourcing (Santamaría, Nieto, & Barge-Gil, 2009). We can include both indicators as control variables by drawing on the questions in the IAB EP survey concerning the technical state of a company's equipment (1 "state of the art" – 4 "out of date") and its investment activities (1 for investments in 2016, 0 otherwise).

Drawing upon additional evidence in Akerman et al. (2015) and their discussion of the link between productivity and digital transformation, we further control for high-speed internet access. Finally, we also include general company-specific controls, such as dummies for family-owned businesses (Zahra, 2012) and export activities, as these indicators have both been shown to affect firm-level innovativeness (Peters & Rammer, 2013).

The main challenge in estimating the impact of initial VET on firm-level innovativeness is that a firm's participation in the dual VET system may not be random. Thus, when deciding on the estimation approach, it is necessary to address the problem of a potential self-selection into training in a robustness test. Assuming selection on observables, we could cope with the potential selection bias by applying either matching (Abadie & Imbens, 2011; Z. Zhao, 2004) or entropy balancing (Hainmueller, 2012). Both techniques are data pre-processing methods that aim to eliminate the self-selection bias by balancing out the set of observable characteristics. Entropy balancing (EB) is a technique that has recently emerged in the literature on treatment effects. It is to be understood as a generalization of the propensity score weighting approach (Hainmueller, 2012). EB generates weights so that specified moment conditions of covariate distributions of treatment and control group are balanced. The balancing reduces model dependency (Hainmueller, 2012; Hainmueller & Xu, 2013; Q. Zhao & Percival, 2017).

We have opted for EB in our study for three reasons: first, EB allows us to include a larger set of balance constraints compared to matching; second, in relying on EB we can retain the full information from the original data and do not have to discard observations (as would be the case with matching); and third, the method is also computationally attractive, as the search algorithm attains the weighting solution rather quickly, even with a large data set like ours. By contrast, matching procedures often involve an intricate search process, which often does not result in a satisfying level of covariate balance and – in some cases – can even prevent the reduction of potential self-selection bias (Hainmueller, 2012; Hainmueller & Xu, 2013; Q. Zhao & Percival, 2017).

5. Results

5.1. Baseline results

We start with the presentation of a basic replication of the Swiss study of Rupietta and Backes-Gellner (2019). According to the results displayed in Table 2, German companies participating in initial VET have an 11.7% higher probability of being innovative than non-training companies. Thus, the point estimate in our estimation sample is five-percentage points higher than in the Swiss study, which reports a point estimate of 6.8%. Turning to product innovation, we observe a marginal effect of 0.116, which is again higher than the coefficient reported in the Swiss study (0.061). We further observe a positive association between initial VET activities and process innovation (0.072). Here, our results differ from Rupietta and Backes-Gellner (2019), who report a non-significant marginal effect of 0.034. Overall, the replication results provide evidence in favor of an overall positive association between initial VET and general firm-level innovativeness. The effect sizes and significance levels in the German sample are higher compared to those reported in the Swiss study. Moreover, we find some support for the argument that the association between initial VET and product innovation is stronger than in case of process innovation.

Turning to the estimation models for radical and incremental innovations (Table 2, Columns 4 and 5), we observe the pattern of results that we expected based on the theoretical literature: the positive impact of initial VET on firm-level innovativeness primarily relates to incremental (DUI) learning and innovation (marginal effect of 0.117). In case of radical innovation, the respective coefficient is lower

(0.025). These results are consistent with the theoretical reasoning presented above, postulating a stronger correlation with incremental rather than radical product innovation.

Table 2. Baseline results

	Linear probability models				
	General innovation	Product innovation	Process innovation	Radical product innovation	Incremental product innovation
For comparison: Rupietta and Backes-Gellner (2019) results based on Swiss data					
Training company	0.068***	0.061***	0.034	not reported	not reported
Replication results based on German data					
Training company	0.117***	0.116***	0.072***	0.025***	0.117***
R^2	0.144	0.141	0.095	0.053	0.148
Adj. R^2	0.141	0.138	0.092	0.049	0.145
Observations	11,764	11,766	11,769	11,773	11,764

Notes: The table displays marginal effects from linear probability models, estimated for different dependent variables (binary indicators for general, product, process, radical and incremental innovation). Further controls include firm size, indicators for the educational composition of a firm's workforce, competition measures, an indicator for a shortage of skilled workers, indicators for foreign ownership, economic sector and sixteen federal states. The coefficient estimates for the control variables are reported in the Appendix (Table A. 1). Significance levels are based on robust standard errors and denoted as: * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9317.de.en.v1.

5.2. Results based on the extended set of controls

In their pioneering study, Rupietta and Backes-Gellner (2019) are unable to control for two important inputs into the knowledge production process that are associated with different modes of learning: the existence of in-house R&D activities and continuing training of employees. As highlighted in Section 4, this is an important limitation, which can upward bias the results of the baseline specification due to omitted variables. Therefore, to check the robustness of the baseline results to the inclusion of additional covariates, we extend the control strategy and add a number of additional variables to the estimation models. In particular, we include indicators on R&D, company-financed continuing training and several technology and investment dummies. Additionally, we control for a firm's digital infrastructure and a number of other company-level characteristics that have been shown to affect the propensity to innovate (and are listed in Table 1). The estimation results for the full set of controls are given in Table 3. As expected, the extended control strategy significantly reduces the estimated association between initial VET and all outcome measures of innovation. The coefficients on participation in VET remain positive for all innovation types, although they are much lower and partly not significant.

Table 3. Results of models with the extended control strategy differentiated by firm size

	General innovation				Product innovation				Radical product innovation				Incremental product innovation				Process innovation			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Training company	0.031 ***	0.049 **	0.011	0.032	0.030 ***	0.049 ***	0.012	0.034	0.003	0.007	-0.002	0.003	0.022 **	0.037 **	0.002	0.018	0.027 ***	0.028 **	0.016	0.040 *
Controls																				
Company size	0.000	-0.004	0.001 *	0.000	0.000	-0.004	0.001 *	0.000	0.000	0.001	0.001 *	0.000	0.000	-0.002	0.001	0.000	0.000 ***	0.002	0.000	0.000 ***
Share qualified workers	0.031 *	0.043	0.060 *	0.020	0.023	0.036	0.054	0.012	0.008	-0.009	0.010	0.042	0.040 **	0.061 **	0.029	0.064	0.007	0.025	0.018	-0.033
Share of university graduates	0.159 ***	0.095	0.131 **	0.283 ***	0.155 ***	0.101 *	0.115 *	0.300 ***	0.098 ***	0.016	0.147 ***	0.119 **	0.177 ***	0.116 **	0.123 **	0.337 ***	0.080 ***	0.058	0.091 *	0.081
Shortage of skilled workers	0.041 ***	0.052 **	0.050 ***	0.016	0.036 ***	0.049 **	0.042 **	0.013	0.012 *	0.041 ***	-0.003	0.002	0.039 ***	0.048 **	0.038 **	0.021	0.035 ***	0.011	0.043 ***	0.039 **
Continuing training	0.094 ***	0.098 ***	0.084 ***	0.075 **	0.089 ***	0.093 ***	0.088 ***	0.058 *	0.012 **	0.016 **	0.007	0.007	0.081 ***	0.078 ***	0.086 ***	0.068 **	0.044 ***	0.042 ***	0.035 ***	0.081 ***
R&D activities	0.261 ***	0.320 ***	0.295 ***	0.209 ***	0.282 ***	0.330 ***	0.311 ***	0.239 ***	0.147 ***	0.181 ***	0.180 ***	0.115 ***	0.320 ***	0.362 ***	0.346 ***	0.266 ***	0.219 ***	0.297 ***	0.208 ***	0.187 ***
Investment activities	0.126 ***	0.120 ***	0.120 ***	0.162 ***	0.121 ***	0.115 ***	0.113 ***	0.165 ***	0.024 ***	0.029 ***	0.019 **	0.009	0.104 ***	0.093 ***	0.096 ***	0.152 ***	0.054 ***	0.052 ***	0.044 ***	0.090 ***
Technical equipment	0.045 ***	0.054 ***	0.041 ***	0.027 **	0.045 ***	0.054 ***	0.041 ***	0.029 **	0.011 ***	0.016 ***	0.003	0.010	0.047 ***	0.044 ***	0.060 ***	0.037 ***	0.030 ***	0.021 ***	0.024 ***	0.056 ***
Export activities	0.112 ***	0.183 ***	0.077 ***	0.072 ***	0.104 ***	0.171 ***	0.080 ***	0.059 **	0.024 ***	0.031 **	0.025 **	0.021	0.091 ***	0.120 ***	0.080 ***	0.060 **	0.052 ***	0.067 ***	0.053 ***	0.029
Competitive pressure	0.062 ***	0.055 ***	0.063 ***	0.085 ***	0.061 ***	0.055 ***	0.061 ***	0.096 ***	0.003	-0.006	0.012	0.028	0.051 ***	0.045 ***	0.045 **	0.095 ***	0.018 **	0.017 **	0.004	0.036
Demand expectation	0.072 ***	0.074 ***	0.075 ***	0.060 ***	0.070 ***	0.069 ***	0.073 ***	0.064 ***	0.025 ***	0.030 ***	0.029 ***	0.016	0.062 ***	0.060 ***	0.059 ***	0.070 ***	0.036 ***	0.031 ***	0.051 ***	0.022
Foreign company	-0.024	-0.041	-0.056	0.017	-0.027	-0.035	-0.064 *	0.007	0.003	-0.003	-0.046 **	0.040	-0.031 *	-0.019	-0.087 ***	-0.000	0.006	0.000	-0.032	0.036
Broadband	0.020 *	0.017	0.033 *	-0.009	0.022 **	0.014	0.038 *	0.005	0.007	0.005	0.013	-0.010	0.031 ***	0.040 ***	0.019	0.010	0.001	0.005	0.004	-0.020
Family business	-0.055 ***	-0.043	-0.064 ***	-0.034 *	-0.054 ***	-0.046	-0.062 ***	-0.039 **	-0.017 **	-0.044 **	0.000	-0.025 *	-0.064 ***	-0.031	-0.076 ***	-0.044 **	-0.024 **	0.005	-0.013	-0.033 *
Observations	10,581	4,757	3,402	2,422	10,582	4,758	3,402	2,422	10,586	4,762	3,401	2,423	10,581	4,759	3,399	2,423	10,584	4,761	3,400	2,423
R^2	0.217	0.142	0.195	0.226	0.215	0.141	0.193	0.232	0.083	0.079	0.100	0.075	0.230	0.139	0.197	0.243	0.149	0.119	0.114	0.135
Adj. R^2	0.214	0.133	0.184	0.211	0.211	0.132	0.182	0.217	0.079	0.069	0.088	0.057	0.227	0.130	0.186	0.228	0.145	0.110	0.102	0.118

Notes: The table displays marginal effects from linear probability models, estimated for different dependent variables (binary indicators for general, product, radical and incremental product, and process innovation) by company size classes (I: whole sample; II: 1-9 employees; III: 10-49 employees, IV: 50 or more employees). Further controls include indicators for economic sector and sixteen federal states. Significance levels are based on robust standard errors and denoted as: * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01. Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9317.de.en.v1.

In particular, as expected, we cannot observe any positive impact of initial VET on radical product innovation, which is a result consistent with our theoretical reasoning. For the whole sample, we observe a positive relationship between VET and general innovation (3.1%***), product (3.0%***) and incremental product (2.2%**) as well as process innovation (2.7%***). Hence, based on an extended set of controls, we find evidence in favor our argumentation in Subsection 2.4.Additionally, the association between VET and product and process innovation are both significant with the former being stronger in comparison to process innovation, while Rupietta and Backes-Gellner (2019) do not observe an effect for process innovation. This novel finding can probably be explained by the fact that process innovations often are a result of hands-on experience of employees and their intimate familiarity with the technological processes involved. The knowledge associated with improvements in production and services processes thus often contains a relatively high degree of tacitness (Gopalakrishnan, Bierly, & Kessler, 1999), which can explain the role of initial VET in this context. Moreover, by looking at the estimates differentiated by firm size, it can be seen that the significant effects for the whole sample are mainly due to microenterprises (Table 3). We observe higher and significant correlations only for companies with less than 10 employees while the coefficients are insignificant for companies with more employees. Hence, especially in very small firms, apprentices can play a crucial role in (incremental) innovation activities.

Hence, very small DUI mode firms should profit most from the knowledge diffusion stemming from vocational education institutions (on this issue, see Section 2). A closer look at the control variables further explains the reasons for the change in the estimated coefficients (Table 3). In line with previous research (e.g. Hall and Jaffe 2018; Heidenreich 2009), we observe a very strong association between R&D and all output measures of innovation. Companies that report formal R&D activities have a between 14.7% and 36.2% higher probability (depending on the type of innovation) of reporting innovation outputs. Similarly, companies that invest in new technology and report a more advanced technological equipment display a significantly higher probability to innovate, which is also a result known from the literature (Barney, 1991; Smith, 2005). Like Bauernschuster et al. (2009) and Peters and Rammer (2013), we also observe a positive impact of continuing training on innovation. Leaving out these central inputs into the knowledge production process would lead to overestimating the impact of initial VET activities on the innovativeness of individual companies.

5.3. Robustness test: results based on entropy balancing

As noted above, the results in Table 3 may be biased due to potential self-selection into initial VET. To address this issue, we balance the estimation sample on the set of observable variables, i.e. we equate the covariate distribution across training and non-training firms. The results of estimations based on balanced data are reported in Table 4 (for more details, see Table A.2 in the Appendix). In balanced LPMs, we obtain coefficients that are slightly higher than those estimated in the regressions reported in Table 3. We still do not observe any association between participation in initial VET and radical production innovation, which is again consistent with our theoretical reasoning. For all other innovation measures of innovation, we now observe significant associations between 3.0% and 3.9% for the whole sample. The coefficients for different firm size groups support the results reported in Table 3. After controlling for selection on observables, the results for the whole sample are again driven by a positive correlation between initial VET and innovation in microenterprises with less than 10 employees.

Table 4. Results based on entropy balancing differentiated by firm size

	General innovation				Product innovation				Radical product innovation				Incremental product innovation				Process innovation			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Training company	0.038***	0.048**	0.015	0.058*	0.039***	0.053**	0.014	0.067**	-0.002	0.005	-0.005	-0.007	0.033**	0.044**	0.009	0.043	0.030***	0.033**	0.014	0.042
Controls																				
Company size	-0.000	-0.008	0.000	-0.000	-0.000	-0.009*	0.000	-0.000	0.000	0.001	0.001	0.000	-0.000	-0.005	-0.000	-0.000	0.000	0.002	-0.000	0.000
Share qualified workers	0.008	0.031	0.069	-0.053	0.000	0.014	0.067	-0.048	-0.012	-0.015	-0.012	0.012	0.018	0.052	0.029	-0.001	0.001	0.029	0.024	-0.044
Share of university graduates	0.204***	0.093	0.276***	0.204***	0.195***	0.088	0.242***	0.232***	0.149***	0.119	0.214***	0.126	0.228***	0.143	0.236***	0.275***	0.116**	0.077	0.232***	0.016
Shortage of skilled workers	0.044***	0.070***	0.017	0.049**	0.034***	0.063**	0.010	0.034	0.012	0.049***	0.003	-0.004	0.033**	0.061**	0.000	0.040	0.044***	0.020	0.038*	0.058**
Continuing training	0.081***	0.106***	0.077***	0.010	0.077***	0.094***	0.087***	-0.005	0.016*	0.019*	0.012	-0.008	0.072***	0.079***	0.080***	0.033	0.047***	0.051***	0.030*	0.085***
R&D activities	0.264***	0.240***	0.298***	0.229***	0.295***	0.258***	0.317***	0.277***	0.171***	0.190***	0.203***	0.124***	0.335***	0.335***	0.359***	0.299***	0.224***	0.268***	0.196***	0.212***
Investment activities	0.115***	0.111***	0.106***	0.150***	0.109***	0.105***	0.098***	0.149***	0.020**	0.019*	0.007	0.032	0.100***	0.094***	0.085***	0.140***	0.052***	0.050***	0.036**	0.078**
Technical equipment	0.045***	0.061***	0.030**	0.036**	0.044***	0.062***	0.026*	0.037**	0.020***	0.028***	0.006	0.029**	0.051***	0.043***	0.054***	0.044***	0.034***	0.027***	0.020	0.059***
Export activities	0.103***	0.233***	0.082***	0.043	0.096***	0.220***	0.092***	0.019	0.011	0.040*	0.034**	-0.054	0.082***	0.174***	0.079***	0.024	0.046***	0.086***	0.060***	-0.010
Competitive pressure	0.070***	0.053***	0.041*	0.163***	0.069***	0.052***	0.041*	0.167***	0.012	0.002	0.009	0.055**	0.063***	0.046**	0.026	0.165***	0.027**	0.023	-0.017	0.096***
Demand expectation	0.076***	0.087***	0.088***	0.053**	0.079***	0.073***	0.091***	0.073***	0.028***	0.035**	0.046***	-0.003	0.069***	0.071***	0.066***	0.076***	0.048***	0.048***	0.068***	0.022
Foreign company	-0.001	0.006	-0.058	0.011	0.000	0.005	-0.057	0.012	0.010	0.012	-0.071***	0.058	-0.004	0.006	-0.061	0.006	-0.003	-0.037	-0.047	0.011
Broadband	0.018	0.032	0.045*	-0.043	0.022	0.030	0.047*	-0.033	0.010	0.006	0.012	0.002	0.028*	-0.006	0.032	-0.025	-0.018	0.056***	0.007	-0.062*
Family business	-0.052***	0.019	-0.058*	-0.071***	-0.043**	0.005	-0.047	-0.061**	0.015	-0.028	0.035*	0.003	-0.057***	0.011	-0.058*	-0.064**	-0.027	0.032	-0.004	-0.048*
Observations	10,581	4,757	3,402	2,422	10,582	4,758	3,402	2,422	10,586	4,762	3,401	2,423	10,581	4,759	3,399	2,423	10,584	4,761	3,400	2,423
R^2	0.213	0.157	0.201	0.257	0.211	0.155	0.200	0.261	0.095	0.108	0.153	0.089	0.232	0.159	0.200	0.272	0.154	0.152	0.134	0.158
Adj. R^2	0.209	0.147	0.190	0.247	0.208	0.144	0.189	0.247	0.092	0.099	0.142	0.070	0.229	0.151	0.189	0.257	0.151	0.144	0.122	0.142

Notes: The table displays marginal effects from linear probability models, estimated for different dependent variables (binary indicators for general, product, radical and incremental product, and process innovation) by company size classes (I: whole sample; II: 1-9 employees; III: 10-49 employees, IV: 50 or more employees). Further controls include indicators for economic sector and sixteen federal states. Significance levels are based on robust standard errors and denoted as: * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01. Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9317.de.en.v1.

Overall, the results based on balanced data confirm that there is a positive association between initial VET and firm-level innovation. However, the observed associations are lower than those reported in the Swiss study of Rupietta and Backes-Gellner (2019) (Table 2). Moreover, it also shows that this effect applies only to incremental product and process innovations in very small firms with fewer than 10 employees.

6. Conclusion and discussion

There is a risk that a R&D focused innovation policy will underestimate the role and transformative potential of economic agents not investing in internal R&D resources. The most recent innovation literature does not question the role of R&D in knowledge production, but it no longer regards R&D investments as “a sine-que-non” for innovation (Shefer & Frenkel, 2005). In proceeding beyond the linear model of innovation, corresponding studies stress the strong variety of R&D and non-R&D-based ways of learning in companies, which may lead to different kinds of innovation outcomes. In this context, special attention is paid to the ongoing relevance of tacit skills and experience-based know-how under the conditions of the knowledge economy. In this literature, VET is increasingly acknowledged as an important driver of a mode of learning and innovation that extends beyond formal processes of R&D and science. In light of this, policy-makers who aim to foster innovation in less R&D-oriented knowledge environments or motivate companies to bridge the gap between R&D and production through innovation-related exchanges on the shop floor may consider the potential role of VET systems.

However, the empirical literature on the importance of VET for innovation remains sparse and studies on the subject often remain conceptual. Overall, corresponding research argues that companies can profit from VET in terms of innovation for three different reasons, which in turn constitute fundamental aspects of a knowledge economy’s competitiveness: First, VET enhancea the skill and competence portfolio of employees; as a result, a VET trained production workforce will be more able to engage in incremental innovation. Second, going beyond the individual capability argument, initial VET activities incentivize companies to establish internal organizational structures and learning environments that facilitate the transfer of (tacit) knowledge within firms and are therefore conducive for building up absorptive capacities at the organizational level of the firm. Third, the interaction with external VET education institutions may enable companies (especially the very small ones) to get in touch with emerging technology trends and external knowledge inputs by fostering knowledge dissemination. For example, VET schools may serve as agents of knowledge diffusion regarding new technologies, and the continuous updating of VET curricula may support the transfer of specialized knowledge and new technologies from industrial leaders to less tech-savvy enterprises (which are often found in the small business sector).

Even if the arguments in favor of the positive impact of VET on innovation seem persuasive, there remains the threat that they can overestimate the actual role of VET on firm-level innovation. For example, large manufacturing firms that follow the science-driven mode of innovation may treat training activity as crucial for quality considerations in manufacturing processes, but they may also lack the commitment to utilize the involvement in VET activities as a starting point for transforming their organizational innovation culture. By contrast, innovation stimuli stemming from VET education institutions can hold essential importance to low-tech companies that lack internal R&D resources (Alhusen & Bennat, 2021; Toner, 2010). Hence, there is a need for further empirical research to establish whether and for which types of enterprises participation in VET will result in superior innovation outcomes. This study directly addresses this research gap and provides empirical evidence on the role of VET for innovation.

To date, the empirical testing of the quantitative link between initial VET and innovation is underdeveloped. The Swiss study of Rupietta and Backes-Gellner (2019) was the first to provide empirical evidence on this issue. Taking this as a starting point, we begin our analysis replicating the models estimated by Rupietta and Backes-Gellner (2019). Here, we observe effects of similar direction but higher magnitude as reported by the original study. In the second step, we extend the set of controls to examine the sensibility of the estimated coefficients to the inclusion of further important drivers of companies' innovation outcomes. As expected, we observe a significant decrease in the measures of associations between initial VET and innovation outcomes. Finally, to improve the precision of the estimates, we employ a maximum EB procedure to account for problems associated with selection on observables.

As a result, we observe that the correlation between initial VET and innovation may be less robust than conceptually postulated. The participation in VET has virtually no effect on radical product innovation. For the total business population, we observe a positive effect of VET activities on incremental product innovation and process innovation. However, this effect is mainly due to microenterprises with fewer than 10 employees. We conclude from this finding that the knowledge diffusion function that the VET system has in knowledge economies (at least at the regional level) primarily holds relevance for the smallest of the training companies.

Our results holds some relevance for innovation policy. They imply that small firms' participation in the VET system helps them to improve their skill and competence portfolio, establish structures conducive to organizational learning and strengthen their capacity to absorb technological knowledge from VET education institutions. In this case, promoting companies' engagement in the VET system should not only be regarded as a policy tool that aims to foster a smooth integration of youth into the regular labor market, but it can also serve as a measure of innovation policy for the small enterprise sector. Similarly, the technological upgrade of vocational schools and training centers should not only be considered as a tool of modern education policy, but also as an integral part of (small firm-oriented) innovation policy in knowledge-based economies.

One further implication of our study refers to the measurement of innovation. Interestingly, expenditure on training is still not consequently incorporated into the standard sets of innovation indicators. Although the revisions of the Oslo Manual (OECD/Eurostat, 2018; OECD and Statistical Office of the European Communities, 2005) reflect the growing appreciation of innovation sources besides R&D, they still seem to underestimate the role of VET for firm-level innovativeness. The most recent edition of the Oslo Manual (OECD/Eurostat, 2018) distinguishes "general training" from "training for innovation", implying that general skill enhancement of the production workforce does not result in any significant improvement of productivity or the innovative capacity of individual business establishments. Expenditure on initial VET (e.g. training of apprentices) is explicitly excluded as innovation-irrelevant investment (OECD/Eurostat, 2018). This reflects the prevailing conviction that production-related skill enhancement and organizational learning in manufacturing environments should be treated as the firm-specific, on-site qualification of low-skilled workforce (Dalitz & Toner, 2016; Hirsch-Kreinsen, 2008; Krueger & Kumar, 2004) without any relevance for innovation activities. The results of our study call such assumptions into question. Based on our results, the treatment of initial VET activities in methodological guidelines for innovation measurement may be thoroughly reconsidered.

Regarding future research, there is an ongoing need for further empirical research to establish whether and for which types of enterprises the participation in initial VET helps to facilitate organizational learning and is associated with superior innovation outcomes. Further progress in the understanding of the role of VET in innovation can be achieved by advancing and combining insights from quantitative research and qualitative methods. The latter can help to identify the potential mechanisms and channels of learning and knowledge transfer within initial VET, such as feedback and documentation systems (Barabasch and Keller 2020; Hodge and Smith 2019). Following the blueprint of Figueiredo et al. (2020) – who examine learning processes in multinational subsidiaries – qualitative research could address the question of how VET participation can help to establish a vital learning environment at the company level.

Quantitatively, the central challenge refers to improving the identification strategy, as our empirical analysis does not allow to draw strict causal inferences. For example, one could argue that innovation activities trigger a higher demand for skilled workers, which may affect the decision to start training activities within the dual VET system (Jansen, Pfeifer, Schönfeld, & Wenzelmann, 2015; Rupietta & Backes-Gellner, 2019). This would imply problems associated with reverse causality. Similarly, it could be that we should control for managerial ability (which unfortunately is unobservable in our dataset), as the human capital of managers or owners has been shown to have a positive impact on firm-level innovativeness (Andries & Czarnitzki, 2014; Kraiczy, Hack, & Kellermanns, 2015; McGuirk, Lenihan, & Hart, 2015; Moilanen, Østbye, & Woll, 2014).

In this respect, it would be promising to examine the long-term innovation effects of initial VET activities based on panel data to control for such fixed effects or to apply an instrumental variable approach to cope with endogeneity. Moreover, the effect of starting or stopping training activities on aggregate innovation outcomes could be analyzed as the quota of companies conducting vocational training varies over time (Seeber & Seifried, 2019). In addition, further research on the effect of changes in regulations or training schemes (e.g. the updating of VET curricula) on innovation activities could be a promising starting point to gain a better understanding of the link between initial VET and firm-level innovation. Hence, there remains a need and room for further research on the subject matter.

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Appendix A

Table A. 1. Baseline results, full set of controls

	Linear probability models				
	General innovation	Product innovation	Process innovation	Radical product innovation	Incremental product innovation
Training company	0.117***	0.116***	0.072***	0.025***	0.107***
Controls					
Company size	0.000**	0.000**	0.000***	0.000	0.000**
Share of qualified workers	0.108***	0.096***	0.055***	0.024***	0.111***
Share of university graduates	0.490***	0.495***	0.254***	0.225***	0.513***
Competitive pressure	0.087***	0.085***	0.032**	0.011**	0.076***
Demand expectation	0.116***	0.114***	0.063***	0.036***	0.103***
Foreign company	0.029*	0.026	0.042***	0.025**	0.031*
Shortage of skilled workers	0.062***	0.056***	0.044***	0.017***	0.056***
Observations	11,764	11,766	11,769	11,773	11,764
R^2	0.144	0.141	0.095	0.053	0.148
Adj. R^2	0.141	0.138	0.092	0.049	0.145

Notes: Further controls include indicators for economic sector and sixteen federal states. Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9317.de.en.v1.

Table A. 2. Results of the balancing procedure, all establishments

	Treat			Control		
	mean	variance	skewness	mean	variance	skewness
Company size	149.9	1865789	39.29	149.7	480362	6.36
Share of qualified workers	.63	.06	-.81	.63	.07	-.82
Share of academics	.06	.02	3.31	.06	.02	3.06
Competitive pressure	.83			.83		
Demand expectation	.33			.33		
Foreign company	.07			.07		
Shortage of skilled workers	.36			.36		
Continuing training	.81			.81		
R&D activities	.19			.19		
Investment activities	.73			.73		
Technical state of equipment	2.82			2.82		
Export activities	.33			.33		
Broadband connection	.81			.81		
Family business	.73			.73		

Notes: Further balancing constraints include indicators for economic sector and sixteen federal states. Source: IAB Establishment Panel, Wave 2017. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9317.de.en.v1.

Chapter III

A hidden source of innovation? Revisiting the impact of initial vocational training on technological innovation

with Jörg Thomä and Kilian Bizer

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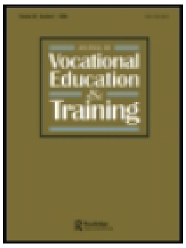

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A hidden source of innovation? Revisiting the impact of initial vocational training on technological innovation

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ABSTRACT

While an increasing number of studies postulate that vocational education and training (VET) activities have a positive impact on the innovative capacity of training companies, empirical evidence on the topic remains contradictory. This study exploits establishment data from a representative survey of German companies to estimate the relationship between firms' participation in initial VET and their innovation outcomes. Our results show that the direct effects of initial VET on technological innovation in small and medium-sized enterprises (SMEs) are on average quite weak. If at all, a training firm's initial VET activities are associated with product innovation activities and not with process innovation. Larger effects can only be observed in case of microenterprises with fewer than ten employees. In these firms, initial VET is associated with a higher probability of (local) new-to-market product innovation if it is accompanied by changes in organisational processes that support individual learning and knowledge creation. We conclude from this finding that the knowledge diffusion function of the VET system primarily holds relevance for the smallest of the training companies and that initial VET is only positively related to technological innovation when it goes along with organisational learning in the training company.

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Introduction

In recent years, the question of the role that vocational education and training (VET) potentially plays for innovation has gained increasing attention in scholarly research (e.g. Barabasch and Keller 2020; Hodge and Smith 2019; Lund and Karlsen 2020; Gómez, Igone, and Aguirre Larrakoetxea 2018; Rodríguez-Soler and Brunet Icart 2018; Rupietta and Backes-Gellner 2019; Rupietta, Meuer, and Backes-Gellner 2021). Regarding the role of VET institutions in this context, for example, it has been empirically shown that they provide an important contribution to the functioning of regional innovation systems (Lund and Karlsen

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2020; Gómez, Igone, and Aguirre Larrakoetxea 2018; Rodríguez-Soler and Brunet Icart 2018).

It would be expected that the empirical evidence at the company level is analogous to this, although surprisingly this is not the case. The studies conducted by Hodge and Smith (2019) and Rupietta and Backes-Gellner (2019) provide different results regarding the direct influence of initial VET activities on technological innovation activities in training firms (i.e. in terms of the contribution of VET students to a firm's propensity to introduce new or significantly improved products, services or processes). While the first study – based on qualitative interviews from Australia – does not provide clear evidence that VET students contribute directly to a firm's technological innovativeness, the second study – based on Swiss firm data – provides quantitative evidence that apprenticeship training has a positive impact on technological innovation under the conditions of dual VET systems.

According to Rupietta and Backes-Gellner (2019), the effect of initial VET on innovation is stronger for small and medium-sized enterprises (SMEs), and tends to apply to product rather than process innovations. However, since SMEs are a quite heterogeneous entity in terms of innovation (Thomä and Bizer 2013 de Jong and Marsili 2006), it remains unclear exactly to which subgroup(s) of SMEs this effect applies. This is relevant insofar as it is known from the empirical literature on the motives of companies to participate in apprenticeship that the productivity of VET students is on average higher the smaller a training company is (see e.g. Mohrenweiser and Backes-Gellner 2010; Muehlemann and Wolter 2014; Muehlemann 2016) – which, conversely, could indicate that there may be a positive relationship between initial VET and innovation in very small firms in particular. Moreover, Rupietta and Backes-Gellner's non-significant result on process innovation outcomes appears surprising given that – compared to product innovation – the knowledge associated with improvements in business processes often contains a relatively high degree of tacitness (Gopalakrishnan, Bierly, and Kessler 1999), which should be related with a stronger importance of VET-based learning and skills in this context (Thomä 2017). Moreover, the Swiss study of Rupietta and Backes-Gellner (2019) does not distinguish between different degrees of innovative novelty. However, especially regarding incremental innovation, a potential contribution by VET students could be expected (Toner 2010).

By contrast, the qualitative results of Hodge and Smith (2019) imply that a VET student's contribution to firm-level innovation should not be overestimated, at least under conditions of full-time, school-based vocational training systems with company practice periods being constrained to temporarily limited work placements. The following pointed question by Hodge and Smith (2019) illustrates this: 'If VET students, like any students, are novices in an occupational area, why would we expect to find they contribute to innovation?' (p. 16). They nevertheless argue that VET activities may still contribute to a firm's technological innovativeness in two relevant ways: through knowledge diffusion and via organisational learning. With regard to the former, they expect VET students to be potential mediators of knowledge diffusion stemming from vocational education institutions. This may explain the finding of Rupietta and Backes-Gellner (2019) that the effects on innovation are stronger in smaller firms, given that – mostly at the level of regional innovation systems – SMEs are probably profiting most from the VET system's important function in terms of knowledge diffusion (Lund and Karlsen 2020; Gómez, Igone, and Aguirre Larrakoetxea 2018; Rodríguez-Soler and Brunet Icart 2018). Regarding the second driver, according to Hodge and Smith (2019), initial VET can lead to improved day-to-day organisational practices in training firms (including changes in workplace organisation, new organisational practices etc.) – either through a direct role of VET students in introducing such organisational changes or through the more general changes in organisational learning processes that follow a company's decision to participate in initial VET. Such organisational innovations have been shown to significantly improve the technological innovation performance of non-R&D-intensive SMEs (Rammer, Czarnitzki, and Spielkamp 2009; Hervas-Oliver et al. 2015) – which raises the question of how initial VET, organisational changes and technological innovation are related in the case of (smaller-sized) training firms (Rupietta, Meuer, and Backes-Gellner 2021).

Hence, the question remains whether conducting initial VET actually fosters technological innovativeness at the company level. Against this background, our paper aims to contribute to the literature in two related ways. First, compared to the Australian study of Hodge and Smith (2019), our empirical analysis uses a broad data set from Germany, a country where the dual system of VET forms an integral part of the national innovation system (Thomä 2017). Due to the duality of vocational training (i.e. the combination of long periods of practical learning in companies and theoretical learning at vocational schools), German VET students may contribute to firm-level innovation to a stronger degree compared to VET students in countries where initial VET takes place mainly in full-time vocational schools with limited practical periods during the time of training. Moreover, we aim to provide empirical evidence for the relationship between initial VET and technological innovation by placing a special emphasis on the role of knowledge diffusion and organisational learning, and hence supplement the study of Hodge and Smith (2019).

Second, regarding the Swiss study of Rupietta and Backes-Gellner (2019), we add to the literature by distinguishing between different categories of SMEs to shed further light on the role of firm size in the present context. Moreover, by using a wider set of control variables and developing a comprehensive theoretical foundation for explaining the potential impact of initial VET on smaller firms' technological innovation activities we complement Rupietta and Backes-Gellner (2019). In a broader sense, this is also a contribution to the empirical literature that quantitatively addresses the question of whether training companies benefit from their investments in initial VET already during the apprenticeship period in economic terms (e.g. Zwick 2007; Mohrenweiser and Backes-Gellner 2010; Muehlemann and Wolter 2014).

Innovation in the majority of SMEs: Learning beyond R&D

Overview on the conceptual framework

In line with Hodge and Smith (2019) and Rupietta and Backes-Gellner (2019), we assume that knowledge diffusion and organisational learning are important determinants of innovation for many SMEs in Germany (Figure 1).[1] Our main argument at this point is that initial VET activities at the company level are closely involved in corresponding learning processes and knowledge dynamics, leading to a mutual reinforcing relationship between these three elements and SME innovation, which tends to be overlooked by innovation scholars and policy-makers alike (Gómez, Igone, and Aguirre Larrakoetxea 2018). Thus, our conceptual framework is not only based on the dynamic relationship between organisational learning and knowledge diffusion as key innovation drivers in less R&D-intensive segments of the SME sector, but also locates within it the interactive and reciprocal interplay with the VET system.

The first dimension of the concept refers to the key importance that the dual VET system has in terms of knowledge diffusion, especially at the regional level. Effective diffusion of new technologies throughout the economy is an essential precondition for SMEs' innovation success hence constituting a crucial starting point for policy measures and support. By means of knowledge diffusion, SMEs frequently receive the necessary stimulus for introducing innovations. Thus, increasing the absorptive capacity of smaller firms concerning the use of external knowledge, focusing on a broad set of institutions that affect learning and innovation (including VET institutions such as vocational schools or vocational training centres), integrating SMEs in regional innovation systems and upgrading workforce skills in SMEs to facilitate participation in innovation are vital in this context (Rammer, Czarnitzki, and Spielkamp 2009; Hervás-Oliver et al. 2021; Thomä 2017). The second dimension relates to the fact that informal ways of learning by doing, using and interacting (DUI) are particularly strong in the case of SME innovation, not least in the 'German Mittelstand' (Pahnke and Welter 2019; Alhusen et al. 2021). In Germany, the VET trained workforce plays a key role for DUI-based innovation activities in non-R&D-intensive firms and industries (Thomä 2017; Thomä and Zimmermann 2020). Moreover, DUI-based technological innovation usually requires deep organisational learning in order to be successfully implemented at the company level (Rammer, Czarnitzki, and Spielkamp 2009).

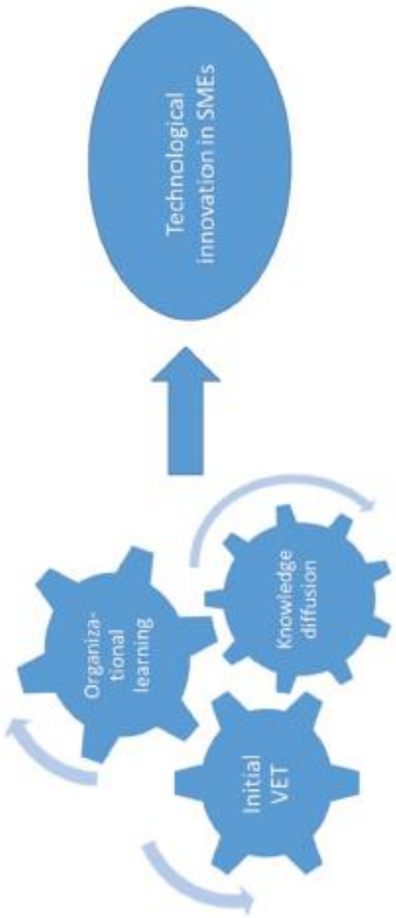

Figure 1. Initial VET as a driving factor for innovation in SMEs.

Finally, our conceptual framework (and the following empirical analysis) is based on a general and broad definition of innovation that applies to all sectors of the economy (Gault 2018). The advantage of this definition of innovation is that we have comparable information for the entire spectrum of training companies in a large number of industries and can thus examine the general link between initial VET and SME innovation. The potential drawback of this innovation definition is certainly that the more specific relationships between individual aspects of a company's innovation processes and initial VET can only be partially captured by this broad, rather abstract measurement approach.

Dimension 1: VET and knowledge diffusion

Toner (2010) argues that the VET system plays a critical role in knowledge diffusion, particularly regarding innovation in SMEs, which are not at the frontier of technological development. The author stresses the importance of vocational education institutions such as vocational schools, vocational colleges or vocational training centres as being highly responsive to the particular needs of local industries, offering customised training programs, serving as technology intermediaries between equipment or software producers and local businesses, and informing their students about new technologies, which increases the absorption capacity of a training company's workforce in terms of both practical skills and innovation-relevant knowledge.

The empirical studies of Gómez, Igone, and Aguirre Larrakoetxea (2018), Rodríguez-Soler and Brunet Icart (2018) and Lund and Karlsen (2020) analyse the role of vocational education institutions for the functioning of regional innovation systems with some indications of effects at the company level. For example, it is argued that VET institutions represent a main source of external technological knowledge for innovating SMEs in Spain. Moreover, it is shown that this is especially the case for DUI-based innovation activities in training companies, which are triggered by the demand-based and problem-solving-oriented training opportunities provided by VET institutions and 'the type of skills and expertise held by their staff and the long-lasting [trust-based] relationships between these and local firms' (Gómez, Igone, and Aguirre Larrakoetxea 2018). For the Spanish regions of Catalonia and Aragon, Rodríguez-Soler and Brunet Icart (2018) find that geographical proximity to VET institutions is crucial in this context.

Lund and Karlsen (2020) confirm the results of the Spanish studies with a focus on two Norwegian manufacturing regions, concluding that VET institutions are important sources of external knowledge for local SMEs. According to their results, vocational colleges promote the competitiveness of manufacturing firms by developing programs for education tailored to regional industries that consider current technological trends and state-of-the-art technologies and new materials, which shows how VET institutions are driving the dissemination of new technologies in training companies. According to the authors of this study, these findings provide a better understanding of the DUI mode of innovation in training companies.

For the case of Switzerland, Rupietta and Backes-Gellner (2019) establish that the involvement of highly innovative companies in institutionalised curricula-updating processes promote technology and knowledge diffusion among training-companies enhancing companies' innovation capacities. Following their argument, training firms constantly face new technologies of the industrial leaders. By learning about these technologies, training firms can develop certain competitive advantages over non-training companies. In this process, SMEs are assumed to benefit from absorbing and adapting new knowledge and technologies whereas large companies are attributed to contribute innovative input to curricula updating.

Dimension 2: VET and organisational learning

Technological innovation activities at the company level can be based on different modes of learning. In this respect, according to Jensen et al. (2007), innovating firms differ according to the degree to which they have integrated formal processes of learning related to R&D and the extent to which they use informal ways of DUI learning. The innovation activity of smaller firms is often described as minimally or not at all R&D-intensive and, hence, being strongly rooted in the DUI mode (Baldwin and Gellatly 2003; de Jong and Marsili 2006; Tödtling and Kaufmann 2002). Important elements of DUI-based innovation activities in SMEs are an emphasis on experience-based learning from informal problem-solving communication, interactive learning with customers or suppliers, the overall importance of locally embedded tacit knowledge and the fostering of organisational learning within the firm (Thomä and Zimmermann 2020).

According to Toner (2010), processes of learning by doing and using are at the core of VET activities in training companies. Hence, it is only logical to expect a close link between a company's participation in the VET system and its integration of the DUI mode of learning and innovation (Thomä 2017). Within the DUI mode, practical problem-solving skills developed in production processes hold key importance for innovation activities at the firm level (Jensen et al. 2007). The VET system provides employees with corresponding skills and underpinning knowledge and hence raises the workforce's absorptive capacities (Toner 2010). In this way, knowledge flows within and between firms are facilitated (Rupietta and Backes-Gellner 2019) and VET students are enabled to potentially act as technology gatekeepers (Rupietta, Meuer, and Backes-Gellner 2021). As a result, some studies in the DUI literature stress the importance of VET as an important driver of innovation processes in SMEs (Thomä 2017; Thomä and Zimmermann 2020; Alhusen and Bennat 2021).

The VET literature argues that apprenticeship activities can positively influence the organisational learning processes of training companies in two interrelated ways (Barabasch and Keller 2020; Hodge and Smith 2019; Rupietta, Meuer, and Backes-Gellner 2021): Either through the direct contribution of VET students to new day-to-day organisational practices implemented in their training company, or more indirectly through the implementation of a more distinctive learning culture developed in training companies as a result of the decision to participate in the VET system. Such organisational learning processes, in turn, are an important determinant of the DUI mode of innovation (Thomä 2017; Parrilli, Balavac, and Radicic 2020; Parrilli and Radicic 2021). Indeed, organisational learning and creating a corresponding business culture are considered by Asheim and Parrilli (2012) to be the micro-foundation of DUI-based technological innovation, which is why Thomä (2017) considers organisational innovation to foster individual learning and knowledge creation (e.g. through promoting teamwork among employees, delegating decision-making powers, restructuring customer relationships, developing a general culture of open communication etc.) as a necessary prerequisite for the successful integration of the DUI mode at the level of the firm. To sum up, it can be expected that initial VET activities exert a positive impact on DUI-based technological innovation in SMEs if they are accompanied by vital processes of organisational learning.

Data

The empirical analysis is based on balanced panel data from the IAB EP dataset, an employer survey from the German Federal Employment Agency (Bellmann et al. 2019). The IAB EP dataset considers all firms in Germany, which conduct initial VET, as long as their apprentices are not exempt from social security contributions. Further information on the dataset and the survey design is provided by Ellguth, Kohaut, and Möller (2014).

Our analysis focuses on the panel waves for 2009–2019, which are accessed via a remote data execution system. Information on 45,013 SMEs is used for the present analysis. For this purpose, the SME definition applied by the European Union (maximum 249 employees) has been applied. In our sample, 38% firms report technological innovation outcomes and 44% conduct initial VET activities (Table 1). The main variables of interest are indicators for technological innovation (the dependent variables) and organisational changes as well as initial VET (the explanatory variables), with all three indicators varying across firm size categories (Table 1). The survey questions on technological innovation comply with the Oslo Manual measurement guidelines (OECD/Eurostat 2018).[2]

Information on organisational changes[3] is included in the IAB EP dataset at two-year intervals. Since the corresponding survey questions refer to organisational changes conducted within the firm in the last two years, we have replaced

Table 1. Descriptive statistics by firm size categories.

	Description	I Mean	I S.D.	II Mean	II S.D.	III Mean	III S.D.	IV Mean	IV S.D.
Dependent variables									
General innovation	1 if firm conducted product and/or process innovation	0.38	0.49	0.29	0.45	0.42	0.49	0.52	0.50
New-to-market product innovation	1 if firm conducted new-to-market product innovations	0.06	0.23	0.03	0.18	0.06	0.25	0.09	0.29
New-to-firm product innovation	1 if firm conducted new-to-firm product innovation	0.18	0.38	0.14	0.35	0.20	0.40	0.23	0.42
Incremental product innovation	1 if firm conducted product innovation which is not new to the market or to the firm	0.31	0.46	0.23	0.42	0.34	0.47	0.44	0.50
Process innovation	1 if firm conducted process innovation	0.13	0.33	0.08	0.26	0.14	0.35	0.21	0.41
Explanatory variable									
Initial VET	1 if firm employs apprentices (VET students)	0.44	0.50	0.19	0.39	0.55	0.50	0.78	0.42
Organizational changes	1 if firm conducted organizational changes	0.30	0.46	0.17	0.37	0.36	0.48	0.51	0.50
Control variables									
Company size	Total number of employees	32.70	47.00	4.47	2.32	23.90	11.09	110.84	52.69
Share of workers with vocational qualification	Employees with completed vocational training in total employment (%)	0.57	0.28	0.48	0.28	0.64	0.26	0.63	0.25
Share of workers with university degree	Employees with higher education in total employment (%)	0.08	0.17	0.05	0.14	0.09	0.18	0.12	0.19
Competitive pressure	1 for medium/substantial competitive pressure	2.93	1.00	2.87	0.99	2.96	0.99	2.98	1.04
Demand expectation	1 if company expects increasing business volume next year	2.05	0.59	2.02	0.56	2.07	0.61	2.08	0.64
Foreign company	1 if company is foreign owned	0.04	0.20	0.02	0.15	0.03	0.18	0.10	0.30
Shortage of skilled workers	1 if a company reports lack of skilled workers	0.14	0.35	0.07	0.26	0.18	0.38	0.24	0.43
Continuing training	1 if a company provides continuing training to their employees	0.63	0.48	0.43	0.49	0.73	0.45	0.90	0.29
R&D activities	1 if a company conducts in-house R&D	0.07	0.26	0.03	0.16	0.08	0.27	0.16	0.37
Investment activities	1 if a company made investments in 2016	0.59	0.49	0.43	0.50	0.67	0.47	0.79	0.40
Technical equipment	State of a company's technical equipment (1 'state-of-the-art' – 4 'out of date')	2.73	0.75	2.67	0.77	2.76	0.75	2.80	0.72
Export activities	1 for exporting companies	0.20	0.40	0.09	0.28	0.24	0.43	0.42	0.49

Notes: Firm size category (I: full sample; II: 1–9 employees; III: 10–49 employees, IV: 50–249 employees). Source: IAB Establishment Panel, Waves 2009–2019. Data access was provided via remote data execution. DOI: 10.5164/IAB.IABBP9319.de.en.v1

missing values in survey years without information on organisational changes with values from the following year. Finally, the binary variable 'initial VET' refers to information from the IAB EP survey on whether a company currently employs apprentices (i.e. VET students). Finally, our dataset includes a broad set of control variables (see Table 1).

Estimation strategy

We conduct our analysis using standard ordinary least square estimators with random effects. Since our dependent variables are binary indicators, we employ linear probability models (LPMs). For consistency, we follow Rupietta and Backes-Gellner (2019) and rely on LPM – which is justified as comparable results can be expected from linear and non-linear models (Angrist and Pischke 2008). Due to the binary character of our explanatory variable on initial VET and its relative persistence over time, we opt for random effects models, as fixed effect estimation would cause information loss with respect to companies that continuously train apprentices (Wooldridge 2013). However, we later also resort to fixed effects models to check the robustness of our results.

Our estimation model is thus given by:

$$INNO_{jt} = \gamma_0 + \gamma_1 VET_{jt}\#\#ORGA_{jt} + \sum_{k=1}^{K} \gamma_k x_{kjt} + \alpha_j + e_{jt}, \tag{1}$$

where INNO constitutes the indicator on technological innovation (1 for innovating companies), VET equals 1 if the firm is currently conducting initial VET activities (1 for companies that employ apprentices), ORGA indicates organisational learning that results from changes in a firm's organisational practices (equals 1 for companies with organisational changes), k denotes the number of control variables, j denotes the number of companies and e is the error term.

In our set of controls, first we include information on workforce qualification based on the share of qualified employees and the share of employees with an academic qualification. Second, we measure competition by analysing the responses to a question on the competitive pressure in the firm's market environment. Third, as a control variable for demand changes, we employ an indicator on the expected business volume. As Rupietta and Backes-Gellner (2019) we control for economic sector, firm size, shortage of skilled workers, foreign ownership and regional dummies. Furthermore, we additionally include controls for continuing training and in-house R&D, as a positive impact on innovation activities can be expected through knowledge creation and improved knowledge flow (Bauernschuster, Falck, and Heblich 2009).

In addition, we take into account information on the technical status of equipment and investment activity, the former enabling a firm to transform resources into innovations based on its technological endowment. Investment increases this endowment and the associated capabilities (Barney 1991; Heidenreich 2009). Our estimation strategy includes both indicators as control variables related to the IAB-EP survey questions on a firms' investment activity and on the technical state of a firm's equipment.

Finally, we also include an indicator for export activities, as these positively affect innovation at the firm level (Peters and Christian 2013). We conduct the analysis for our entire sample of SMEs as well as differentiated by firm size in three categories to investigate the correlation between initial VET and technological innovation for different subgroups of SMEs (fewer than ten, 10 to 49 and between 49 and 250 employees).

Results

We observe significant associations for initial VET and general innovation (+3.0%) and new-to-firm product innovation (+1.6%). Given the corresponding baseline probabilities (i.e. the mean Y-outcomes, see Table 2), both effect sizes must be considered weak. Hence, similar to Hodge and Smith (2019), our results suggest that the direct effect of initial VET to technological innovation in SMEs is rather small on average and should not be overestimated. For organisational changes, the correlation is significant for all innovation types in almost all firm size categories (Table 2), underlining the link between organisational learning and SME innovation discussed above.

Turning to the interaction between initial VET and organisational changes, we observe a significant association (+4.1%) with new-to-market product innovations in firms with fewer than 10 employees. Hence, in very small firms, initial VET is related to the introduction of (local) new-to-market product innovation if, at the same time, accompanying changes in the training firm's organisational processes support individual learning and knowledge creation. Given the baseline probability of 3% in this case (Table 2), the corresponding correlation must be deemed strong.[4] This result is in line with our conceptual framework in Section 2. On the one hand, it shows that initial VET can only be related positively with technological innovation in smaller firms if it is accompanied by organisational learning at the company level. Indeed, a number of authors argue that initial VET in countries with a dual VET system, such as Germany or Switzerland, is often associated with a distinct learning and training culture in training firms (Deissinger 2012; Harris and Thomas 2003; Pilz 2008; Thomas; Deissinger 2015; Wiemann and Matthias 2020). And from the literature on innovation modes, it is known that DUI mode learning can also drive the generation of more radical technological innovation when it is accompanied by organisational innovation (Apanasovich 2016). On the other hand, we conclude from this finding that the knowledge diffusion function of the VET system is particularly relevant for the smallest of the training companies. This is because a more radical innovation performance (compared to incremental product innovation) relies more heavily on the absorptive capacity of firms in terms of external knowledge acquisition (Forés and Camisón 2016). The knowledge diffusion processes necessary for this seem to take place above all when training companies succeed in generating product innovations on the basis of organisational learning that have a high degree of novelty, at least in their local/regional market environment.

Table 2. Regression results (random effects).

	Linear probability models																			
	General innovation				New-to-market product innovation				New-to-firm product innovation				Incremental product innovation				Process innovation			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Initial VET	0.030 ***	0.013	0.020	0.065	0.001	−0.004	0.003	−0.022	0.016 **	0.006	0.009	0.048 *	0.014	0.007	0.009	0.056	0.006	0.002	0.010	−0.007
Organizational changes	0.142 ***	0.151 ***	0.135 ***	0.134 ***	0.027 ***	0.021 ***	0.035 ***	0.027	0.083 ***	0.094 ***	0.062 ***	0.108 ***	0.112 ***	0.111 ***	0.117 ***	0.120 ***	0.071 ***	0.057 ***	0.088 ***	0.078 **
VET#ORGA	−0.042 ***	−0.012	−0.031	−0.061	0.015	0.041 **	−0.004	0.021	−0.019	0.009	−0.008	−0.052	−0.024 *	−0.003	−0.026	−0.051	0.005	0.028	−0.019	0.010
Controls																				
Company size	0.000 ***	0.002	0.001 *	0.000	0.000	−0.002 **	0.001 **	−0.000	0.000	0.001	0.000	−0.000	0.000 ***	0.004	0.001	0.000	0.000 ***	0.003	0.000	0.000 *
Share qualified workers	0.060 ***	0.043 *	0.076 **	0.034	0.010	0.004	−0.002	0.055 *	0.024 *	0.030	0.006	−0.010	0.049 ***	0.020	0.084 ***	0.077	0.019 *	0.019	0.025	0.002
Share of university graduates	0.176 ***	0.100 **	0.196 ***	0.294 ***	0.055 **	−0.022	0.080 *	0.116	0.047	−0.010	0.059	0.112	0.145 ***	0.102 **	0.158 **	0.249 **	0.116 ***	0.095 ***	0.130 **	0.070
Shortage of skilled workers	0.010	−0.003	0.016	0.016	−0.002	0.013 *	−0.007	−0.003	0.013 *	0.012	0.014	0.017	−0.002	−0.012	0.003	−0.003	0.019 ***	0.013	0.012	0.038 **
Continuing training	0.061 ***	0.074 ***	0.051 ***	−0.006	0.011 ***	0.007 *	0.015 **	0.001	0.028 ***	0.043 ***	0.007	0.020	0.055 ***	0.062 ***	0.054 ***	0.005	0.023 ***	0.024 ***	0.026 ***	0.014
R&D activities	0.189 ***	0.235 ***	0.188 ***	0.166 ***	0.118 ***	0.134 ***	0.136 ***	0.088 ***	0.108 ***	0.145 ***	0.103 ***	0.094 ***	0.205 ***	0.263 ***	0.213 ***	0.165 ***	0.126 ***	0.162 ***	0.109 ***	0.136 ***
Investment activities	0.063 ***	0.065 ***	0.047 ***	0.086 ***	0.011 ***	0.014 ***	0.003	0.015	0.036 ***	0.036 ***	0.033 ***	0.043 **	0.065 ***	0.059 ***	0.062 ***	0.096 ***	0.033 ***	0.033 ***	0.031 ***	0.035 **
Technical equipment	0.040 ***	0.052 ***	0.035 ***	0.017	0.007 ***	0.003	0.011 **	0.013	0.019 ***	0.021 ***	0.009	0.029 **	0.038 ***	0.049 ***	0.030 ***	0.025 **	0.033 ***	0.024 ***	0.042 ***	0.041 ***
Export activities	0.072 ***	0.075 ***	0.075 ***	0.034	0.018 **	0.012	0.019 *	0.005	0.048 ***	0.037 **	0.056 ***	0.047 *	0.065 ***	0.062 ***	0.082 ***	0.027	0.021 **	0.023	0.029 **	−0.001
Competitive pressure	0.027 ***	0.027 ***	0.033 ***	0.013	0.002	0.002	0.001	0.009	0.016 ***	0.017 ***	0.026 ***	−0.004	0.020 ***	0.022 ***	0.019 ***	0.017	0.010 ***	0.004	0.021 ***	0.004

(*Continued*)

Table 2. (Continued).

	Linear probability models																			
	General innovation				New-to-market product innovation				New-to-firm product innovation				Incremental product innovation				Process innovation			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Demand expectation	0.025***	0.027***	0.027***	0.020**	0.004	0.001	0.004	0.011	0.016***	0.013**	0.022***	0.010	0.028***	0.027***	0.027***	0.032***	0.015***	0.016***	0.014**	0.014
Foreign company	0.021	0.077	0.045	−0.030	−0.036**	−0.022***	−0.035	−0.039	−0.018	0.029	−0.009	−0.047	0.034	0.086*	0.060	−0.013	−0.033	−0.002	−0.011	−0.066*
Baseline innovation probability	0.38	0.29	0.42	0.52	0.06	0.03	0.06	0.09	0.18	0.14	0.20	0.40	0.31	0.23	0.34	0.44	0.13	0.08	0.14	0.35
Observations	23,237	10,704	8,627	3,906	23,250	10,714	8,631	3,905	23,254	10,715	8,632	3,907	23,241	10,707	8,628	3,906	23,242	10,710	8,629	3,903
Overall R^2	0.211	0.166	0.188	0.225	0.075	0.053	0.085	0.078	0.103	0.096	0.101	0.111	0.203	0.157	0.194	0.217	0.134	0.115	0.123	0.137

*Notes: The table displays marginal effects from linear probability models with random effects, estimated for different innovation outcome variables by firm size category (I: full sample; II: 1–9 employees; III: 10–49 employees, IV: 50–249 employees). Further controls include indicators for each observation year, economic sector and federal state. Significance levels are based on robust standard errors and denoted as: * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.*

Table 3. Regression results (fixed effects).

	Linear probability models																			
	General innovation				New-to-market product innovation				New-to-firm product innovation				Incremental product innovation				Process innovation			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Initial VET	0.017	0.005	0.008	0.027	−0.002	−0.002	−0.003	−0.036	0.009	0.004	−0.004	0.020	0.009	0.002	0.008	0.019	0.011	0.004	0.011	−0.004
Organizational changes	0.100***	0.094***	0.084***	0.089**	0.012*	0.008	0.013	0.006	0.051***	0.056***	0.022	0.072**	0.078***	0.062***	0.079***	0.077*	0.051***	0.039***	0.054***	0.046
VET#ORGA	−0.031**	−0.004	−0.013	−0.040	0.016*	0.046**	0.010	0.021	−0.015	0.010	0.008	−0.035	0.018	0.007	−0.017	−0.033	0.008	0.022	−0.000	0.022
Controls	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Baseline innovation probability	0.38	0.29	0.42	0.52	0.06	0.03	0.06	0.09	0.18	0.14	0.20	0.40	0.31	0.23	0.34	0.44	0.13	0.08	0.14	0.35
Observations	25,927	11,947	9,628	4,352	25,944	11,958	9,635	4,351	25,949	11,960	9,636	4,353	25,931	11,951	9,628	4,352	25,934	11,953	9,632	4,349
Overall R^2	0.153	0.098	0.125	0.087	0.057	0.036	0.052	0.030	0.056	0.049	0.042	0.025	0.141	0.088	0.116	0.077	0.096	0.063	0.079	0.073

Notes: The table displays marginal effects from linear probability models with fixed effects, estimated for different innovation outcome variables by firm size category (I: full sample; II: 1–9 employees; III: 10–49 employees, IV: 50–249 employees). The control variables are identical to the estimations in Table 2. Significance levels are based on robust standard errors and denoted as: * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

It is interesting that the interaction effect is negative for the entire sample – although the effect size is again very small compared to the base probability (Table 2). The differentiation by innovation type suggests that this is mainly due to the case of incremental product innovations. There, the interaction effect is also significant and negative, probably reflecting the fact that incremental innovation activity means continuous learning along well-established paths – and it is precisely here that organisational changes often have a very disruptive effect (Bourke and Roper 2017).

As a robustness check, we run the regression analysis again with fixed-effects models (see Table 3). We also obtain a significant association for the interaction for new-to-market innovations in microenterprises with fewer than 10 employees (+4.6%), while the main correlation for organisational changes is not significant in this case. The latter can be explained by the fact that fixed effects estimations do not consider variables that are constant over time (Wooldridge 2013) and thus tend to underestimate the relationship between continuous organisational learning and innovation (Ganter and Hecker 2013).

Conclusion

Regarding the role of VET in the context of innovation, previous studies show that VET institutions have a relevant contribution to the functioning of regional innovation systems. It would be expected that the empirical evidence at the company level is analogous to this, although surprisingly this is not the case as only a small or no direct relation between initial VET and innovation has been found at the company level. Hence, the question remains whether and for which types of firms a participation in initial VET results in technological innovation.

In this paper, we provide a conceptual framework for the channels through which initial vocational training activities can have a positive impact on innovation activity, especially in (less R&D-intensive) SMEs. On this basis, we empirically examine the impact of initial VET on technological innovation in the German SME sector. Such a quantitative testing of the hypothesis on a positive link between initial VET and firm-level innovation is underdeveloped. To our knowledge, the study of Rupietta and Backes-Gellner (2019) was the first to provide some empirical evidence on this issue. However, their estimates are in contrast to the results obtained by Hodge and Smith (2019) – a study that 'did not find clear evidence that VET student placement could directly contribute to new or significantly new products, services, methods or processes' (p. 16).

In contrast to the findings of Rupietta and Backes-Gellner (2019), our results suggest that the direct associations between initial VET and technological innovation are actually quite weak. In this respect, our study confirms the findings of Hodge and Smith (2019). However, in line with Rupietta and Backes-Gellner (2019), we find that a training firm's initial VET activities are associated, if at all, with production innovation activities and not with process innovation.

Moreover, our results suggest that initial VET strengthens the technological innovation capacity of training firms via knowledge diffusion and organisational learning, as already assumed by Hodge and Smith (2019). However, this is only true for very small training companies. In case of microenterprises with fewer than ten employees, initial VET is related to the introduction of (local) new-to-market product innovations if, at the same time, accompanying changes in the training firm's organisational processes support individual learning and intra-firm knowledge creation. We conclude from this that active participation in the VET system primarily promotes the innovation activities of very small firms through knowledge diffusion and organisational learning that enables firms to develop the capacity to absorb new external knowledge.

From a policy perspective, our results imply that the participation of micro-enterprises in the VET system helps to improve their skills and competence portfolio, creates structures within the firm that promote organisational learning, and increases absorptive capacities of training companies in terms of technological knowledge from VET institutions. Hence, particularly the smallest among training companies seem to benefit from the knowledge transfer from the VET system. As a result, these firms should be more likely to succeed in overcoming – at least in part – some of their size-related disadvantages in innovation. Promoting a small firm's engagement in the VET system should therefore not only be regarded by policy-makers as a tool to foster the smooth integration of youth into the regular labour market and secure a supply of skilled workers, but also as a measure of innovation policy towards the small business sector. At the same time, the technological upgrading of vocational schools and training centres should therefore not only be a measure of modern education policy, but also an integral part of an SME-oriented innovation policy.

A possible limitation of our study could be the fact that the empirical analysis is based on a general a broad definition of innovation that is applicable across all economic sectors. While this approach has clear advantages with regard to quantitative measurement and comparability, it may also have disadvantages when it comes to capturing informal processes of non-R&D-based interactive learning and experience-based know-how (including what this might mean in terms of initial VET and its concrete contributions to innovation) – which can be very specific to certain business environments.

This potential limitation opens the way for future research efforts. In general, there is an ongoing need for further empirical studies to examine the relationship between VET and innovation. With regard to less generalisable aspects of innovation, it would be crucial to examine the complex interplay between initial VET, organisational learning and (DUI mode) technological innovation in specific firm and industry contexts using qualitative research methods, thus complementing the findings of the present quantitative study.

A key challenge for future quantitative studies would be to improve the estimation strategy in terms of causality to rule out the possibility that our results are biased in this respect. Future research could also investigate whether the type of initial VET matters. Our paper has investigated the link between initial VET and technological innovation under the conditions of a country with a dual VET system. In countries with a full-time school-based VET system, the results might differ to a certain extent, since under the conditions there, VET students have only limited practical phases in companies during their time of training. It would also be interesting to compare the innovation contribution of apprentices with that of vocationally trained skilled workers. In the present analysis, no relationship was found between initial VET and process innovation. However, from a theoretical point of view, we would expect a positive relation between VET and process innovation outcomes, as the knowledge associated with business process improvements often contains a relatively high degree of tacitness. It seems reasonable to assume that apprentices still have too little experiential knowledge to contribute effectively to process innovation, whereas VET-trained skilled workers have probably already built up precisely this practical experience and strong familiarity with the business processes concerned to make a significant contribution to the introduction of process innovations. Investigating whether this is indeed the case could be a promising avenue for future research efforts.

Notes

1. At the same time, we fully acknowledge that the relationship between training activities and a firm's propensity to innovate is complex, as causality may run in opposite directions (Bauernschuster, Falck, and Heblich 2009).
2. The questions asked in the IAB survey 2017 were: 'In the last business year of 2016, did your establishment improve or further develop a product or service which had previously been part of your portfolio?' (*incremental product innovation*); 'In the last business year of 2016, did your establishment start to offer a product/service that had been available on the market before?' (*new-to-the-firm product innovation*); 'Have you started to offer a completely new product or service in the last business year of 2016 for which a new market had to be created?' (*new-to-market product innovation*); 'Did you develop or implement procedures in the last business year of 2016 which have noticeably improved production processes or services?' (*process innovation*).
3. The questions on organisational changes were as follows: 'Has one of the following changes taken place within your establishment/office in the last two years?: Restructuring of procurement and distribution channels and/or of customer relations; Restructuring of departments or areas of activities; Downward shifting of responsibilities and decisions; Introduction of team work/working groups with their own responsibilities; Introduction of units/departments carrying out their own cost and result calculations; Improvement of quality management'.
4. At this point it should be noted that, especially in the case of small firms, new-to-market product innovations 'do not necessarily need to be world firsts as innovations, but may gain their innovative character from market boundaries such as a regional business focus or a concentration on specific customer groups.' (Thomä and Bizer 2013, 38).

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Chapter IV

Duale Ausbildung, betriebliche Lernumgebung und Innovationsfähigkeit von Kleinstunternehmen

with Jörg Thomä and Jörg Lahner

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Zusammenfassung

In diesem Aufsatz wird der Zusammenhang zwischen aktiver Ausbildungsbeteiligung im dualen System und Innovationsfähigkeit von Betrieben mit weniger als zehn Beschäftigten untersucht. Die Ergebnisse zeigen, dass in Kleinstbetrieben nicht nur ein direktes Zusammenspiel von dualer Ausbildung und dem Vorliegen einer lernförderlichen Innovationsumgebung die Hervorbringung von technologischen Innovationen begünstigen kann, sondern dass neben diesem Interaktionseffekt noch eine weitere Verkettung besteht: Eine Ausbildungsbeteiligung schafft Anreize zum Aufbau oder zur Verbesserung der Lernumgebung in Kleinstbetrieben und fördert auf diese Weise deren Innovationsfähigkeit. Der Aufsatz präsentiert empirische Evidenz für diese Wirkungskette von dualer Ausbildung über organisatorische Neuerungen zu technologischer Innovation und problematisiert vor diesem Hintergrund den seit geraumer Zeit zu verzeichnenden Rückgang der Ausbildungsbeteiligung im Kleinstbetriebssektor.

Abstract

In this article the contribution of dual vocational education and training (VET) to the innovative capacity of smaller firms with less than ten employees is examined. Results show that dual VET in micro enterprises promotes direct interaction between dual apprenticeships and the presence of a work environment conducive to learning which facilitates technological innovation. In addition, there is a further effect – qualitative studies suggest a chain of effects that goes beyond simple interaction: participation in dual VET provides incentives to implement organisational changes, which in the next step are a relevant driver of technological innovation in micro enterprises. According to this view, dual VET also promotes firm-level innovativeness indirectly by first strengthening the learning capacity of the micro enterprise. The authors analyse this chain of effects quantitatively based on mediation analysis using German panel data with a focus on micro enterprises and discuss their findings against the backdrop of the persistent decline in dual VET participation in the German micro enterprise sector.

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Duale Ausbildung, betriebliche Lernumgebung und Innovationsfähigkeit von Kleinstunternehmen

Aktuelle Studien legen nahe, dass von einer aktiven Ausbildungsaktivität ein unmittelbarer Beitrag zur Innovationstätigkeit von kleineren Unternehmen ausgeht. Dieser Beitrag schließt daran an und zeigt, dass eine Ausbildungsbeteiligung von Kleinstbetrieben Anreize zum Aufbau oder zur Verbesserung der Lernumgebung schafft und auf diese Weise die Innovationsfähigkeit fördert. Vor dem Hintergrund des gegenwärtigen Rückgangs der Ausbildungsbeteiligung im Kleinstbetriebssektor werden daraus innovations- und bildungspolitische Implikationen abgeleitet.

EIKE MATTHIES, JÖRG THOMÄ, JÖRG LAHNER

1 Einleitung

Der anhaltende Rückgang der Ausbildungsbeteiligung unter Kleinstbetrieben mit weniger als zehn Beschäftigten steht aktuell auf der bildungspolitischen Agenda (Bundesministerium für Bildung und Forschung 2022; Pahnke et al. 2020). Wichtig ist hierbei, dass gerade diese Betriebe mit einer aktiven Ausbildungstätigkeit nicht nur das Ziel der mittelfristigen Fachkräftesicherung verbinden, sondern Auszubildende auch besonders häufig bereits während der Ausbildungszeit im Betriebsalltag produktiv einsetzen (Mohrenweiser/Backes-Gellner 2010; Mohrenweiser/Zwick 2009; Muehlemann 2016; Muehlemann/Wolter 2014). Nicht zuletzt aufgrund dieser produktiven Tätigkeiten ist ein positiver Beitrag der Ausbildungsbeteiligung zur Wettbewerbsfähigkeit von Kleinstbetrieben zu erwarten, der durch den fortwährenden Ausstieg aus der dualen Ausbildung gefährdet ist (Pahnke et al. 2020). Eben hierfür sprechen die Ergebnisse von Matthies et al. (2023), wonach vor allem im Kleinstbetriebssektor eine aktive Ausbildungsbeteiligung die Hervorbringung von Innovationen befördert. Vor diesem Hintergrund erscheint der anhaltende Rückgang der Ausbildungsbeteiligung der Kleinstbetriebe aufgrund von Rekrutierungsschwierigkeiten und anhaltend hoher Rate vorzeitiger Vertragslösungen (Eckelt et al. 2020; Pahnke et al. 2020) nicht nur aus Perspektive der Fachkräftesicherung, sondern auch aus Innovationssicht kritisch.

Konkret identifiziert die Studie von Matthies et al. (2023) für Kleinstbetriebe mit weniger als zehn Beschäftigten einen innovationsförderlichen Charakter des interaktiven Zusammenspiels von Wissenstransfer, der Existenz einer lernförderlichen Organisationsumgebung und betrieblicher Ausbildungstätigkeit. Die Ergebnisse zeigen, dass organisatorische Neuerungen zur Verbesserung der (innovationsbezogenen) Zusammenarbeit im Betrieb – z. B. die Reorganisation von Aufgabenverteilungen oder die Einführung von Gruppenarbeit – als sogenannte Moderator-Variable agieren, welche den Effekt einer Ausbildungstätigkeit auf die technologische Innovationsfähigkeit von Kleinstbetrieben positiv verstärkt. Ausbildungstätigkeit, die in eine lernförderliche Organisationsumgebung eingebettet ist, erhöht demnach die Wahrscheinlichkeit, dass Kleinstbetriebe neue oder verbesserte Produkte oder Dienstleistungen hervorbringen. Dieser Effekt ist im Kern darauf zurückzuführen, dass durch eine innerbetriebliche Lernumgebung, in der Auszubildende aktiv in Unternehmensprozesse einbezogen sind und in der ein hohes Maß an betrieblicher Ausbildungsqualität gesichert ist, die Ausbildungstätigkeit zum integralen Bestandteil der Unternehmenskultur werden kann (Pilz 2009; Rauner et al. 2013).

Neben diesem sich gegenseitig verstärkenden „Moderator-Effekt" zwischen Ausbildungsbeteiligung und lernförderlicher Organisationsumgebung im Betrieb dürfte jedoch eine Ausbildungstätigkeit die Innovationskraft von Kleinstbetrieben noch über eine andere Wirkungskette anregen. Eine Reihe von Studien legt nahe, dass einerseits der institutionelle Aufbau des dualen Ausbildungssystems den Wissenstransfer zwischen Berufsbildungseinrichtungen und Ausbildungsbetrieben befördert (Alhusen/Bennat 2021; Lund/Karlsen 2020; Porto Gómez et al. 2018; Proeger 2020; Rupietta/Backes-Gellner 2019; Schultheiss/Backes-Gellner 2022; Toner 2010) und andererseits Auszubildende als „Moment des Wandels" agieren können (Pfeiffer et al. 2017), indem sie gerade in kleineren Betrieben eine Verbesserung von Prozessen initiieren (Barabasch/Keller 2020; Hodge/Smith 2019). Gleichzeitig gehört es zu den rechtlichen Voraussetzungen einer Ausbildungstätigkeit, dass neben der fachlich-persönlichen Eignung des Ausbildungspersonals auch die Ausbildungsstätte selbst „nach Art und Einrichtung für die Berufsausbildung [geeignet sein muss]" (Berufsbildungsgesetz § 27), um sicherzustellen, dass die für die Durchführung der Ausbildung notwendigen materiellen Ressourcen und Bedingungen vorhanden sind (Guellali et al. 2017) – ein Umstand, der häufig einen ersten Anreiz zum Aufbau einer lernförderlichen Organisationsumgebung im Ausbildungsbetrieb stiftet, zumal die Eignung durch die Kammern fortlaufend geprüft und überwacht wird (Berufsbildungsgesetz § 32). Aus der Innovationsforschung ist zudem bekannt, dass organisatorische Neuerungen zur Verbesserung der innerbetrieblichen Austausch- und Wissensprozesse den Wesenskern eines Lern- und Innovationsmodus bilden, in dessen Rahmen kleinere Unternehmen auch ohne eigene Forschung und Entwicklung (FuE) auf Basis von erfahrungsbasiertem „Learning by Doing, Using, Interacting (DUI)" innovativ sein können (Jensen et al. 2007; Thomä 2017) – und dass eben dieser DUI-Modus durch eine Ausbildungsbeteiligung angeregt wird bzw. eng damit verzahnt ist (Alhusen/Bennat 2021; Rupietta/Backes-Gellner 2019; Thomä/Bizer 2021). Kurz gesagt: Eine Ausbildungsbeteiligung dürfte gerade den Kleinstbetrieben vielfältige Lernmöglichkeiten eröffnen, wovon im Resultat deren Innovationsfähigkeit profitiert.

Vor diesem Hintergrund liegt die Vermutung nahe, dass eine Ausbildungstätigkeit neben dem genannten „Moderator-Effekt" noch einen weiteren, indirekten Effekt auf die Einführung neuer Produkte und Prozesse in Kleinstbetrieben hat: Sie regt den Aufbau einer lernförderlichen Organisationsumgebung an und initiiert auf dieser Grundlage technologische Innovationen. Der Faktor Lernumgebung würde aus dieser Perspektive als sog. „Mediator" im Sinne eines Bindeglieds zwischen dualer Ausbildung und Innovationstätigkeit in Kleinstbetrieben fungieren (Schultheiss/Backes-Gellner 2022). Im vorliegenden Beitrag gehen wir diesem Wirkungszusammenhang nach, indem wir uns der folgenden Forschungsfrage widmen: Handelt es sich in Kleinstbetrieben bei dem Zusammenhang zwischen dualer Ausbildung, innerbetrieblicher Lernumgebung und Innovationsfähigkeit neben dem Moderations- auch um einen Mediationseffekt? Die Unterscheidung zwischen Moderator- und Mediatoreffekt ist gerade vor dem obigen Hintergrund wichtig, weil letzterer gegebenenfalls neue Hinweise darauf gibt, wie die sinkende Ausbildungsbeteiligung im Kleinbetriebssektor unter Innovations- und Wettbewerbsgesichtspunkten zu bewerten ist.

Nachfolgend wird in Abschnitt 2 der theoretische Erklärungsrahmen näher hergeleitet, woraufhin in Abschnitt 3 die verwendete Datenquelle und das methodische Vorgehen beschrieben werden. Abschnitt 4 stellt die Ergebnisse der durchgeführten Mediationsanalyse dar. Diese werden in Abschnitt 5 diskutiert. Auf dieser Grundlage werden abschließend (Abschnitt 6) vor dem Hintergrund des anhaltenden Rückgangs der Ausbildungsbeteiligung im Kleinstbetriebssektor verschiedene innovations- und bildungspolitische Implikationen abgeleitet.

2 Theoretischer Hintergrund: Moderator- und Mediatoreffekte der Ausbildung

Bei der Betrachtung des Zusammenhangs zwischen dualer Ausbildung und Innovationstätigkeit gilt es, zwei unterschiedliche Literaturstränge zu unterscheiden: einerseits Studien zur Beteiligung dual ausgebildeter Fachkräfte an unternehmerischer Innovationstätigkeit (Albizu et al. 2017; Freel 2005; Thomä 2017; Thomä/Zimmermann 2020; Toner 2010); andererseits Untersuchungen bezüglich der unmittelbaren Einflüsse einer aktiven Ausbildungsbeteiligung von Betrieben auf deren Innovationsfähigkeit (Matthies/Haverkamp et al. 2022; Matthies et al. 2023; Rupietta et al. 2021; Rupietta/Backes-Gellner 2019). Letzterer steht im Mittelpunkt der folgenden Analyse. Relevante empirische Beiträge befassen sich dabei unter anderem mit der Funktion von Berufsbildungseinrichtungen des dualen Ausbildungssystems in regionalen Innovationssystemen. Sie identifizieren Berufsschulen und berufliche Bildungsstätten als wichtige Wissensquelle für kleine und mittelgroße Unternehmen (KMU) und Anbieter spezieller, auf den Bedarf regionaler Unternehmen zugeschnittener Ausbildungsprogramme (Lund/Karlsen 2020; Porto Gómez et al. 2018; Rodriguez-Soler/Icart 2018).

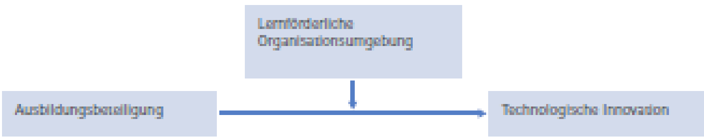
Daran anknüpfend befassen sich empirische Beiträge ebenso mit dem Zusammenhang von Ausbildungs- und Innovationstätigkeit auf der betrieblichen Ebene. So ermitteln Rupietta/Backes-Gellner (2019) auf Basis von Schweizer Querschnittsdaten einen Effekt von Ausbildungstätigkeit insbesondere für KMU und vor allem für Produktinnovationen.[1] Die Aktualisierung von Ausbildungscurricula in Bezug zu neuen Technologien führt zu deren Anwendung in der Breite von Ausbildungsbetrieben, was einen Wissens- und Technologietransferkanal eröffnet und Anreize zur Herausbildung eines DUI-basierten Lern- und Innovationsmodus setzt (Rupietta/Backes-Gellner 2019; Schultheiss/Backes-Gellner 2022). Gleichzeitig finden Matthies/Haverkamp et al. (2022) auf Basis von deutschen Querschnittsdaten direkte Effekte für KMU allgemein und für Betriebe mit weniger als zehn Beschäftigten für allgemeine Innovationstätigkeit, Firmenneuheiten, inkrementelle Produktinnovation und Prozessinnovationen. Anhand von Schweizer Querschnittsdaten beschreiben Rupietta et al. (2021) Auszubildende darüber hinaus als „Gatekeeper", die den Einfluss von organisatorischen Neuerungen in den Geschäftsprozessen von Unternehmen auf Prozessinnovationen, Patente und Verkaufszahlen von verbesserten Produkten stimulieren – und damit wiederum die Herausbildung des DUI-Lern- und Innovationsmodus auf Unternehmensebene unterstützen.

Die genannten Studien ließen dabei allerdings weitgehend die Frage offen, ob es sich beim Zusammenhang zwischen Ausbildungsbeteiligung und Innovation um direkte oder indirekte Effekte handelt und für welche Innovationsarten dies gegebenenfalls gilt. Einen ersten Schritt in diese Richtung machen Matthies et al. (2023) auf Basis von Paneldaten, indem sie aufzeigen, dass das parallele Vorliegen einer lernförderlichen Organisationsumgebung im Betrieb den Beitrag einer aktiven Ausbildungsbeteiligung auf die Innovationsfähigkeit von Kleinstbetrieben mit weniger als zehn Beschäftigten positiv verstärkt (sog. Interaktions- bzw. Moderator-Effekt). In Anknüpfung an die Literatur zu betrieblichen Innovationsmodi (für einen Überblick s. Apanasovich 2016 und Santos et al. 2022) wird dabei die Durchführung organisatorischer Neuerungen als Indikator für das Vorliegen einer lernförderlichen Organisationsumgebung – den innerbetrieblichen Wesenskern des DUI-Modus – genutzt, wobei sich ein „Moderator-Effekt" für das Zusammenspiel von Ausbildungstätigkeit und Innovation zeigt (*Abbildung 1*). Ein direkter Einfluss der Ausbildung auf die Innovationsfähigkeit von Kleinstbetrieben besteht nach den Ergebnissen von Matthies et al. (2023) dagegen nicht.

Dieser „Moderator-Effekt" von Ausbildung auf Innovation entsteht, wenn die Ausbildungsbeteiligung ein integraler Bestandteil der Unternehmenskultur ist (Pilz 2009) und Auszubildende aufgrund der lernförderlichen Organisationsumgebung aktiv in betriebliche Prozesse und deren Verbesserung einbezogen sind (Rauner et al. 2013). Daneben findet sich jedoch auch empirische Evidenz hinsichtlich einer weiteren indirekten Innovationswirksamkeit der Ausbildung, indem über eine Ausbildungsbeteiligung zunächst überhaupt erst einmal der Aufbau einer innovationsförderlichen innerbetrieblichen Lernumgebung bzw. deren Verbesserung angeregt wird (Barabasch/Keller 2020; Hodge/Smith 2019). Im Sinne eines „Mediator-Effekts" könnte dies dann als Bindeglied zwischen Ausbildungsaktivität und Innovationstätigkeit fungieren (Schultheiss/Backes-Gellner 2022).

ABBILDUNG 1

Lernförderliche Organisationsumgebung als Moderator



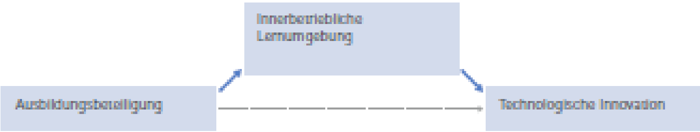
Quelle: Eigene Darstellung

Anhaltspunkte für den vermuteten Mediationseffekt gibt es verschiedene. So hat der Einstieg eines Betriebs in das duale Ausbildungssystem oft zunächst organisatorische Anpassungen zur Verbesserung bzw. Sicherstellung einer adäquaten innerbetrieblichen Lernumgebung zur Folge, um die rechtlichen Anforderungen hinsichtlich der Eignung als Ausbildungsstätte, der Arbeits- und Geschäftsprozesse sowie der geforderten Ausbildungsmittel zu erfüllen, sodass alle Auszubildenden „über genügend Material, Raum und Betreuung durch die Ausbilderinnen und Ausbilder" verfügen (Guellali et al. 2017, S. 24). Auch im späteren Ausbildungsgeschehen sind die beteiligten Betriebe immer wieder gefordert, durch den Aufbau und die Pflege einer lern- und interaktionsförderlichen Ausbildungs- und Arbeitsumgebung eine qualitativ hochwertige Ausbildung zu gewährleisten (Deissinger 2015; Pilz 2009; Rauner et al. 2013), die es Auszubildenden ermöglicht, ganzheitlich entlang der Prozesse im Betrieb zu lernen und berufliche Handlungsfähigkeit zu erlangen (Deitmer et al. 2013; Ebbinghaus 2016). Kurzum: Betriebliche Ausbildungsbeteiligung dürfte gerade in den Kleinstbetrieben einen Anreiz zum Aufbau einer lernförderlichen Organisationsumgebung schaffen, von dem aus der Innovationsforschung bereits hinlänglich bekannt ist eine wichtige Grundlage dafür zu bilden, den gerade für kleinere Unternehmen typischen informellen und wenig FuE-basierten DUI-Lern- und Innovationsmodus zu eta-

1 Im IAB-Betriebspanel, der von uns verwendeten Datenquelle, werden folgende Innovationen abgefragt (jeweils bezogen auf das vorangegangene Geschäftsjahr): Produktinnovation (inkrementell): Verbesserung/Weiterentwicklung bereits angebotener Leistungen/Produkte; Produktinnovation (Firmenneuheit): Neue Leistung/neues Produkt aus Betriebssicht, aber nicht für den Markt; Produktinnovation (Marktneuheit): Völlig neue Leistung/neues Produkt im Markt; Prozessinnovation: Neue Verfahren, die den Produktionsprozess oder das Bereitstellen von Dienstleistungen merklich verbessert haben.

ABBILDUNG 2

Aufbau oder Verbesserung der innerbetrieblichen Lernumgebung als Mediator



Quelle: Eigene Darstellung

WSI Mitteilungen

bilieren (Hervas-Oliver et al. 2016; Kirner et al. 2009; Thomä/Bizer 2021).

Folglich stellt sich die Frage, ob neben dem bereits identifizierten innovationsförderlichen Zusammenspiel von Ausbildungsbeteiligung und lernförderlicher Organisationsumgebung (Moderator-Effekt) auch eine Mediation erkennbar ist, ob Ausbildungsbeteiligung also die Gestaltung der innerbetrieblichen Lernumgebung anregt und auf diese Weise die Innovationstätigkeit fördert (*Abbildung 2*). Die Unterscheidung zwischen Moderator- und Mediatoreffekt ist von Interesse, weil letzterer gegebenenfalls Hinweise darauf geben kann, wie die sinkende Ausbildungsbeteiligung im Kleinbetriebssektor aus innovationspolitischer Sicht zu bewerten ist.

3 Daten und Methode

Zur Analyse der Mediationshypothese werden Daten des IAB-Betriebspanels, einer repräsentativen Betriebsumfrage des Instituts für Arbeitsmarkt- und Berufsforschung, der Jahre 2011–2019 ausgewertet.[2] Neben Informationen zu Betriebsgröße, Exportaktivitäten, technologischer Ausstattung, Zusammensetzung der Beschäftigtenstruktur und Wirtschaftszweigen werden auch das Vorliegen von Ausbildungsaktivität, technologischen Innovationen und organisatorischen Neuerungen abgefragt.

Die Abfrage technologischer Innovationstätigkeit erfolgt im Sinne der gängigen Standards zur Messung von Innovationen im Produkt- und Dienstleistungsbereich (differenziert nach inkrementell, Firmen- und Marktneuheit) sowie im Kontext von neuen oder merklich verbesserten Prozessen und Verfahren (siehe Fußnote 1; ergänzend dazu: OECD/Eurostat 2018). Informationen zu organisatorischen Neuerungen als Maßnahmen zum Aufbau oder zur Verbesserung der innerbetrieblichen Lernumgebung in Anlehnung an den Innovationsmodus-Ansatz von Jensen et al. (2007) stehen für die Jahre 2012, 2014, 2015, 2017 und 2019 zur Verfügung.[3] Die Lücken aufgrund fehlender Erhebungsjahre können geschlossen werden, da sich die Abfrage der organisatorischen Neuerungen jeweils auf die zwei Vorjahre bezieht. Die organisatorischen Veränderungsmaßnahmen werden in einem binären Indikator zur Erfassung der innerbetrieblichen Lernumgebung zusammengefasst.

Der Datensatz enthält Informationen zu 15 268 Betrieben mit weniger als zehn Beschäftigten (*s. Tabelle 1*). 28 % dieser Kleinstbetriebe entwickeln technologische Innovationen und 15,4 % berichten über organisatorische Neuerungen. Die Betriebe haben durchschnittlich 4,5 Beschäftigte, 18,8 % bildeten zum Befragungszeitpunkt aus. Beruflich qualifizierte Fachkräfte stellen mit durchschnittlich 48,2 % den größten Anteil der Beschäftigten.

Zur Analyse des Mediationseffekts werden Strukturgleichungsmodelle verwendet (Ripamonti/Barberis 2021; Zhao et al. 2010). Die Nutzung von Paneldaten ermöglicht dabei die Analyse von Wirkungsmechanismen in einer zeitlichen Abfolge. Dies erhöht die Qualität der Mediationsanalyse (Fiedler et al. 2018; Jose 2016). Zouaghi et al. (2020) folgend werden aufgrund der binären abhängigen Variablen generalisierte Strukturgleichungsmodelle mit Probit-Modellen und Cluster-robusten Standardfehlern geschätzt, um die sich über drei Jahre erstreckende Kette „Ausbildungsbeteiligung in t–2 trägt zu organisatorischen Neuerungen und damit lernförderlicher Organisationsumgebung in t–1 bei, die wiederum technologische Innovationen in t fördern" (*Abbildung 3*) zu untersuchen.

In der Mediationsanalyse berücksichtigen wir neben direkten und indirekten Effekten eine Reihe von Kontrollvariablen sowie auch Informationen zu organisatorischen Neuerungen in t–2 und zu technologischen Innovationsaktivitäten in t–1 und t–2, um für zeitinvariante Effekte, die mit der abhängigen Variable korrelieren, kontrollieren zu können sowie Simultanität und umgedrehte Kausalität so weit wie möglich auszuschließen (Jose 2016). Als abhängige Variablen verwenden wir die Innovationstätigkeit im Allgemeinen sowie die Einführung von Markt- oder

2 IAB-Betriebspanel 2011–2019 (https://fdz.iab.de/betriebsdaten/iab-betriebspanel-iab-bp-version-9319-v1), DOI: 10.5164/IAB.IABBP9319.de.en.v1.

3 Folgende organisatorische Neuerungen werden betrachtet: Neugestaltung der Beschaffungs- und Vertriebswege bzw. Kundenbeziehungen, Reorganisation von Abteilungen oder Funktionsbereichen, Verlagerung von Verantwortung und Entscheidungen nach unten, Einführung von Gruppenarbeit/eigenverantwortlichen Arbeitsgruppen, Einrichtung von Einheiten mit eigener Kosten-/Ergebnisermittlung, Verbesserung der Qualitätssicherung.

TABELLE 1

Deskriptive Statistik

	Beschreibung	Mittelwert	S.D.
Abhängige Variablen: Technologische Innovation			
Allgemein Innovation	1 mind. eine technologische Innovation eingeführt	0,280	0,449
Marktneuheit	1 Marktneuheit eingeführt	0,029	0,169
Firmenneuheit	1 Firmenneuheit eingeführt	0,132	0,339
Inkrementelle Produktinnovation	1 inkrementelle Produktinnovation durchgeführt	0,216	0,412
Prozessinnovation	1 Prozessinnovation durchgeführt	0,074	0,261
Mediator: Organisatorische Neuerungen			
Aufbau/Verbesserung der innerbetrieblichen Lernumgebung	1 mind. eine organisatorische Neuerung durchgeführt	0,154	0,361
Unabhängige Variable: Ausbildungstätigkeit			
Ausbildungsaktivität	1 Unternehmen beschäftigt Auszubildende	0,188	0,391

Anmerkungen: Deskriptive Statistiken zu den Kontrollvariablen (Unternehmensgröße, Anteil dual Qualifizierte, Anteil Akademiker*innen, Wettbewerbsdruck, Erwartete Geschäftsentwicklung, Betrieb in ausländischem Eigentum, Fachkräftemangel, Weiterbildungsaktivität, FBE-Aktivitäten, Investitionen, Technische Ausstattung, Exportaktivitäten) sind auf Anfrage bei den Autoren erhältlich.

Quelle: IAB-Betriebspanel 2011–2019; eigene Berechnungen

Firmenneuheiten, inkrementellen Produktinnovationen und Prozessinnovationen.

Um zeitvariante Effekte zu berücksichtigen, wird ein stochastischer Effekt auf Unternehmensebene für die abhängige Variable berücksichtigt (Jiang/Ni 2020). Die Mediationseffekte wurden Bartus (2017) folgend berechnet und die Signifikanzen gemäß Zhao et al. (2010) bestimmt: Signifikant ist ein Effekt, wenn 1 nicht im Konfidenzintervall enthalten ist bzw. wenn der p-Wert signifikant ist.

Da der indirekte Effekt, den wir beobachten, ein Ergebnis aus zwei Parametern (Ausbildungsbeteiligung und organisatorische Neuerungen) ist, kann dessen Verteilung verzerrt und damit die ermittelte Signifikanz ungenau sein. Dies kann durch Bootstrapping ausgeglichen werden, wobei durch wiederholtes Ziehen aus dem Sample die Variabilität der beiden Parameter berücksichtigt wird (Zhao et al. 2010). Zur Überprüfung der Signifikanz werden die Schätzungen daher als Robustheitstest zusätzlich noch einmal mit Bootstrapping durchgeführt.

Um weitere Wirkungsketten ausschließen und die Möglichkeit einer umgedrehten Mediationskette von Innovation über organisatorische Neuerungen hin zur Ausbildungstätigkeit überprüfen zu können (Jose 2016), haben wir zudem Fiedler et al. (2018) folgend zusätzlich Modelle mit Ausbildungstätigkeit als abhängige und Innovationstätigkeit als erklärende Variable geschätzt. Ergänzend wurden außerdem Schätzungen mit Ausbildungstätigkeit als Mediator für die Beziehung zwischen organisatorischen Neuerungen und Innovationstätigkeit vorgenommen.

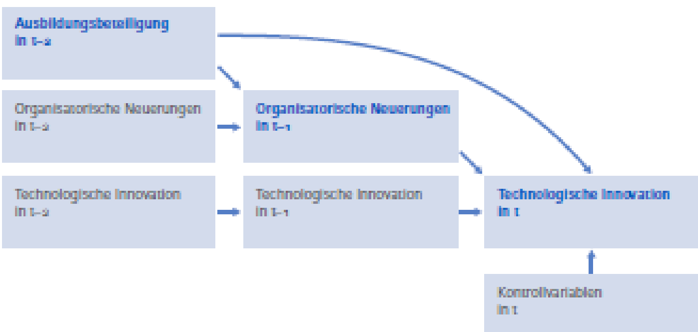
4 Ergebnisse

In *Tabelle 2* sind die Ergebnisse der Mediationsanalyse für die unterschiedlichen Innovationsarten (abhängige Variablen), bei denen eindeutige Ketten identifiziert werden konnten, im Überblick aufgeführt.[4]

Differenziert werden die möglichen direkten Effekte einer lernförderlichen Organisationsumgebung auf technologische Innovationen (Hervas-Oliver et al. 2016; Sap-

ABBILDUNG 3

Schematische Darstellung Mediationsanalyse



Quelle: Eigene Darstellung

4 Die Schätzergebnisse sind im Detail einschließlich der

prasert/Clausen 2012), von Ausbildungstätigkeit auf technologische Innovationen (Matthies/Haverkamp et al. 2022; Rupietta/Backes-Gellner 2019), von Ausbildungstätigkeit auf die Lernförderlichkeit einer Organisationsumgebung (Barabasch/Keller 2020; Hodge/Smith 2019; Pfeiffer et al. 2017) sowie der indirekte Effekt von Ausbildungstätigkeit auf technologische Innovationen mit Maßnahmen zum Aufbau oder zur Verbesserung der innerbetrieblichen Lernumgebung als Mediator.

dungstätigkeit von Kleinstbetrieben folglich deren Innovationswahrscheinlichkeit indirekt um 2,9–3,9 %** erhöhen. Ein direkter Effekt ist nicht erkennbar. Die Robustheitstests bestätigen dieses Ergebnis.

Bei Firmenneuheiten ist darüber hinaus ein direkter Zusammenhang mit Ausbildungstätigkeit erkennbar, der jedoch nur schwach signifikant ist (8,8 %*). Hier handelt es sich um eine partielle, also teilweise Mediation, bei der rund 49 % des Gesamteffekts auf den indirekten und 51 %

TABELLE 2

Ergebnisse Strukturgleichungsmodelle, bei denen eine eindeutige Kette erkennbar ist

Getestete Pfade	Direkter Effekt	Indirekter Effekt	Mediationseffekt	95 % Konfidenzintervall
Innovation allgemein				
Org. Neuerungen → Innovation allgemein	1,576***			1,44–1,72
Ausbildung → Innovation allgemein	1,073			0,98–1,17
Ausbildung → Org. Neuerungen	1,088**			1,02–1,16
Ausbildung → Org. Neuerungen → Innovation allgemein		1,039**	Vollständig	1,01–1,07
Marktneuheit				
Org. Neuerungen → Marktneuheit	1,402***			1,21–1,63
Ausbildung → Marktneuheit	0,989			0,84–1,17
Ausbildung → Org. Neuerungen	1,088**			1,02–1,16
Ausbildung → Org. Neuerungen → Marktneuheit		1,029**	Vollständig	1,00–1,06
Firmenneuheit				
Org. Neuerungen → Firmenneuheit	1,499***			1,36–1,65
Ausbildung → Firmenneuheit	1,088*			0,99–1,19
Ausbildung → Org. Neuerungen	1,088**			1,02–1,16
Ausbildung → Org. Neuerungen → Firmenneuheit		1,035**	Partiell: 48,8%	1,00–1,06
Prozessinnovation				
Org. Neuerungen → Prozessinnovation	1,477***			1,32–1,65
Ausbildung → Prozessinnovation	0,988			0,88–1,11
Ausbildung → Org. Neuerungen	1,088**			1,02–1,16
Ausbildung → Org. Neuerungen → Prozessinnovation		1,033**	Vollständig	1,01–1,06

Anmerkungen: Odds-Ratio für direkte und indirekte Effekte mit organisatorischen Neuerungen als Mediator auf Basis von generalisierten Strukturgleichungsmodellen mit probit-Schätzungen unter Berücksichtigung von random effects auf Firmenebene. Kontrolliert wird für Firmengröße, Wirtschaftszweig, Qualifikation Mitarbeitende, Fachkräftemangel, Weiterbildungsaktivität, F&E, Investitionen, Exportaktivitäten, Wettbewerbsdruck, Umsatzerwartung, technische Ausstattung, Eigentumsstrukturen, Bundesland und Beobachtungsjahre 2011–2019.
Bei inkrementellen Innovationen ist keine eindeutige Kette erkennbar, weshalb die Ergebnisse nicht dargestellt werden.
Signifikanzniveau: *p<0,1; **p<0,05; ***p<0,01

WSI Mitteilungen

Quelle: IAB-Betriebspanel 2011–2019; eigene Berechnungen

Die Kette „Ausbildungsbeteiligung in t–2 trägt zu organisatorischen Neuerungen und damit lernförderlicher Organisationsumgebung in t–1 bei, die wiederum technologische Innovationen in t fördert" ist für alle Innovationsarten außer inkrementeller Innovation erkennbar, da bei letzterer ein Effekt in beide Richtungen zu verzeichnen ist. Demzufolge kann Ausbildungstätigkeit zum Aufbau oder der Verbesserung der innerbetrieblichen Lernumgebung beitragen, was im nächsten Schritt wiederum die Wahrscheinlichkeit für technologische Innovationen erhöht. Über diesen Mediationseffekt kann die Ausbildungstätigkeit von Kleinstbetrieben folglich deren Innovationswahrscheinlichkeit indirekt um 2,9–3,9 %** erhöhen. Ein direkter Effekt ist nicht erkennbar. Die Robustheitstests bestätigen dieses Ergebnis.

auf den direkten Effekt zurückzuführen sind. Bei allen anderen Innovationsarten bedingen sich Innovationstätigkeit, organisatorische Neuerungen und Ausbildungstätigkeit im Sinne des beschriebenen Mediationseffekts. Abgesehen von dem indirekten Zusammenhang von Ausbildungs- und Innovationstätigkeit sind keine klaren Wirkungsketten erkennbar. Die erwartete Komplementarität von technologischer Innovation und organisatorischen Neuerungen bestätigt sich (Hervas-Oliver et al. 2016; Sapprasert/Clausen 2012).

5 Diskussion

Die durchgeführte Mediationsanalyse für Kleinstbetriebe in Deutschland hat indirekte, qua Maßnahmen zum Aufbau bzw. zur Verbesserung der innerbetrieblichen Lernumgebung vermittelte Zusammenhänge einer Ausbildungsbeteiligung auf technologische Innovationen im Allgemeinen, Marktneuheiten und Prozessinnovationen aufgezeigt. Für Firmenneuheiten wurde ein direkter und ein indirekter Zusammenhang gefunden. Damit erfährt die Mediationshypothese außer im Fall der inkrementellen Produktinnovationen [5] ihre Bekräftigung. Diese indirekten Zusammenhänge dürften daraus resultieren, dass Betriebe durch eine Ausbildungsbeteiligung über Mechanismen wie die fortlaufende Aktualisierung von Ausbildungsordnungen (Schultheiss/Backes-Gellner 2022), Verbesserungsvorschläge von Auszubildenden (Hodge/Smith 2019; Pfeiffer et al. 2017), die Qualitätssicherung in der Ausbildung (Deissinger 2015) sowie nicht zuletzt zur Einhaltung der rechtlichen Voraussetzungen für Erwerb und Beibehaltung einer Ausbildungsberechtigung (gemäß Berufsbildungsgesetz) dazu angeregt werden, die Lernförderlichkeit ihrer innerbetrieblichen Organisationsumgebung fortwährend auf den Prüfstand zu stellen, was im Ergebnis deren Innovationsfähigkeit stärkt. Die vorliegenden Ergebnisse bekräftigen somit die Ergebnisse von qualitativ-methodischen Studien zu den Auswirkungen einer Ausbildungstätigkeit auf die innerbetriebliche Lernumgebung (Barabasch/Keller 2020; Hodge/Smith 2019; Proeger 2020) und damit verbundene konzeptionelle Erklärungen zum möglichen Einfluss der Ausbildungsbeteiligung auf die Innovationsfähigkeit von Betrieben (Rupietta/Backes-Gellner 2019; Schultheiss/Backes-Gellner 2022).

Im Bezug zur Basiswahrscheinlichkeit ist der Effekt für die allgemeine Innovationstätigkeit zwar als eher gering einzuschätzen. Für Prozessinnovationen wird die Wahrscheinlichkeit jedoch bereits um die Hälfte erhöht. Dasselbe gilt für die Kombination von direktem und indirektem Effekt hinsichtlich Firmenneuheiten. Für Marktneuheiten dahingegen verdoppelt der Mediationseffekt die Innovationswahrscheinlichkeit, wobei zu berücksichtigen ist, dass es sich in den meisten Fällen des hier untersuchten Kleinstbetriebssektors um Produktneuheiten auf regionalen Märkten handeln dürfte.

Für letztere Innovationsart bestehen somit zwei Effekte gleichzeitig: Ein Moderations- (Matthies et al. 2023) und ein Mediationseffekt. Im Falle von Marktneuheiten in Kleinstbetrieben stärkt folglich sowohl die Gleichzeitigkeit (Moderation) von Ausbildungstätigkeit und dem Vorliegen einer lernförderlichen Organisationsumgebung die Innovationsfähigkeit als auch die Mediationswirkung, die von der Ausbildungsbeteiligung über organisatorische Neuerungen hin zur Hervorbringung technologischer Innovationen reicht.

Hinsichtlich unmittelbarer Korrelationen ist festzustellen, dass der im Rahmen dieser Untersuchung zu beobachtende direkte Innovationseffekt der Ausbildungsbeteiligung von geringer Signifikanz ist, die beim Robustheitstest mittels Bootstrapping-Methode gänzlich verloren geht. Somit ist vor allem von einem indirekten Zusammenhang zwischen Ausbildungstätigkeit und Innovationstätigkeit in Kleinstbetrieben auszugehen. Dies bestätigt die Ergebnisse von Matthies et al. (2023), steht aber zunächst im Widerspruch zu den Ergebnissen von Matthies/Haverkamp et al. (2022) und Rupietta/Backes-Gellner (2019). Wird jedoch in Betracht gezogen, dass die beiden letztgenannten Papiere mit Querschnittsdaten arbeiten und die beschriebenen Moderator- und Mediationseffekte nicht berücksichtigen, liegt die Interpretation nahe, dass die in dieser Studie ermittelten indirekten Effekte in den Querschnittsdatenanalysen als direkte Effekte gemessen wurden. Insgesamt erweitert die vorliegende Studie damit das Verständnis hinsichtlich des Zusammenhangs zwischen dualer Ausbildung, lernförderlichen Organisationsumgebung und technologischer Innovation auf betrieblicher Ebene.

Eine Einschränkung der vorliegenden Studie ist, dass wir zwar zusätzlich zum Moderations- einen Mediationseffekt identifizieren, auf Basis der vorliegenden Daten und der verwendeten Methodik jedoch nicht abschließend klären können, welcher der beiden Effekte überwiegt bzw. mit welchem Gewicht zu Buche schlägt. Dies näher zu untersuchen, obliegt zukünftigen Forschungsarbeiten. Dasselbe gilt für die Analyse kausaler Zusammenhänge. Mediationsmodelle beruhen auf starken Annahmen, weshalb wir versucht haben, Rückschlüsse auf Kausalität nur sehr vorsichtig zu ziehen. Auch an dieser Stelle kann die zukünftige Forschung zum Thema ansetzen.

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durchgeführten Robustheitstests auf Anfrage bei den Autoren erhältlich.

5 Dies ist darauf zurückzuführen, dass im Fall von inkrementellen Produktinnovationen keine eindeutige Wirkungskette identifiziert werden kann. Es zeigt sich zwar auch hier der vermutete Wirkungskanal von Ausbildungstätigkeit über organisatorische Lernumgebung auf Innovation. Gleichzeitig liegt jedoch auch eine umgekehrte Wirkungskette vor, gemäß derer – wenn auch nur gering signifikant – ein indirekter Effekt von der Innovationsseite auf die Ausbildungstätigkeit ausgeht. Dies führt dazu, dass im Gegensatz zu den anderen Innovationsarten kein klarer Wirkungszusammenhang erkennbar ist, weshalb der vermutete Mediationseffekt bei inkrementellen Produktinnovationen nicht eindeutig ist.

6 Fazit und Politikimplikationen

Der ermittelte indirekte Mediationseffekt hat vor dem Hintergrund der anhaltend sinkenden Ausbildungsbeteiligung von Kleinstbetrieben in Deutschland besondere Relevanz. Es bedarf daher geeigneter Unterstützungsmaßnahmen, um den Ausstieg dieser Betriebe aus dem dualen Ausbildungssystem mit den daraus resultierenden negativen Konsequenzen für deren Innovations- und Wettbewerbsfähigkeit und damit deren potenzielle weitere Unternehmensentwicklung zu verhindern (Eckelt et al. 2020). Für die Politik sollte es darum gehen, in Kleinstbetrieben den förderlichen Zusammenhang zwischen dualer Ausbildung, innerbetrieblicher Lernumgebung und Innovation zu stärken. Besondere Unterstützung ist bei der Suche und Rekrutierung von Ausbildungsinteressenten notwendig, damit kleine Betriebe trotz der allgemeinen Rekrutierungsschwierigkeiten auch weiterhin ausbilden können. Konkret gilt es z. B., die Bekanntheit der bereits heute verfügbaren Unterstützungsmaßnahmen zu erhöhen (Eckelt et al. 2020), Ausbildungsverbünde und Lernallianzen weiter zu fördern (Schmierl 2012), vorzeitige Vertragslösungen zu vermeiden und monetäre Anreize für Auszubildende anzubieten (Pahnke et al. 2020).

Ferner sind die Ergebnisse auch für die Innovationspolitik von Interesse. Die sichergestellte Beteiligung an der Ausbildung ermöglicht die Aufrechterhaltung der verschiedenen Wissens- und Technologietransferkanäle des dualen Ausbildungssystems und damit die Stimulation einer lernförderlichen Organisationsumgebung auf Unternehmensebene, die gerade für die Innovationsfähigkeit von Kleinstbetrieben nicht zu vernachlässigen ist. Insofern gilt es, die Lernkultur in Ausbildungsbetrieben auch unter Innovationsgesichtspunkten zu sichern, indem Ausbildungsbedingungen gefördert werden, die interaktives Lernen entlang der betrieblichen Prozesse ermöglichen und dadurch Raum für Innovationsbeiträge durch Auszubildende schaffen – wodurch der für die Innovationsfähigkeit des deutschen Mittelstands so wichtige „Learning by Doing, Using, Interacting"-Modus (DUI-Modus) gestärkt wird (Thomä/Bizer 2021). Auch die mittelstandsorientierte Innovationspolitik sollte daher die duale Ausbildung im Blick behalten, um gerade den „Kleinen" in der Unternehmenslandschaft den Einstieg in das Innovationssystem zu erleichtern. ■

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Chapter V

Skills for innovation: individual contributions of the vocationally trained workforce

with Jörg Thomä

Submitting to: European Planning Studies

Skills for innovation: individual contributions of the vocationally trained workforce

Abstract
A rising number of studies addresses the impact of employee skills beyond university qualification on firm-level innovativeness. However, analyses of the participation of different (vocational) qualifications to different phases in the innovation process, namely invention and implementation, under consideration of different types of innovation and firm-size effects are missing. Investigating data from a repeated survey among (self-)employed persons in Germany (the BIBB/BAuA Employment Surveys) this study addresses these research gaps upon data on individuals. Our analyses reveal that university graduates show highest probability for conducting R&D activities during the invention phase with increasing marginal effects by firm size compared to other qualifications. On the output side during implementation, university graduates show highest likelihoods for introducing non-technological innovations, while masters/technicians act as boundary spanners. Vocationally educated employees in particular experience technical innovations in their working environment with marginal effects in comparison to university graduates increasing with firm size. We conclude that all qualification types matter for innovation with particularly supplementary effects in the invention phase and an innovation-promoting division of labour between the invention and implementation phases underlining the importance of vocational education for the German innovation system.

Keywords
Innovation, skills, vocational education and training, SMEs

1. Introduction

The role that different qualifications and skills play for the innovativeness of companies is increasingly coming into the focus of research (e.g. Andries and Czarnitzki, 2014; Bäckström and Bengtsson, 2019; Birkinshaw and Duke, 2013; Bolli et al., 2018; Høyrup, 2010; Mason et al., 2020; Smith et al., 2012). In this context, some studies go beyond the common focus on university graduates, such as scientists and engineers, and emphasize the innovation contributions of individuals with vocational education and training (VET) qualifications, including the organizational and institutional context within and outside the firm in which their innovation participation is embedded (Albizu et al., 2017; Alhusen and Bennat, 2021; Bolli et al., 2018; Brunet Icart and Rodríguez-Soler, 2017; Freel, 2005; Mason et al., 2020; Thomä, 2017; Toner, 2010). Two main strands of empirical literature have emerged in this context. The first relates to the role of VET employees for the innovation capacity of small and medium-sized enterprises (SMEs). In this context, based on a sample of Spanish SMEs, the results of Albizu et al. (2017) show that VET employees contribute significantly to firm-level innovation, and that this participation increases with a higher innovation capacity of the company and the presence of a within-firm organizational environment that is conducive to learning and employee participation. These results are confirmed by Brunet Icart and Rodríguez-Soler's (2017) study and complemented by the finding that persons with VET qualifications contribute, in particular, to process innovation and incremental product innovation at the firm level. In addition, by also using the example of Spanish SMEs, their findings suggest that the interaction between companies and nearby VET institutions is crucial for a VET employee's involvement in innovation. This points to the importance of the VET system for the functioning of regional innovation systems (on this issue, see e.g. Lund and Karlsen, 2020).

The second strand of empirical studies relates to the interplay between different skills and corresponding qualification groups in a firm's innovation process. Bolli et al. (2018) use the example of Swiss firms to investigate how educational diversity in the workforce affects a company's innovation performance, taking also into account the role of VET employees. Their results suggest that the interaction between different qualification groups is conducive to innovation in case of R&D activities and in the generation of highly innovative new products, while such interaction is less crucial in the practical implementation of innovations. This suggests that the role of VET qualifications in firm-level innovation should also be examined in comparison to the non-VET workforce, distinguishing between the invention and implementation phases. Mason et al. (2020) take these considerations further by using aggregate country data for the U.S. and Western Europe to show that absorptive capacities and patenting output of firms depend not only on university graduates but also strongly on employed persons with higher VET qualifications (i.e. "advanced VETs" such as master craftsmen or technicians), suggesting an innovation-promoting interplay between these two groups in particular during the invention phase of a company's innovation process. In contrast, "VET graduates" (e.g. skilled workers with basic VET qualifications) are found in this study to play a greater role only in later stages of the innovation process, where application-oriented implementation is the primary focus. This confirms that the distinction between innovation phases is important when assessing the innovation participation of the VET workforce, including the interaction with other qualification groups in this respect. At the same time and in line with Freel (2005), it becomes clear that in this context a distinction should be made between the innovation contributions of "VET graduates" and "advanced VETs".

Despite this evidence, a number of questions remain regarding the participation of the VET workforce in firm-level innovation. To date, it is still relatively unclear exactly to which specific elements of the innovation process they make a relevant contribution (see Albizu et al., 2017; Bolli et al., 2018; Brunet Icart and Rodríguez-Soler, 2017; Mason et al., 2020). For example, while VET employees were found to play an important role in the case of process innovations, information is lacking on what types of process innovations this refers to (e.g., whether it is the introduction of new manufacturing or process technologies, the use of new machinery or equipment, or the improvement of organizational processes). At the same time, the question of whether the innovation contributions of the VET workforce depend on the size of the company – which the results of the two Spanish studies mentioned may suggest – has not yet been clarified. Indeed, especially with regard to smaller firms, a notable involvement in innovation activities on the part of persons with VET qualifications is repeatedly assumed in the literature, whereas with regard to the in-house research and development (R&D) activities of larger firms the role of university graduates – notably those of natural sciences and engineering – is usually emphasized (e.g. Acs and Audretsch, 1988; Alhusen and Bennat, 2021; Jensen et al., 2007; Leiponen, 2005; Thomä, 2017; Van Dijk et al., 1997).

Moreover, the VET workforce itself has hardly been differentiated in more detail with regard to individual contributions to innovation so far, which is why the distinction between advanced VETs and VET graduates has not been made clear in the empirical studies mentioned above, or only to some extent. Nevertheless, this is exactly what should be important. Since data on the employment of scientifically trained personnel – i.e. university graduates – are a standard indicator of a company's absorptive capacity (Jensen et al., 2007), it would be reasonable to assume that the individual innovation contributions of the VET workforce fall primarily on the implementation phase of innovation processes. However, as mentioned above, the study by Mason et al. (2020) suggests that advanced VETs play an important role already in the invention phase and that, therefore, a variety of academic and VET qualifications come into play at this stage of the innovation process, promoting the finding of new solutions and ideas. Indeed, the results of a number of studies suggest that advanced VETs are a relevant driver of firm-level innovation (Freel, 2005; Hirsch-Kreinsen, 2015; Hirsch-Kreinsen, 2008; Kirner and Som, 2015; Thomä and Zimmermann, 2020; Weidner et al., 2022). Hence, there is some reason to assume that not only university graduates but also advanced VETs shape the absorptive capacity of an innovating firm and thus play a key role in the invention phase of a firm's innovation process. In addition, they are often the ones who supervise the implementation of organizational innovations in practice, guide technological improvement processes, and act as mediators and translators between scientifically trained R&D personnel and skilled production workers from the shop floor (Finegold and Wagner, 1998; Mason, 2000; Mason et al., 2020; Thomä and Zimmermann, 2020; Weidner et al., 2022). Accordingly, advanced VETs can be expected to make a number of individual contributions to firm-level innovation, which could be different from those of VET graduates – an assumption that requires further investigation.

This potential difference leads to another aspect that is still underexplored in the literature: the mutual interplay between the VET workforce and university graduates. From the analyses of Bolli et al. (2018) and Mason et al. (2020), we know that there are strong complementarities between university graduates and VET employees, at least in the invention phase (whereby, as mentioned, it is still not very clear exactly what their individual innovation contributions look like). This indicates that a company's workforce is made up of different qualification groups, each with specific knowledge assets and skills, which has an overall positive effect on a company's innovation performance. Therefore, for a better understanding of the innovation participation of the VET workforce – and thus in extension of the studies by Albizu et al. (2017) and Brunet Icart and Rodríguez-Soler (2017) – it would be useful to compare their contributions with those of university graduates, in order to possibly obtain evidence of a fruitful interplay between academic and VET qualifications in the innovation process at the level of the firm. In this context, not only should a distinction be made between different innovation phases, as Bolli et al. (2018) and Mason et al. (2020) do, but it should also be investigated how the innovation-promoting influence of educational diversity depends on the size of the company. This is because one of the innovation advantages of large companies is that they have many highly qualified specialists in various innovation-related fields (Nooteboom, 1994; Rothwell, 1989), which should increase the likelihood of an innovation-enhancing "division of labor" between different qualification groups and departments of the company.

This paper aims to address at least some of these issues by analyzing data from a repeated survey among employed persons in Germany (the BIBB/BAuA Employment Surveys). The advantage over the previous studies is that this data is on individuals. The respondents therefore indicate where they are personally involved in the innovation activity of their company, which allows a deeper understanding of the individual innovation contributions of the VET workforce. The resulting picture is also more complete in that it covers not only the level of employees, as in the company data-based studies of Albizu et al., (2017), Bolli et al. (2018) and Brunet Icart and Rodríguez-Soler (2017), but also self-employed persons with their participation in innovation.[2] Furthermore, the data allows us to clearly distinguish between VET graduates and advanced VETs, and to contrast their innovation contributions with those of university graduates so that the "the specific complementarities among education levels […] [become less] obscured" (Bolli et al., 2018, p. 21). In doing so, we can distinguish between input and output indicators of firm-level innovation, which ensures the described need to differentiate between the invention and implementation phases. Since the BIBB/BAuA employment survey is a representative data set, it is also possible to examine the possible influence of firm size in a differentiated manner. All in all, therefore, based on our dataset, we can examine the role and contributions of the VET workforce in the context of firm-level innovation in a more nuanced way than previous studies have been able to do.

The remainder of this paper is organized as follows: Section 2 describes the conceptual background of our study and formulates a set of hypotheses on the individual innovation contributions of the VET workforce. The data set is described in Section 3, while the fourth section presents the empirical analysis. Section 5 summarizes our findings and we conclude with implications for policy and research.

2. Conceptual background

From a theoretical perspective, VET qualifications have several advantages in terms of innovation. Toner (2010) was the first to describe this in detail, by focusing on the role of skilled production workers and, in particular, craftsmen and technicians. He argues for the case of Australia that this qualification group plays an important role in firm-level innovation in both R&D and non-R&D areas, while the main innovation contributions of its members are related to experience-based processes of learning by doing and using, acquiring and applying problem-solving competencies, and participating in incremental innovation. Following on from this, the author sees a key role for the VET system in terms of technology diffusion across the economy.

Based on Toner's (2010) seminal contribution, further studies extend these theoretical considerations and focus on the specific skill set of the VET workforce, emphasizing their ability to communicate with scientists and engineers on innovation-relevant issues due to their comparatively high level of training, which includes both practical and theoretical knowledge elements (EFI, 2014; Ruth and Deitmer, 2010). This "mutual understanding" promotes within-firm knowledge exchange (i.e. learning by interacting) between the R&D department and other parts of the company, such as production and marketing (Backes-Gellner and Rupietta, 2014; Flåten et al., 2015). This is likely to be the case above all in countries with established dual VET systems such as Germany, where apprentices, on the hand, learn "on the job" during their training period and, as a result, acquire experiential knowledge about internal business processes that they later deepen as skilled workers (Ruth and Deitmer, 2010). On the other hand, this practical knowledge is supplemented by the formal knowledge acquired in vocational

[2] The study of Mason et al. (2020) also uses data on individuals, but only provides aggregate results at the country level without presenting individual innovation contributions by qualification groups.

schools, resulting in a mix of practical and theoretical-abstract knowledge that favors innovation-promoting interaction with academically trained personnel (Thomä, 2017).

Based on their skills, members of the VET workforce are able to contribute to creative problem solving and to coping with complexity and unpredictability in firms, which can be expected to contribute positively to (non-R&D-based) innovation (Flåten et al., 2015; Pfeiffer, 2018). Their experience-based knowledge is particularly important at the interface between product innovation, production technology, plants, machines and process planning (Flåten et al., 2015; Pfeiffer, 2016; Toner, 2010). In collaboration with university graduates, the VET workforce therefore participates in both R&D and non-R&D innovation activities such as prototyping or design (Pfeiffer, 2016). In this way, its members actively contribute to process and product innovations, as has already been shown in studies on SMEs (Albizu et al., 2017; Brunet Icart and Rodríguez-Soler, 2017). The emergence of such contributions by the VET workforce is thereby favoured by a learning-promoting design of workplaces that are geared toward interaction, opportunities for learning via 'trial-and-error' and strong individual responsibility, thus offering a high degree of scope for creativity to unfold (Thomä, 2017).

In this context, we argue that with respect to the particular stage of the innovation process, it is useful to distinguish between the roles and contributions of different subgroups of the VET workforce. Individuals with higher VET qualifications (the advanced VETs) are a relevant source of a firm's absorptive capacity (Freel, 2005; Hirsch-Kreinsen, 2015; Hirsch-Kreinsen, 2008; Kirner and Som, 2015; Thomä and Zimmermann, 2020; Weidner et al., 2022) – and are therefore likely to have an important function in generating and testing new ideas in the invention phase of firm-level innovation in interaction with scientists and engineers (Bolli et al., 2018). Moreover, this innovation-promoting interplay between advanced VETs and university graduates should also be related to the fact that advanced VETs in particular can play an intermediary role in the internal learning environment of innovating firms. This is because, at least in countries with broadly anchored VET systems such as Germany or Switzerland, advanced VETs have both high scientific-theoretical knowledge related to new innovative ideas and the deep practice-based experience required to implement them (e.g., in terms of manufacturing processes, prototyping or required equipment and machinery), which enables them to mediate and translate between different qualification groups within the company. For this reason, they are able to orchestrate the knowledge exchange between scientists from the R&D department and skilled workers from production, reducing coordination and communication costs between different skill levels (Finegold and Wagner, 1998; Mason, 2000; Mason et al., 2020; Thomä and Zimmermann, 2020; Weidner et al., 2022). For this reason, we expect that advanced VETs are important "boundary spanners" (Weidner et al., 2022) between the invention and implementation phases, helping to unlock the innovation-enhancing benefits of educational diversity at the level of the firm (Bolli et al., 2018; Mason et al., 2020). This leads us to formulate two hypotheses:

H1: University graduates and advanced VETs both significantly contribute to the invention phase of firm-level innovation.

H2: Advanced VETs are boundary spanners between different skill levels; they are therefore an essential prerequisite for realizing the benefits of educational diversity in innovating firms.

Compared to advanced VETs, we expect VET graduates to be more involved in the implementation phase of firm-level innovation (Mason et al., 2020). VET graduates should also be involved in technological and organizational innovation processes, as they work directly with the innovation-relevant machines, equipment or materials (Kern and Schumann, 1987; Toner, 2010). At the shop floor, however, they often have to perform routine tasks as skilled production workers (Pfeiffer, 2018), which is why we expect less creative innovation contributions overall compared to the group of advanced VETs. Nevertheless, the feedback from VET graduates to upstream business units such as R&D, derived from the application experience they have gained, should provide important impetus for incremental improvements and modifications (EFI, 2014; Mason et al., 2020; Thomä, 2017; Toner, 2010). Hence, our third hypothesis is:

H3: VET graduates contribute primarily to the implementation phase of a company's innovation process.

With regard to the concept of educational diversity (Bolli et al., 2018; Mason et al., 2020), the discussion so far suggests that the role and contributions of the VET workforce can complement those of university graduates in different ways. In this context, the influence of the organizational framework as expressed by the size of an innovating firm is still unclear. As mentioned, the innovation contribution of the VET workforce has so far been empirically shown using the example of SMEs (Albizu et al., 2017; Brunet Icart and Rodríguez-Soler, 2017). However, we expect the benefits of educational diversity to become more pronounced in larger firms.

It is well established in the literature that innovation processes and their determinants differ with firm size (Acs and Audretsch, 1988; Van Dijk et al., 1997). At the same time, it has long been a well-known fact in economic research that increasing size of a company is accompanied by a growing division of labour among the individuals working there (Groenewegen, 2016). Against this background, it is not surprising that firm-level innovation activities are also characterized by a division of labour (Chakrabarti and Hauschildt, 1989) – and that this is probably driven by firm size. After all, one of the key innovation advantages of large firms is precisely that they have many highly and differently qualified specialists in various innovation-related fields (Jensen et al., 2007; Nooteboom, 1994; Rothwell, 1989), which increases the likelihood of an innovation-enhancing "division of labour" between different qualification groups and departments of the firm. Smaller firms, on the other hand, have a higher degree of innovation activities that are carried out by one and the same person (such as the business owner, see Runst and Thomä (2021)) due to a lower degree of subdivision into departments and functions, which is why the innovation-promoting diversity of different qualification groups is likely to have less effect. Therefore, we formulate as a fourth hypothesis:

H4: The division of individual innovation contributions between the VET workforce and university graduates is less pronounced in smaller companies; advantages of educational diversity therefore tend to increase with larger firm size.

3. Data and method

To examine the individual innovation contributions of the VET workforce, we use data from the 2006, 2012 and 2018 BIBB/BAuA employment surveys as pooled cross-sections.[3] These provide employment data from Germany of more or less 15,000 employed persons each, that has been collected jointly by the Federal Institute for Vocational Education and Training (BIBB) and the Federal Institute for Occupational Safety and Health (BAuA). The surveys are conducted at six-year intervals. The sample frame of the BIBB/BAuA employment surveys is the entire German labor force, including the self-employed with core employment defined as persons working at least 10 hours per week and older than 15 years (Rohrbach-Schmidt and Tiemann, 2013, 2011).

The surveys contain detailed information on the qualifications and working conditions of the responding individuals, allowing a comprehensive and representative picture on aspects like education levels, qualifications, tasks, knowledge requirements, work conditions, individual responsibilities or career changes (Rohrbach-Schmidt and Tiemann, 2013, 2011). We restrict our sample to the working population aged 15 to 65 and, because of our interest in business innovation, focus on employees in

[3] BIBB/BAuA Employment Survey of the Working Population on Qualification and Working Conditions in Germany 2006 (doi:10.7803/501.06.1.1.30), 2012 (doi:10.7803/501.12.1.1.60), 2018 (doi:10.7803/501.18.1.1.10).

the manufacturing, construction, trade and service industries. Our sample includes 45,393 observations. 57.5% of the surveyed persons are VET graduates, 9.4% advanced VETs (degrees such as master or technician) and 24.7% are university graduates (Table 1).

Table 1: Descriptive statistics on innovation inputs and outputs, explanatory variables and controls

	Description	Mean	S.D.
Dependent variables on innovation inputs			
Continuous R&D	1 if respondents are often involved in developing / researching / constructing	0.127	0.333
Occasional R&D	1 if respondents are sometimes involved in developing / researching / constructing	0.217	0.412
Continuous innovator without R&D	1 if it occurs frequently that respondents improve existing procedures or try something new without conducting R&D	0.196	0.397
Occasional innovator without R&D	1 if it occurs sometimes that respondents improve existing procedures or try something new without conducting R&D	0.469	0.499
Dependent variables on innovation outputs			
Manufacturing / process technologies	1 if new manufacturing or process technologies have been introduced in the last two years	0.366	0.482
Products / materials	1 if new or significantly changed products or materials have been used in the last two years	0.283	0.451
Machines / plants	1 if new machines or plants have been introduced in the last two years	0.392	0.488
Computer programs	1 if new computer programs have been introduced in the last two years (excluding updating of existing ones)	0.493	0.500
Services	1 if new or significantly changed services have been provided in the last two years	0.301	0.459
Organizational practices	1 if there has been a significant restructuring or reorganization of the personal work environment in the last two years	0.437	0.496
Explanatory variables			
VET graduates	1 if initial VET is completed	0.574	0.494
Advanced VETs	1 if higher VET qualifications (master, technicians)	0.094	0.292
University graduates	1 if university (or applied sciences) degree	0.247	0.432
No formal qualification	1 if no formal qualification	0.073	0.260
Other qualification	1 if civil servants or other training qualification	0.011	0.102
Controls			
Age of respondents	Age in years	44.076	10.834
Male/female	0 if man, 1 if woman	0.476	0.499
East-West	1 if western Germany	0.850	0.357
Nationality	1 if German nationality	0.966	0.180
Employment status	0 “others”	0.019	0.136
	1 “workers”	0.204	0.403
	2 “employees”	0.672	0.470
	3 “self-employed”	0.105	0.307

To capture the invention phase, we resort to two different indicators for the input side of innovation. The first of these indicates how often a respondent researches, develops, or constructs something in the context of his or her own professional activities, which we summarize under the term “R&D”: 12.7% of respondents frequently conduct R&D themselves and 21.7% do so on an occasional basis. In addition, to cover participation in non-R&D-based innovation activities during the invention phase, we resort to a second indicator. This covers individuals who, while stating that they are not engaged in

R&D, at the same time frequently or at least sometimes improve existing processes or try out something new as part of their work – which suggests relatively high creativity requirements. This is true for 19.6% on a frequent basis ("Continuous innovator without R&D") and for 46.9% of respondents on an occasional basis ("Occasional innovator without R&D"). On the output side, in order to cover the implementation phase, we can distinguish between participation in product innovation activities and contributions to process innovations. In this respect, the respondents were asked whether corresponding changes had taken place in their immediate working environment in the last two years. Regarding product innovation, we distinguish between the use of new or significantly changed products or materials (28.3%) and the provision of new or significantly changed services (30.1%). In the case of process innovation activities, on the other hand, we have information on the introduction of new manufacturing or process technologies (36.6%), of new machines or plants (39.2%), completely new computer programs (49.3%) and of new organizational practices (43.7%).

To conduct the empirical analysis, we estimate probit models (pooled cross-section) for the individual innovation indicators as dependent variables. In each case, we employ the following estimation model:

$$inno_{jt} = \gamma_o + \gamma_1 no\_formal\_qualification_{jt} + \gamma_2 other\_qualification_{jt} + \gamma_3 VET\_graduates_{jt} + \gamma_4 advanced\_VETs_{jt} + \sum_{k=1}^{K} \gamma_k x_{kjt} + e_{jt}$$

Inno refers to our indicators on innovation input and output. *No_formal_qualification, other_qualification, VET_graduates* and *advanced_VETs* are the regression variables on a respondents' professional qualification. *University_graduates* are the reference case here. As controls (*x*), we use variables on firm size, economic sector, age of respondents and their employment status, age squared, gender, nationality, survey year and location in Germany. *k* denotes the number of control variables, *j* the number of observations and *e* the error term.

The detailed regression results can be found in the Appendix. In the following section, the predicted probabilities for the qualification groups of VET graduates, advanced VETs and university graduates are visualized in spider web diagrams. In order to assess the statistical significance of the corresponding differences, the marginal effects for VET graduates and VET advanced are then shown in line graphs in reference to university graduates. Finally, this differentiation by marginal effects is carried out again in separate regression models according to four company size classes (1-9 employees, 10-49 employees, 50-249 employees and more than 249 employees), so that the possible division of innovation contributions between the VET workforce and university graduates can be examined in relation to firm size.

4. Empirical results

4.1 Input side

Figure 1 shows the predicted probabilities for innovation contributions in the invention phase (input side). As expected, university graduates are most likely to be involved in continuous R&D (21.8%). VET graduates and advanced VETs show significantly lower probabilities in this respect. These differences are statistically significant (see Figure A.1 in the Appendix). VET graduates also lag significantly behind university graduates in the other input indicators. In general, however, the differences in the cases of occasional R&D and non-R&D innovation activities are less pronounced, which could suggest a relative relevance of VET graduates in certain parts of the invention phase – a result that is supportive with regard to Hypothesis H3. The corresponding marginal effects for VET graduates in comparison to university graduates lie between -1.7% and -5.7% (Figure A.1). The picture is somewhat different for advanced VETs. Both in terms of the probability of occasional R&D and in terms of non-R&D-based

innovation activities, they are almost on the same level as university graduates and do not differ significantly. In line with Hypothesis 1, this suggests that advanced VETs are an important player in the invention phase of firm-level innovation alongside university graduates.

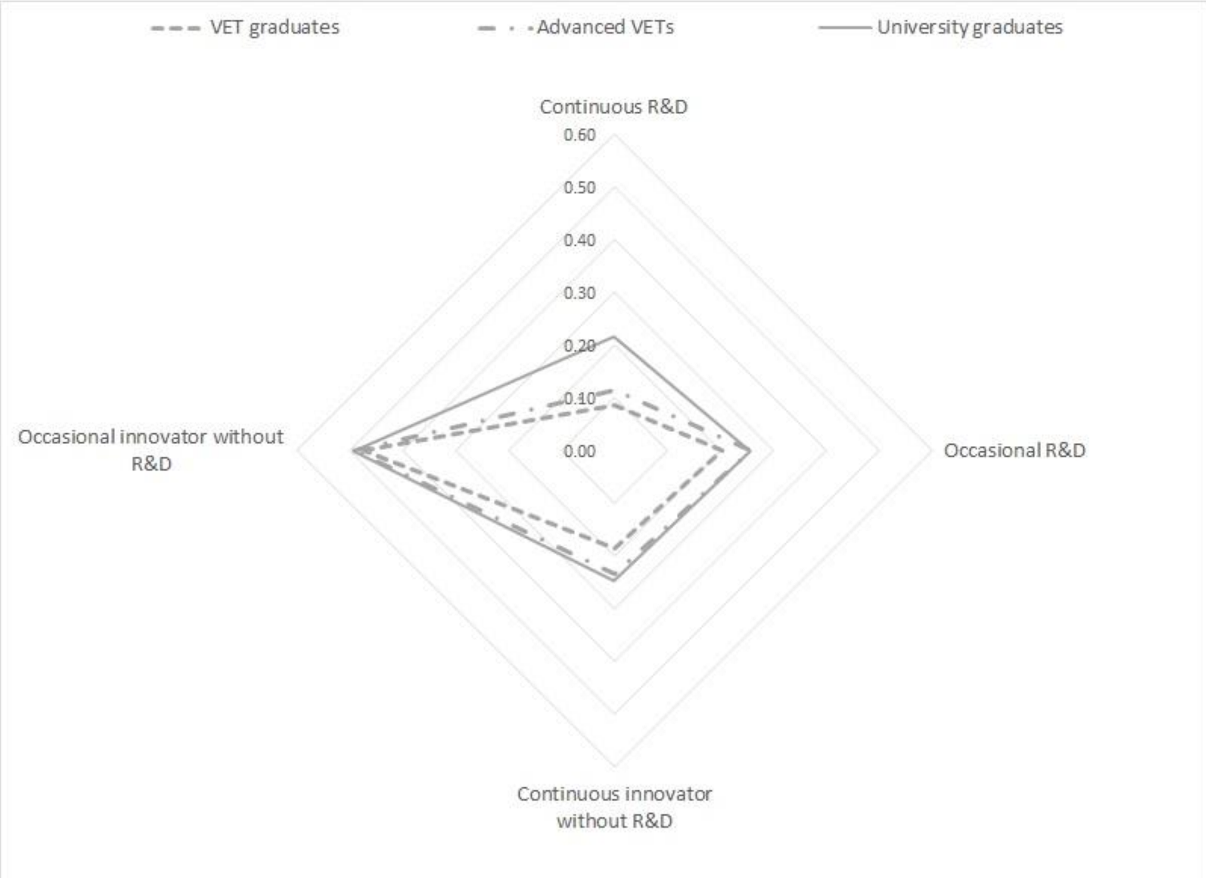

Figure 1: Predicted probabilities for individual innovation contributions during the invention phase differentiated by qualification

Table 2: Marginal effects in comparison to university graduates for innovation inputs by firm size classes (number of employees)

Qualification	**VET graduates**				**Advanced VETs**			
	1-9	10-49	50-249	250+	1-9	10-49	50-249	250+
Continuous R&D	-0.100 ***	-0.094 ***	-0.104 ***	-0.144 ***	-0.070 ***	-0.061 ***	-0.077 ***	-0.106 ***
Occasional R&D	-0.029 *	-0.064 ***	-0.071 ***	-0.050 **	-0.001	-0.017	-0.020	0.019
Continuous innovator without R&D	-0.025 *	-0.062 ***	-0.032	-0.085 ***	-0.026	-0.026	0.021	-0.042 *
Occasional innovator without R&D	-0.017	-0.016	-0.043 **	-0.002	-0.003	0.006	-0.023	0.008

Controls: year, economic sector, east / west Germany, firm size, age, age², employment status, gender and nationality

Table 2 contains the marginal effects for the VET workforce compared to university graduates for the input side differentiated by firm size classes. In the case of continuous R&D, the difference with university graduates widens with firm size, indicating a division of tasks in the invention phase in large companies with more than 250 employees (Hypothesis H4). The picture is less clear for the other input indicators. VET graduates tend to lag behind university graduates across all company size classes, which, in line with Hypothesis 3, suggests that VET graduates are more active in the implementation phase regardless of company size. In the case of advanced VETs, on the other hand, there are no significant differences to university graduates across all company size classes with regard to both participation in occasional R&D and the performance of non-R&D-based innovation activity. This, in turn, is consistent with Hypothesis H1. Evidence with respect to the validity of H4 can thus only be found with respect to continuous R&D.

4.2 Output side

The results on the output side suggest some division of tasks between university and VET graduates. This is indicated by the fact that the areas of these two groups in the spider web diagram are not congruent, but overlap only partially (see Figure 2). The former are more likely to be involved in the implementation of new organizational practices (46.6%), the introduction of service innovations (34.3%) and new computer programs (54.1%), while the latter, consistent with Hypothesis H3, are more strongly involved in the introduction of new manufacturing or process technologies (38.4%), new machinery or equipment (42.2%), and the practical introduction of new products and materials (30.1%). These differences between VET graduates and university graduates are statistically significant (see Figure A2 in the Appendix). In line with Hypothesis H3, this suggests that VET graduates are strongly involved in the implementation phase of the business innovation process.

At the same time, there is evidence of a "boundary spanner" function for advanced VETs (Figure 2; Figure A.2): Their area in the spider web diagram almost completely encloses that of the university and VET graduates, which indicates that advanced VETs are in the implementation phase entrusted with both the practical implementation of innovation steps and guiding the VET graduates in this, as well as taking on more complex management and coordination tasks in collaboration with the group of university graduates. If one also takes into account the strong involvement of the advanced VETs in the invention phase, there is much to suggest that they mediate and translate between the invention and implementation phases, and thus between university and VET graduates, making them an important link in the business innovation process. This speaks in favour of Hypothesis H2.

Table 3 shows the marginal effects for VET graduates and advanced VETs compared to university graduates for the output side differentiated by company size classes. A clear size effect is only evident for the first three indicators listed in Table 3: the introduction of new manufacturing / process technologies, the implementation of new machinery / plants and the introduction of new products / materials. The differences in this regard, and thus the presumed division of tasks between the VET workforce and university graduates are again most pronounced in the largest company size class (plus 249 employees). We interpret this result as a "fitting piece of the puzzle" to the results on the input phase (see Section 4.1): There, the strong weight of university graduates in the area of continuous R&D in large companies was revealed. On the output side, this picture is exactly the other way around when it comes to innovation steps in the production area. In the sense of Hypothesis H4, we interpret this as an indication that there is an innovation-promoting division of labour between the invention and implementation phases between university graduates and the VET workforce, especially in large firms.

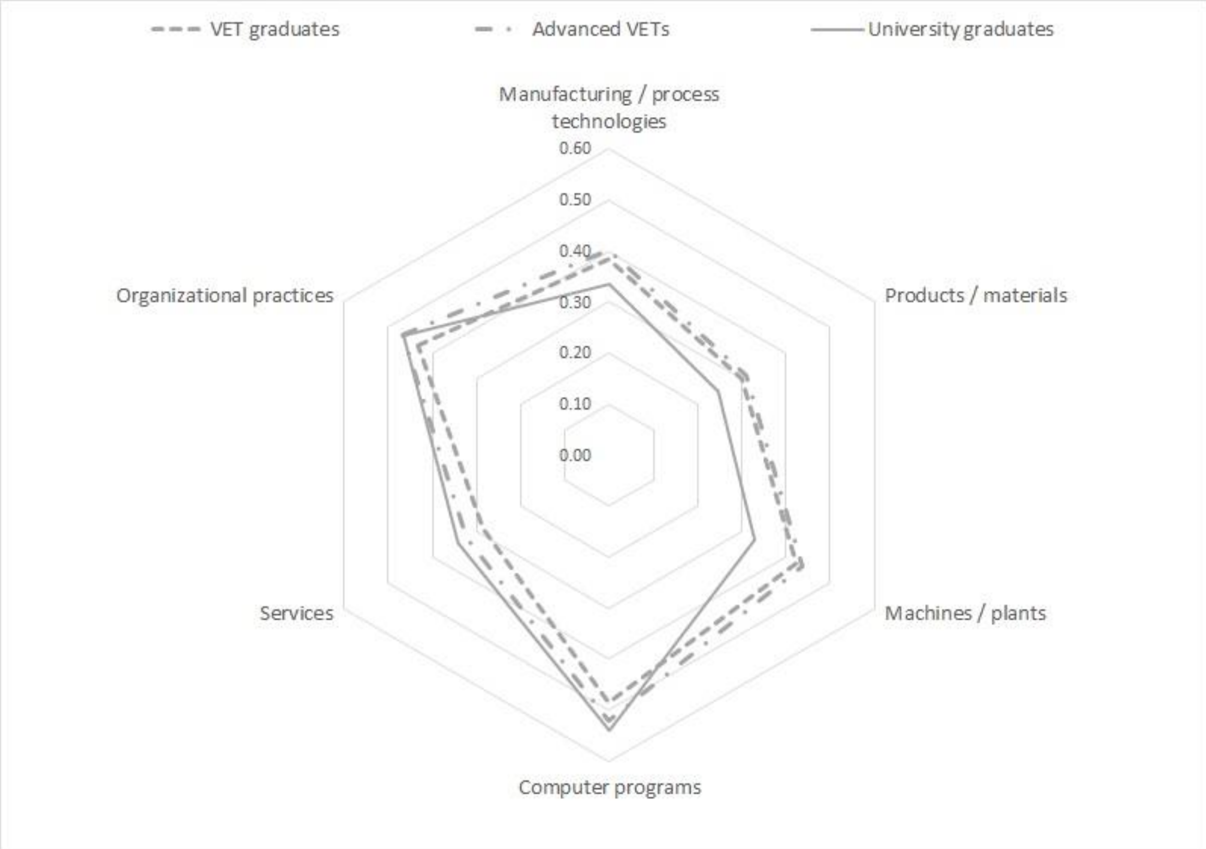

Figure 2: Predicted probabilities for individual innovation contributions during the implementation phase differentiated by qualification

Table 3: Marginal effects in comparison to university graduates for innovation outputs by firm size classes (number of employees)

Qualification	VET graduates				Advanced VETs			
	1-9	10-49	50-249	250+	1-9	10-49	50-249	250+
Manufacturing / process technologies	-0.001	0.036 **	0.045 ***	0.075 ***	0.035 ***	0.044 **	0.063 ***	0.095 ***
Machines / plants	0.069 ***	0.087 ***	0.079 ***	0.099 ***	0.105 ***	0.097 ***	0.080 ***	0.121 ***
Products / materials	0.030 ***	0.056 ***	0.047 ***	0.060 ***	0.043 ***	0.057 ***	0.056 ***	0.075 ***
Computer programs	-0.091 ***	-0.057 ***	-0.061 ***	-0.032 **	-0.068 ***	0.018	-0.047 *	-0.005
Services	-0.065 ***	-0.065 ***	-0.069 ***	-0.047 ***	-0.021	-0.042 *	-0.029	-0.003
Organizational practices	-0.032 ***	-0.013	-0.052 ***	-0.030 ***	0.008	0.023	-0.011	-0.000

Controls: year, economic sector, east / west Germany, firm size, age, age², employment status, gender and nationality;

5. Discussion

The results of our analysis confirm that in order to assess the individual innovation contributions of the VET workforce, it is necessary to distinguish by innovation phase, innovation type and company size, as well as to differentiate by the type of qualification. On the input side of innovation, the university graduates are most likely to engage in continuous R&D. Nevertheless, advanced VETs and VET graduates also make innovation contributions that are relevant to the invention phase. This is often true for SMEs and non-R&D-innovation activities. According to Albizu et al. (2017), Thomä (2017), and Brunet Icart and Rodríguez-Soler (2017), VET employees can have an innovative impact in smaller firms by finding new solutions to problems that often involves trial-and-error processes of learning by doing and using. Moreover, advanced VETs, and to a certain degree also VET graduate, perform R&D at least occasionally, supporting the findings of Turpin et al. (2011) and Pfeiffer (2016) and highlighting that the latter group also contributes to the input side of innovation.

The difference for continuous R&D in comparison to university graduates increases for VET graduates and advanced VETs with firm size for the invention phase indicating a rising division of labor with firm size in the case of frequent R&D activities (Nooteboom, 1994; Rothwell, 1989). The results are also in line with the literature identifying R&D, scientists and engineers as large firm innovation drivers as well as the complementarity of the latter skills for R&D (Barge-Gil et al., 2011; Cohen and Klepper, 1996; Jensen et al., 2007; Leiponen, 2005; Nooteboom, 1994; Rothwell, 1989).

For advanced VETs, we observe – apart from continuous R&D – insignificant marginal effects pointing to their relevance for (non-)R&D innovation inputs (Flåten et al., 2015; Ruth and Deitmer, 2010; Toner, 2010) independently of firm size. This supports the findings of Mason et al. (2020), which suggest that advanced VETs play an important role already in the invention phase and that, therefore, a variety of academic and VET qualifications come into play at this stage of the innovation process, promoting the finding of new solutions and ideas. Our results on the relevance of advanced VETs are also in accordance with their role as company owners and hence innovation drivers (Thomä and Zimmermann, 2020). In conclusion, they are supportive for our H1 that university graduates and advanced VETs both significantly contribute to the invention phase of firm-level innovation, which hence applies for all inputs except for continuous R&D.

Turning to VET graduates, the result on their participation in non-R&D-innovation is at first glance surprising. However, the participation can be explained by the importance of non-R&D innovation drivers, especially for SMEs (Apanasovich et al., 2017; Lee and Walsh, 2016). In this environment, VET employees engage in complex and creative problem solving (Flåten et al., 2015) and cope with complexity and unpredictability on shop floor thus contributing to innovation (Pfeiffer, 2018) based on their practical process and experience-based knowledge (Ruth and Deitmer, 2010). Therefore, this finding on the participation in the invention phase suggests that our results provide only partially support for H3 that VET graduates contribute primarily to the implementation phase of a company's innovation process.

The effect of firm size matters thereby during the invention phase for VET graduates while it is only relevant for advanced VETs in case of continuous R&D, which partially supports H4. Advanced VETs' involvement in R&D and non-R&D inputs also gives a hint on their role as boundary spanners linking VET and university graduates in the invention phase, which provides support for H2.

Overall, with all three qualification types conducting R&D as well as non-R&D innovations, higher and lower skills are relevant for the German innovation system (EFI, 2014; Porter, 1991; Thomä, 2017). The interplay of different qualification backgrounds concerning R&D and beyond in terms of innovation inputs is supported and extended concerning the relevance of VET graduates for non-R&D-inputs (Bolli et al., 2018; Mason et al., 2020; Toner, 2011) while the participation of all qualifications in innovation inputs is more often practiced in smaller companies, which is in line with the literature (Birkinshaw and Duke, 2013).

Turning to the output side, our results point on the one hand to skill complementarities concerning production and related organization (Bolli et al., 2018; Mason et al., 2020) as VET qualifications are particularly relevant for new products, new processes and new machines. Therefore, they provide further evidence for VET graduate's main occupation in the fields of production (Freel, 2005) and their focus on working directly with machinery and materials (Kern and Schumann, 1987) – both independent of firm size. This supports our H3 on VET graduates' contributions to innovation and emphasizes that VET graduates are occupied with product and process innovation independent of firm size (Brunet Icart and Rodríguez-Soler, 2017; Thomä, 2017). Apart from that and in the sense of Hypothesis H4, we interpret this as an indication that there is an innovation-promoting division of labour between the invention and implementation phases among university graduates and the VET workforce, especially in large firms.

Concerning rising labor division with firm size during the implementation phase, our results support the assumption (H4) that marginal effects for VET graduates in comparison to university graduates are smaller on output side for smaller companies than for larger companies, which indicates again rising labor division with firm size. However, this finding is limited to technological innovation.

Advanced VETs then again are found to act as innovators and boundary spanners. In particular, in fields where the marginal effect in comparison to university graduates is insignificant while the difference between VET graduates and university graduates is significant, they can either introduce e.g. an organizational innovation or transfer the relevant knowledge on a new service to the graduated VETs. As masters/technicians also participate in all kinds of innovation outputs and nearly all innovation inputs comparable with university graduates, they bridge different academic and vocational skills and act as boundary spanners between both, skills and innovation phases (Finegold and Wagner, 1998; Mason, 2000; Weidner et al., 2022). Particularly their role as first line managers on shop floor and as process developers (Mason, 2000; Mason and Wagner, 2005; Weidner et al., 2022) is supported by our findings on the relevance of this group for organizational and process innovation. The high likelihood for participation in the introduction of new machines further underlines masters' / technicians' relevance for absorptive capcacity (Weidner et al., 2022) and a firms' ability to adopt new technologies (Lewis, 2020). Technicians and masters therefore seem to constitute the nexus between VETs' and university graduates' innovation activities. Keeping in mind the strong involvement of the advanced VETs in the invention phase, there is much to suggest that they mediate and translate between the invention and implementation phases, and thus between university and VET graduates, making them an important link in the business innovation process, as well. Hence, both findings speak in favour of Hypothesis H2.

6. Conclusion

The role that different qualifications and skills play for the innovativeness of companies is increasingly coming into the focus of research (e.g. Andries and Czarnitzki, 2014; Bäckström and Bengtsson, 2019; Birkinshaw and Duke, 2013; Bolli et al., 2018; Høyrup, 2010; Mason et al., 2020; Smith et al., 2012). In this regard, recent studies point to the innovation relevance of skills beyond academic qualification (Albizu et al., 2017; Brunet Icart and Rodríguez-Soler, 2017; Freel, 2005) as well as to the necessity to differentiate innovation phases, to distinguish between advanced VETs and VET graduates and to consider effects of diversity and firm size (Bolli et al., 2018; Mason et al., 2020). However, several of these aspects have remained unclear, as research on the contributions of different (VET) qualifications to different phases in innovation processes and to different types of innovation, the interdependence with firm size and comparisons among the qualifications has to date remained scarce – especially studies based on data on individuals.

We address these research gaps by conflating literature on the role of VET employees for the innovation capacity of SMEs on the one hand and literature related to the interplay between different skills and corresponding qualification groups in a firm's innovation process on the other. We thereby differentiate university graduates, VET graduates and advanced VETs, R&D and non-R&D innovation activities as well as different types of (process) innovation to enhance the understanding of VET qualifications' contributions to invention and implementation phase in the innovation process.

Analyzing data from the BIBB/BAuA Employment Surveys 2006, 2012 and 2018 on the individual employee's and self-employed person's involvement in the innovation activity of their company as pooled cross-sections we find explicit roles for the different qualifications in invention as well as the in implementation phase. For the invention phase, we identify VET graduates to participate significantly less in R&D innovation inputs in comparison to university graduates except for occasionally innovating without R&D. This is surprising in so far as university graduates are perceived as crucial innovation drivers (Albizu et al., 2017; Andries and Czarnitzki, 2014; Kesting and Parm Ulhøi, 2010). Nevertheless, it has to be kept in mind that feedback from VET graduates to upstream business units such as R&D, derived from the application experience they have gained, should provide important impetus for incremental improvements and modifications (EFI, 2014; Mason et al., 2020; Thomä, 2017; Toner, 2010).

For advanced VETs, participation is only significantly lower for continuously conducting R&D compared with university graduates, who dominate R&D inputs to the invention phase. However, except for conducting continuously R&D, their contribution is comparable with advanced VETs, which suggests that advanced VETs are an important player in the invention phase of firm-level innovation alongside university graduates.

During implementation, VET graduates particularly contribute to technological innovation, advanced VETs act as all-rounders and boundary spanners while university graduates are occupied with organizational and service innovation as well as introducing new computer programs. These findings underline Toners (2011) statement that innovations require different qualifications and occupations to be engaged in generating and adapting as well as diffusing technological and organizational changes.

In terms of firm-size related labor division and particularly for large companies, university graduates are primarily occupied with R&D while VET graduates focus on (technological) implementation. Taking into account advanced VETs' involvement in invention as well as their "boundary spanner" function for the implementation phase, there is much to suggest that they mediate and translate between the invention and implementation phases, and thus between university and VET graduates, making them an important link in the business innovation process. Advanced VETs are therefore a crucial driver of innovation processes.

Overall, we therefore extend the findings of Bolli et al. (2018) and Mason et al. (2020) to that extent, that we identify explicit contributions of different qualifications to the two innovation phases differentiated by firm size and different types of innovation as well as complementarity in terms of positive diversity effects. Moreover and in extension to Albizu et al. (2017) and Brunet Icart and Rodríguez-Soler (2017), contributions of VET graduates to invention phase and specific types of process innovation are revealed.

In concrete terms, we find support for our first hypothesis on the significant contributions of university graduates as well as advanced VETs to the invention phase and for our second hypothesis as advanced VETs seem to act as boundary spanners. Concerning our third hypothesis, our results provide partial support, as VETgraduate's contributions require a differentiated consideration keeping in mind firm size effects, invention relevant non-R&D tasks as well as their technological innovation contributions during implementation phase.

Concerning the fourth hypothesis and even though our results add insights to the empirical literature on diversity (Bolli et al., 2018; Mason et al., 2020), our analysis only provides hints on complementarities of skills in terms of positive diversity effects for firm size and between innovation phases. Our study is thereby limited in so far, as it does not facilitate drawing conclusions on the degree of diversity, which fosters inventions or hinders implementation. Analyses, which link individual and company data, could thereby provide further evidence on the beneficial interplay of different qualifications on firm level concerning innovation processes and cooperation. In this regard, advanced VETs seem to play a crucial role (Freel, 2005; Mason et al., 2020). Examining the explicit means of how they conduct this role leaves room for further research, as well.

An additional research need arises from labor division and its interplay with firm size. It therefore remains to be examined, whether diversity is more important for bigger companies as these employ on the one hand specialists more often (Nooteboom, 1994; Rothwell, 1989) whose combined knowledge enhances capacity for problem-solving while diversity might on the other hand raise communication costs (Bolli et al., 2018).

Against the backdrop of skilled labor shortages and companies' difficulties in finding apprentices for vocational education and training (EFI, 2014; Thomä, 2017), our results facilitate deriving policy implications, particularly for SMEs. Enhancing learning atmosphere concerning company structure and learning climate can be a low-level measure to increase innovativeness and promote a companies' development to a learning organization (Alhusen et al., 2021; Thomä and Zimmermann, 2020). Therefore, an innovation strategy that integrates every employee into innovation processes and that fosters workplaces conducive to learning (Ruth and Deitmer, 2010) designed to facilitate interaction, participation as well as autonomy (Flåten et al., 2015; Lettmayr and Nehls, 2012) is beneficial. Active consideration of employees' ideas by CEOs / management is recommended (Andries and Czarnitzki, 2014). Particularly the German system of innovation, which is characterized by high-quality VET training and intense interactions between employees with different educational background (Cooke and Morgan, 1994; Porter, 1991; Soskice, 1997; Thomä and Zimmermann, 2020), is well advised to strengthen the VET system in general and in particular further training of masters and technicians to sustain innovation capabilities, especially in SMEs (Alhusen and Bennat, 2021; Lewis, 2020; Weidner et al., 2022).

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Appendix A

Table A. 3: Descriptive statistics company size classes

Company size classes	# observations	share
1 employee	2,297	5.29
2 employees	909	2.09
3-4 employees	2,013	4.64
5-9 employees	3,954	13.46
10-19 employees	4,504	10.37
20-49 employees	5,894	13.57
50-99 employees	4,431	10.20
100-249 employees	5,380	12.39
250-499 employees	3,876	8.93
500-999 employees	3,105	7.15
1,000+ employees	7,058	16.25

Table A. 4: descriptive statistics economic sector

Industry	# observations	share
Mining, Electricity, gas and water supply	838	1.89
Food products and tobacco	1,268	2.86
Manufacture of textiles and leather	404	0.91
Manufacture of wood and paper	471	1.06
Printing and service activities related to printing	765	1.73
Manufacture of chemicals	2,140	4.83
Manufacture of basic metals and fabricated metal products and electrical equipment	8,439	19.06
Manufacture of furniture and jewelry	277	0.63
Recycling and disposal	330	0.75
Construction	2,805	6.33
Trade, Repair, Renting	5,128	11.58
Hotels and restaurants	1,154	2.61
Transport, storage and communication	3,047	6.88
Financial intermediation	2,488	5.62
Real estate	532	1.20
Data processing, research and business activities	5,473	12.36
Public administration	25	0.06
Health and social work	8,040	18.16
Other services	660	1.49

Table A. 5: Results regression analysis innovation R&D-inputs

	continuous R&D					**occasional R&D**				
	all	I	II	III	IV	all	I	II	III	IV
No formal qualification	-0.112 *** (0.016)	-0.065 *** (0.020)	-0.093 *** (0.017)	-0.122 *** (0.021)	-0.157 *** (0.020)	-0.110 *** (0.018)	-0.088 *** (0.020)	-0.121 *** (0.024)	-0.125 *** (0.023)	-0.107 *** (0.026)
Others	-0.078 *** (0.014)	-0.105 *** (0.020)	-0.048 *** (0.017)	-0.089 ** (0.039)	-0.073 ** (0.029)	-0.086 *** (0.0187)	-0.103 *** (0.029)	-0.045 (0.031)	-0.199 *** (0.052)	-0.062 *** (0.024)
VET graduates	-0.115 *** (0.010)	-0.100 *** (0.017)	-0.094 *** (0.012)	-0.104 *** (0.011)	-0.144 *** (0.013)	-0.053 *** (0.017)	-0.029 * (0.017)	-0.064 *** (0.017)	-0.071 *** (0.018)	-0.050 ** (0.020)
Advanced VETs	-0.082 *** (0.009)	-0.070 *** (0.021)	-0.061 *** (0.014)	-0.077 *** (0.009)	-0.106 *** (0.008)	-0.001 (0.019)	-0.001 (0.018)	-0.017 (0.013)	-0.020 (0.024)	0.019 (0.028)
Age	0.003 *** (0.001)	0.001 (0.002)	0.003 ** (0.001)	0.007 *** (0.002)	0.001 (0.002)	0.002 * (0.001)	0.002 (0.003)	0.002 (0.003)	-0.001 (0.002)	0.003 (0.002)
Age²	-0.000 *** (0.000)	-0.000 ** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 ** (0.000)
Male/female	-0.069 *** (0.015)	-0.061 *** (0.020)	-0.069 *** (0.017)	-0.067 *** (0.017)	-0.074 *** (0.011)	-0.085 *** (0.017)	-0.082 *** (0.011)	-0.085 *** (0.020)	-0.091 *** (0.017)	-0.084 *** (0.021)
Nationality	-0.017 *** (0.006)	-0.032 *** (0.012)	-0.000 (0.021)	-0.031 ** (0.013)	-0.007 (0.016)	-0.007 (0.017)	-0.072 * (0.039)	-0.062 * (0.032)	0.004 (0.025)	-0.016 (0.018)
Workers	-0.038 ** (0.018)	-0.039 * (0.022)	0.002 (0.016)	-0.034 (0.033)	-0.050 (0.032)	-0.018 ** (0.009)	0.015 (0.021)	0.021 (0.022)	-0.060 ** (0.029)	-0.029
Employees	0.046 *** (0.017)	0.010 (0.025)	0.063 *** (0.015)	0.044 (0.032)	0.062 * (0.032)	0.017 (0.020)	0.033 (0.022)	0.048 * (0.029)	-0.015 (0.034)	0.006
Self-employed	0.062 *** (0.020)	0.055 ** (0.022)	0.050 ** (0.020)	0.094* (0.057)	0.057 (0.076)	0.086 *** (0.025)	0.120 *** (0.023)	0.104 *** (0.031)	-0.012 (0.048)	-0.003
Firm size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic Sector	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
East-West	0.029 *** (0.007)	0.019 ** (0.001)	0.017 ** (0.008)	0.023 ** (0.011)	-0.057 *** (0.009)	0.020 *** (0.006)	0.022 *** (0.008)	0.013 * (0.007)	0.032 *** (0.012)	0.015 (0.013)
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# observations	42,951	9,039	10,288	9,692	13,918	42,951	9,041	10,283	9,691	13,930
R^2	0.146	0.150	0.144	0.154	0.145	0.035	0.043	0.044	0.043	0.025

Marginal effects of probit estimations for innovation inputs by firm size (All: whole sample; I: 1-9 employees; II: 10-49 employees; III: 50-249 employees; IV: 250+ employees); Standard errors in parentheses; Source: BIBB/BAuA Employment Surveys 2018, 2012, 2006

Table A. 6 Results regression analysis innovation non-R&D-inputs

	continuous innovator without R&D					occasional innovator without R&D				
	all	I	II	III	IV	all	I	II	III	IV
No formal qualification	-0.079 *** (0.011)	-0.076 ** (0.033)	-0.087 *** (0.026)	-0.035 (0.027)	-0.103 *** (0.022)	-0.100 *** (0.013)	-0.099 *** (0.035)	-0.133 *** (0.027)	-0.099 *** (0.029)	-0.076 *** (0.026)
Others	-0.007 (0.019)	-0.052 (0.046)	-0.073 (0.047)	-0.005 (0.029)	-0.002 (0.031)	-0.014 (0.020)	-0.010 (0.061)	0.054* (0.031)	-0.067 (0.064)	-0.036 (0.045)
VET graduates	-0.057 *** (0.008)	-0.025 * (0.013)	-0.062 *** (0.019)	-0.032 (0.020)	-0.085 *** (0.013)	-0.017 ** (0.008)	-0.017 (0.017)	-0.016 (0.015)	-0.043 ** (0.019)	-0.002 (0.022)
Advanced VETs	-0.011 (0.011)	-0.026 (0.033)	-0.026 (0.018)	0.021 (0.028)	-0.042 * (0.022)	-0.003 (0.015)	-0.003 (0.033)	0.006 (0.027)	-0.023 (0.028)	0.008 (0.033)
Age	0.002 (0.001)	-0.008 ** (0.004)	0.001 (0.002)	0.009 *** (0.003)	0.004 (0.005)	0.009 *** (0.002)	0.013 *** (0.003)	0.010 *** (0.003)	0.005 (0.004)	0.006 (0.006)
Age^2	-0.000 ** (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000*** (0.000)	-0.000 (0.000)	-0.000 (0.000)
Male/female	-0.025 ** (0.010)	-0.011 (0.013)	-0.027 ** (0.014)	-0.050 *** (0.016)	-0.011 (0.012)	0.017 *** (0.005)	0.005 (0.017)	0.024 *** (0.008)	0.032 *** (0.010)	0.009 (0.013)
Nationality	-0.006 (0.009)	-0.025 (0.034)	0.008 (0.020)	0.001 (0.028)	-0.010 (0.018)	0.037 * (0.020)	0.088 ** (0.043)	-0.022 (0.036)	0.065 ** (0.029)	0.029 (0.036)
Workers	-0.033 ** (0.015)	-0.004 (0.038)	0.043 * (0.024)	-0.088 * (0.047)	-0.065 *** (0.10)	-0.035 ** (0.014)	-0.068 ** (0.035)	-0.059 (0.038)	0.050 (0.044)	-0.057 ** (0.022)
Employees	0.022 (0.014)	0.030 (0.038)	0.078 *** (0.025)	-0.014 (0.048)	-0.000 (0.023)	0.021 (0.013)	-0.013 (0.029)	-0.008 (0.038)	0.112 *** (0.039)	-0.000 (0.022)
Self-employed	0.116 *** (0.016)	0.138 *** (0.039)	0.165 *** (0.022)	0.095 (0.129)	0.024 (0.067)	0.017 (0.017)	-0.021 (0.038)	-0.007 (0.036)	0.091 (0.115)	-0.010 (0.067)
Firm size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic Sector	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
East-West	0.036 *** (0.006)	0.050 *** (0.014)	0.029 ** (0.013)	0.023 * (0.013)	0.041 *** (0.007)	0.028 *** (0.008)	0.012 (0.014)	0.019 (0.017)	0.042 *** (0.016)	0.039 *** (0.008)
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# observations	27,910	5,959	7,146	6,503	8,302	27,921	5,959	7,149	6,506	8,306
R^2	0.026	0.038	0.027	0.027	0.026	0.009	0.011	0.013	0.013	0.007

Marginal effects of probit estimations for innovation inputs by firm size (All: whole sample; I: 1-9 employees; II: 10-49 employees; III: 50-249 employees; IV: 250+ employees); Standard errors in parentheses; Source: BIBB/BAuA Employment Surveys 2018, 2012, 2006

Table A. 7: regression results innovation outputs

	Manufacturing / process technologies					**Products / materials**					**Machines / plants**				
	all	I	II	III	IV	all	I	II	III	IV	all	I	II	III	IV
No formal qualification	0.004 (0.021)	-0.033 * (0.017)	-0.019 (0.033)	-0.017 (0.016)	0.053 (0.034)	0.021 ** (0.010)	-0.016 (0.025)	0.032 (0.020)	0.004 (0.017)	0.036 *** (0.014)	0.058 *** (0.019)	0.015 (0.024)	0.031 (0.032)	0.057 ** (0.023)	0.097 *** (0.030)
Others	0.057 *** (0.016)	0.014 (0.044)	0.037 (0.027)	0.122 * (0.066)	0.048 (0.041)	0.057 ** (0.022)	0.063 ** (0.025)	0.046 (0.033)	0.085 *** (0.025)	0.034 (0.059)	0.044 (0.032)	0.043 (0.052)	0.037 (0.058)	0.036 (0.036)	0.046 (0.047)
VET graduates	0.048 *** (0.010)	-0.001 (0.010)	0.036 ** (0.017)	0.045 *** (0.015)	0.075 *** (0.015)	0.056 *** (0.014)	0.030 *** (0.012)	0.056 *** (0.014)	0.047 ** (0.023)	0.060 *** (0.015)	0.093 *** (0.012)	0.069 *** (0.018)	0.087 *** (0.026)	0.079 *** (0.010)	0.099 *** (0.014)
Advanced VETs	0.066 *** (0.010)	0.035 *** (0.010)	0.044 ** (0.021)	0.063 *** (0.013)	0.095 *** (0.015)	0.064 *** (0.015)	0.043 *** (0.013)	0.057 *** (0.020)	0.056 *** (0.019)	0.075 *** (0.021)	0.108 *** (0.009)	0.105 *** (0.027)	0.097 *** (0.018)	0.080 *** (0.016)	0.121 *** (0.020)
Age	0.003 ** (0.001)	-0.002 (0.003)	0.007 *** (0.002)	0.004 (0.005)	0.003 (0.003)	0.001 (0.001)	-0.003 (0.003)	0.001 (0.003)	0.003 (0.002)	0.004 (0.004)	0.002 (0.001)	-0.002 (0.003)	0.004 (0.004)	0.002 (0.004)	0.003 (0.003)
Age^2	-0.000 *** (0.000)	0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 *** (0.000)	-0.000 (0.000)	-0.000 * (0.000)	-0.000 (0.000)	-0.000 (0.000)
Male/female	-0.061 *** (0.013)	-0.081 *** (0.011)	-0.046 *** (0.017)	-0.053 *** (0.017)	-0.066 *** (0.019)	-0.080 *** (0.015)	-0.091 *** (0.018)	-0.082 *** (0.020)	-0.076 *** (0.016)	-0.079 *** (0.020)	-0.128 *** (0.013)	-0.128 *** (0.020)	-0.121 *** (0.017)	-0.120 *** (0.012)	-0.140 *** (0.018)
Nationality	-0.043 *** (0.012)	-0.003 (0.020)	-0.036 (0.023)	-0.063 ** (0.027)	-0.060 ** (0.028)	-0.039 ** (0.017)	-0.016 (0.018)	-0.048 ** (0.024)	-0.058 *** (0.020)	-0.030 (0.028)	-0.042 *** (0.013)	-0.046 * (0.026)	-0.048 * (0.027)	-0.065 *** (0.020)	-0.014 (0.026)
Workers	-0.024 (0.051)	-0.026 (0.048)	-0.076 (0.072)	-0.086 (0.059)	0.025 (0.038)	0.102 *** (0.027)	0.054 ** (0.022)	0.070 * (0.040)	0.184 *** (0.023)	0.103 ** (0.048)	0.118 *** (0.022)	-0.021 (0.035)	0.051 (0.032)	0.129 *** (0.035)	0.237 *** (0.019)
Employees	-0.074 (0.052)	-0.019 (0.049)	-0.097 (0.077)	-0.130 ** (0.062)	-0.063 * (0.036)	0.049 * (0.027)	0.051 ** (0.022)	0.041 (0.044)	0.121 *** (0.022)	0.019 (0.042)	-0.003 (0.013)	-0.054 (0.037)	-0.031 (0.025)	0.016 (0.031)	0.052 *** (0.013)
Self-employed	-0.028 (0.059)	-0.023 (0.051)	-0.036 (0.090)	0.012 (0.108)	0.002 (0.009)	0.090 ** (0.037)	0.068 *** (0.026)	0.095 * (0.055)	0.125 *** (0.042)	0.200 ** (0.081)	0.160 *** (0.029)	0.055 (0.052)	0.175 *** (0.034)	0.237 *** (0.049)	0.217 *** (0.066)
Firm size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic sector	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
East-West	0.001 (0.007)	0.008 (0.016)	0.013 (0.014)	0.002 (0.013)	-0.021 *** (0.008)	-0.006 (0.006)	-0.008 (0.014)	-0.015 (0.010)	-0.008 (0.008)	0.016 (0.010)	-0.014 (0.009)	-0.010 (0.012)	-0.016 (0.024)	-0.031 ** (0.015)	0.005 (0.015)
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
#observations	42,497	8,975	10,184	9,568	13.,765	42,540	9,010	10,195	9,566	13,762	42.705	9,023	10,232	9,625	13,823
R^2	0.067	0.040	0.024	0.039	0.051	0.059	0.073	0.054	0.058	0.054	0.085	0.062	0.074	0.085	0.104

Marginal effects of probit estimations for innovation outputs by firm size (All: whole sample; I: 1-9 employees; II: 10-49 employees; III: 50-249 employees; IV: 250+ employees); Standard errors in parentheses; Source: BIBB/BAuA Employment Surveys 2018, 2012, 2006

Table A. 8: regression results innovation outputs

	Computer programs					**Services**					**Organizational practices**				
	all	I	II	III	IV	all	I	II	III	IV	all	I	II	III	IV
No formal qualification	-0.100 *** (0.015)	-0.096 *** (0.028)	-0.127 *** (0.016)	-0.118 *** (0.023)	-0.075 *** (0.022)	-0.070 *** (0.012)	-0.106 *** (0.028)	-0.093 *** (0.022)	-0.081 *** (0.021)	-0.027 (0.025)	-0.073 *** (0.011)	-0.041 (0.027)	-0.047 * (0.025)	-0.109 *** (0.014)	-0.094 *** (0.028)
Others	-0.053 *** (0.016)	-0.045 (0.035)	-0.085 * (0.048)	-0.052 (0.073)	-0.038 (0.034)	-0.022 (0.019)	-0.018 (0.030)	-0.120 *** (0.032)	0.002 (0.034)	0.015 (0.046)	-0.015 (0.026)	-0.003 (0.044)	-0.090 * (0.052)	0.063 * (0.037)	-0.019 (0.057)
VET graduates	-0.054 *** (0.013)	-0.091 *** (0.021)	-0.057 *** (0.015)	-0.061 *** (0.021)	-0.032 ** (0.016)	-0.057 *** (0.005)	-0.065 *** (0.013)	-0.065 *** (0.016)	-0.069 *** (0.011)	-0.047 *** (0.006)	-0.033 *** (0.007)	-0.032 ** (0.013)	-0.013 (0.018)	-0.052 *** (0.013)	-0.030 *** (0.010)
Advanced VETs	-0.021 (0.013)	-0.068 ** (0.027)	0.018 (0.030)	-0.047 * (0.026)	-0.005 (0.008)	-0.019 (0.013)	-0.021 (0.016)	-0.042 * (0.023)	-0.029 (0.021)	-0.003 (0.012)	-0.003 (0.008)	0.008 (0.016)	0.023 (0.020)	-0.011 (0.020)	-0.000 (0.015)
Age	0.013 *** (0.001)	0.005 ** (0.002)	0.015 *** (0.004)	0.015 *** (0.004)	0.014 *** (0.003)	0.013 *** (0.002)	0.007 *** (0.002)	0.015 *** (0.003)	0.010 *** (0.003)	0.015 *** (0.003)	0.014 *** (0.002)	0.005 * (0.003)	0.011 *** (0.002)	0.023 *** (0.004)	0.015 *** (0.003)
Age²	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 ** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)	-0.000 *** (0.000)
Male/female	-0.043 *** (0.017)	-0.072 *** (0.027)	-0.038 ** (0.018)	-0.037 ** (0.018)	-0.028 * (0.015)	-0.060 *** (0.013)	-0.073 *** (0.013)	-0.078 *** (0.019)	-0.060 *** (0.013)	-0.032 *** (0.012)	-0.027 *** (0.006)	-0.020 ** (0.009)	-0.032 *** (0.008)	-0.039 ** (0.013)	-0.016 ** (0.008)
Nationality	0.001 (0.017)	0.041 * (0.023)	-0.027 (0.023)	-0.026 (0.032)	-0.004 (0.013)	-0.017 (0.013)	0.007 (0.019)	-0.001 (0.023)	-0.037 (0.023)	-0.038 (0.023)	-0.002 (0.015)	0.007 (0.025)	-0.010 (0.025)	-0.047 (0.031)	0.037 * (0.021)
Workers	-0.105 *** (0.034)	-0.159 *** (0.031)	-0.070 (0.051)	-0.163 *** (0.031)	-0.088 * (0.048)	-0.062 ** (0.024)	-0.059 ** (0.026)	-0.047 (0.034)	-0.057 * (0.033)	-0.081 * (0.042)	-0.089 ** (0.037)	-0.051 (0.034)	-0.112 * (0.062)	-0.115 ** (0.048)	-0.089 *** (0.032)
Employees	0.011 (0.032)	-0.023 (0.032)	0.059 (0.052)	-0.024 (0.027)	0.014 (0.047)	-0.002 (0.027)	0.018 (0.022)	0.006 (0.029)	0.009 (0.033)	-0.017 (0.045)	-0.040 (0.039)	0.014 (0.029)	-0.074 (0.069)	-0.048 (0.050)	-0.043 * (0.025)
Self-employed	0.107 *** (0.035)	0.046 (0.032)	0.169 *** (0.052)	0.132 *** (0.042)	-0.027 (0.087)	0.100 *** (0.031)	0.118 *** (0.032)	0.087 *** (0.031)	0.046 (0.059)	0.059 (0.078)	-0.031 (0.040)	0.037 (0.026)	-0.070 (0.074)	-0.077 (0.059)	-0.180 ** (0.078)
Firm size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic sector	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
East-West	0.026 *** (0.004)	0.016 (0.011)	0.018 * (0.010)	0.021 ** (0.010)	0.045 *** (0.009)	0.016 *** (0.005)	-0.014 (0.011)	0.016 (0.013)	0.036 *** (0.007)	0.031 *** (0.011)	0.049 *** (0.007)	0.028 *** (0.009)	0.029 ** (0.013)	0.073 *** (0.010)	0.055 *** (0.014)
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# observations	41,847	8,910	9,918	9,534	13,663	42,489	8,991	10,188	9,562	13,741	42,784	9,011	10,238	9,647	13,888
R^2	0.069	0.084	0.052	0.039	0.028	0.034	0.051	0.034	0.031	0.030	0.065	0.033	0.024	0.024	0.022

Marginal effects of probit estimations for innovation outputs by firm size (All: whole sample; I: 1-9 employees; II: 10-49 employees; III: 50-249 employees; IV: 250+ employees); Standard errors in parentheses; Source: BIBB/BAuA Employment Surveys 2018, 2012, 2006

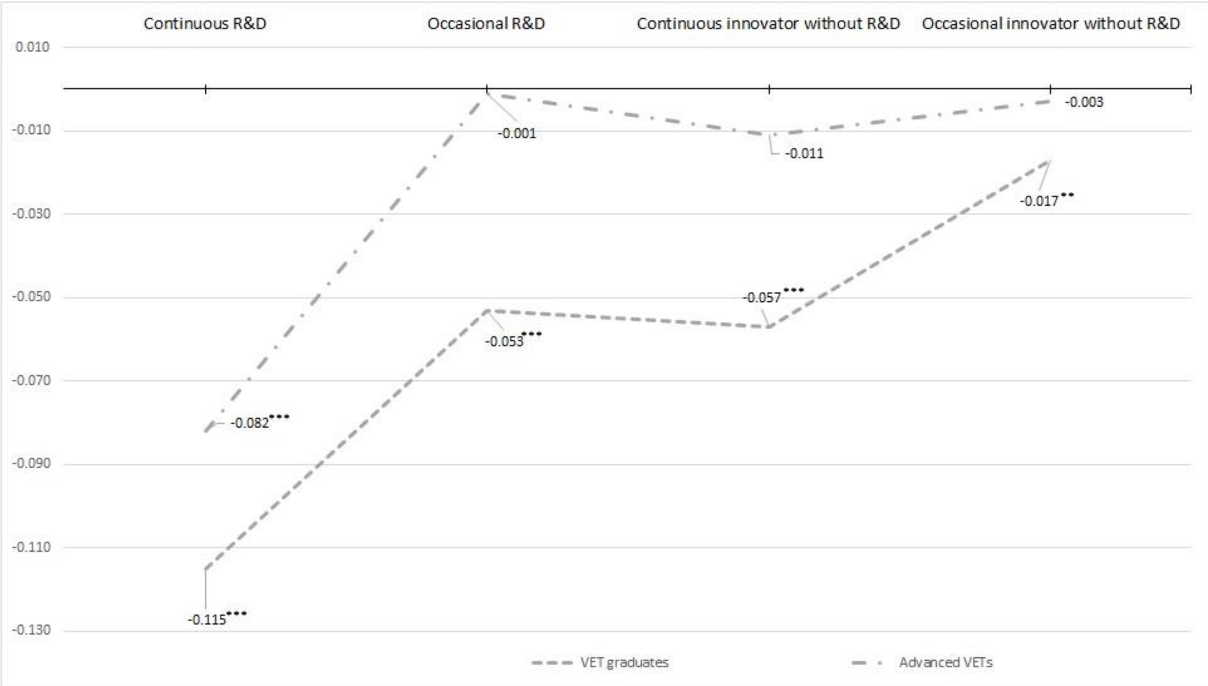

Figure A1: Marginal effects for innovation inputs by VET qualification with reference to university graduates

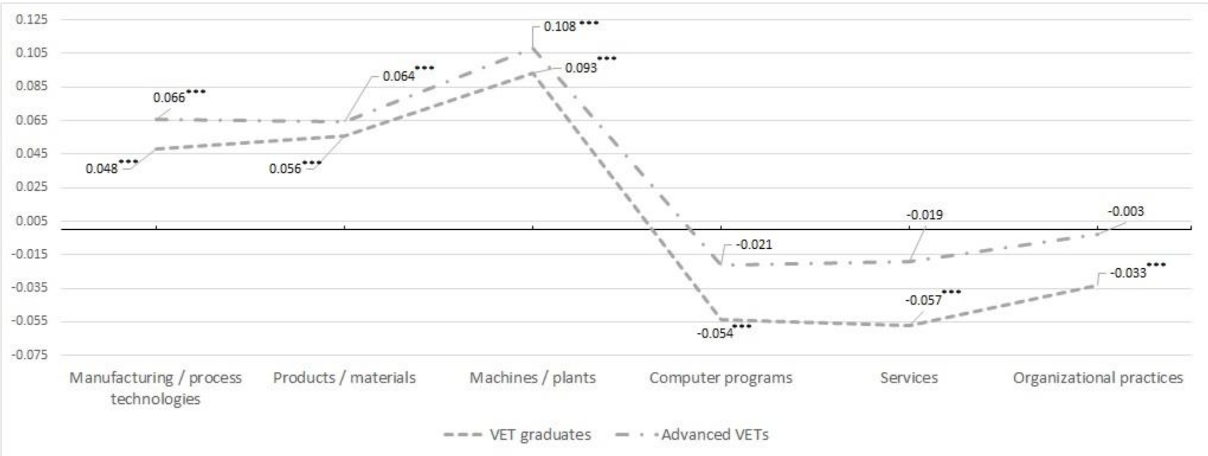

Figure A2: Marginal effects for innovation outputs by VET qualification with reference to university graduates

Kalkulierte Eigenanteile

Liste der Papiere, deren Autoren, der Status der Publikation und der kalkulierte Eigenanteil:

Titel	Autor:innen	Status	Ziel-Journal	Eigenanteil Eike Matthies
Does initial vocational training foster innovativeness at the company level? Evidence from German establishment data	Eike Matthies, Katarzyna Haverkamp, Jörg Thomä, Kilian Bizer	Veröffentlicht als ifh working paper (überarbeitete Version)	Journal of Knowledge Economy (revise and resubmit)	50
A hidden source of innovation? Revisiting the impact of initial vocational training on technological innovation	Eike Matthies, Jörg Thomä, Kilian Bizer	Veröffentlich in Journal of Vocational Education and Training (doi: 10.1080/13636820.2023.2201602)	Journal of Vocational Education and Training	55
Duale Ausbildung, betriebliche Lernumgebung und Innovationsfähigkeit von Kleinstunternehmen	Eike Matthies, Jörg Thomä, Jörg Lahner	Veröffentlicht in WSI-Mitteilungen (doi: 10.5771 /0342-300X-2023-4-271)	WSI-Mitteilungen	55
Skills for innovation: individual contributions of the vocationally trained workforce	Eike Matthies, Jörg Thomä	Veröffentlicht als ifh working paper geplant	European Planning Studies	55

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