ifh Working Paper No. 47/2025*

Task allocation and innovation: revisiting the role of vocational education and training in manufacturing firms

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Abstract

This paper examines the individual innovation contributions of the vocational education and training (VET) workforce compared to university graduates such as scientists and engineers. For this purpose, individual-level data from the German manufacturing sector are used, distinguishing between persons with initial and higher VET qualifications. The empirical results on various input and output indicators show that the VET workforce is not only involved in the implementation phase of the firm's innovation process, but also makes a relevant contribution to the invention phase. Moreover, the empirical evidence suggests a certain division of labour between VET employees and university graduates, which is more likely to occur in large firms due to their higher degree of functional specialisation and task differentiation among employees. There is also some evidence to support the hypothesis that employees with higher VET qualifications, such as master craftsmen or technicians, act as 'boundary spanners' throughout the innovation process, ensuring that effective interactive learning can take place between VET employees from the shop floor and academically trained R&D personnel, so that the benefits of educational workforce diversity can be realised. The paper concludes with implications for policy, management and further research.

JEL: I2; J24; M53; O15; O30; O31

Keywords: Innovation; Vocational education and training (VET); Skills; Diversity; Firm size

* An earlier version of this paper was published as part of Eike Matthies' doctoral thesis, see http://dx.doi.org/10.53846/goediss-10055 (accessed 16 January 2025).

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1. Introduction

The role of different qualifications and skills in the innovativeness of firms is increasingly the focus of research (e.g. Høyrup 2010; Birkinshaw and Duke 2013; Andries and Czarnitzki 2014; Bolli et al. 2018; Bäckström and Bengtsson 2019; Mason et al. 2020). In this context, some studies go beyond the usual focus on academically trained personnel, such as scientists and engineers (hereafter referred to as '*university graduates*'), and highlight the innovation contributions of individuals with vocational education and training (VET) qualifications, including the business and regional contexts in which their innovation participation is embedded (Toner 2010; Brunet Icart and Rodríguez-Soler 2017; Albizu et al. 2017; Bolli et al. 2018; Mason et al. 2020; Alhusen and Bennat 2021; Lewis 2023).

In this field, two main strands of empirical literature have developed. The first relates to the role of the VET workforce for the innovation capacity of small and medium-sized enterprises (SMEs) from manufacturing industries. Based on a sample of Spanish SMEs, the results of Albizu et al. (2017) show that individuals with VET qualifications contribute significantly to firm-level innovation, and that this participation increases with a higher innovation capacity of the company and the presence of an organisational environment within the firm that is conducive to learning and employee participation. These findings are confirmed by the Brunet Icart and Rodríguez-Soler (2017) study, and complemented by their finding that individuals with vocational qualifications contribute in particular to process innovation and incremental product innovation in manufacturing SMEs. In addition, their findings suggest that the interaction between companies and nearby VET institutions is crucial for the involvement of the VET workforce in business 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; Hädrich et al. 2024; Friedrich and Kagel 2025).

The second strand of empirical studies relates to the interplay between different qualifications and skills in a firm's innovation process, pointing to positive effects of educational workforce diversity on innovation (Østergaard et al. 2011; McGuirk and Jordan 2012). Using the example of Swiss firms, Bolli et al. (2018) investigate how the educational diversity of the firm's workforce affects its innovation performance, also taking into account the role of individuals with VET qualifications. Their results suggest that the interaction of different qualification groups within the firm is conducive to innovation especially in the case of research and development (R&D) activities and in the development of highly innovative new products – i.e., on the input side of innovation – while such interaction also takes place, but seems to be less crucial in the practical implementation of innovations (i.e., on the output side of innovation). This implies that the role of VET qualifications in firm-level innovation should also be examined in comparison with other qualification groups (in particular university graduates as typical R&D personnel), while also distinguishing between the invention and implementation phases of business innovation.

Mason et al. (2020) take these considerations further by using aggregate country data for the US and Western Europe to show that absorptive capacities and patenting of firms depend not only on university graduates but also strongly on employees with *higher VET* qualifications such as master craftsmen or technicians (hereafter referred to as '*HVETs*'), suggesting an innovation-promoting interplay between these two highly-qualified groups in particular during the invention phase of a firm’s innovation process. On the other hand, skilled personnel who have completed *initial VET* through a dual apprenticeship as their highest professional qualification (hereafter referred to as '*IVETs*') only seem to play a greater role in later stages of the innovation process, where the focus is on application-oriented implementation. This suggests that the distinction between innovation phases is indeed important when assessing the individual innovation contributions of the VET workforce, including the corresponding interaction with university graduates in the firm. At the same time, it becomes clear that in this context a distinction should be made between the innovation participation of IVETs and that of HVETs.

Despite this evidence, a number of questions remain about the participation of the VET workforce in firm-level innovation. It is still relatively unclear to which specific elements of the business innovation process relevant contributions are made. For example, while individuals with VET qualifications have been found to play an important role in the case of process innovations, there is a lack of information on the specific types of process innovation involved (e.g., whether it is the introduction of new production 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 might suggest – has not yet been clarified. In fact, especially with regard to smaller firms, the literature repeatedly assumes a significant involvement of people with VET qualifications in innovation activities, while with regard to the in-house R&D capabilities of larger firms, the role of university graduates – especially those from science and engineering – is usually emphasised (e.g., Acs and Audretsch 1988; Van Dijk et al. 1997; Leiponen 2005; Jensen et al. 2007; Thomä 2017; Alhusen and Bennat 2021).

In addition, the VET workforce itself has so far been little differentiated in terms of individual contributions to innovation, so that the distinction between IVETs and HVETs in terms of their participation in business innovation is not yet entirely clear. As data on university graduates are a standard indicator of the absorptive capacity of a company (OECD/Eurostat 2018), it is reasonable to assume that the individual innovation contributions of the VET workforce are mainly in the implementation phase rather than in the invention phase of the innovation processes. However, as mentioned above, the study by Mason et al. (2020) suggests that HVETs already play an important role in the invention phase, and that therefore a variety of scientific and non-scientific tertiary qualifications come into play on the input side of the innovation process, promoting creativity and the finding of new solutions and ideas. Indeed, a number of studies argues that HVETs are a relevant driver of innovation at the firm-level (Freel 2005; Hirsch-Kreinsen 2008; Hirsch-Kreinsen 2015; Thomä and Zimmermann 2020; Weidner et al. 2022). Thus, there is reason to assume that not only university graduates, but also HVETs, shape the absorptive capacity of innovating firms 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 IVETs during the application-oriented implementation of innovations, guide technological improvement processes at the shop floor, and act as mediators and translators between the R&D department and production (Finegold and Wagner 1998; Mason 2000; Mason et al. 2020; Thomä and Zimmermann 2020; Weidner et al. 2022). Accordingly, it can be expected that HVETs make a number of individual contributions to firm-level innovation that differ from those of IVETs – an assumption that requires further investigation.

This leads to another aspect that is still underexplored in the literature: the innovation-promoting interplay between the VET workforce and university graduates. From the analyses of Bolli et al. (2018) and Mason et al. (2020), we can expect that there are strong complementarities between the innovation contributions of university graduates and the VET workforce, at least in the invention phase (although, as mentioned above, it is still not very clear exactly what the individual innovation contributions look like). This suggests that a company's personnel is made up of different qualification groups, each with specific knowledge assets and skills, and that the interaction of which has an overall positive effect on a firm's innovation performance. Therefore, for a better understanding of the innovation participation of the VET workforce – and thus extending the studies on manufacturing SMEs by Albizu et al. (2017) and Brunet Icart and Rodríguez-Soler (2017) – it would be useful to compare the innovation contributions of IVETs and HVETs with those of university graduates, in order to possibly obtain evidence of a fruitful diversity (or even interplay) of academic and VET qualifications in the innovation process. In this context, it should not only be distinguished between different innovation phases, as Bolli et al. (2018) and Mason et al. (2020) argue, but it should also be investigated how the innovation-promoting influence of educational workforce diversity depends on the size of the firm. This is because one of the innovation advantages of large firms is that they have many highly qualified specialists in various innovation-related fields (Nooteboom 1994; Rothwell 1989), which should create the potential for an innovation-promoting division of labour or task allocation between different qualification groups and departments when a firm increases in size.

This paper aims to address these issues by analysing data from a repeated survey of employed persons in Germany (the BIBB/BAuA Employment Surveys for the years 2006, 2012 and 2018). The advantage over previous studies is that these data relate to individuals and their workplaces, i.e., they are individual-level data rather than firm-level data. The respondents therefore indicate where they are personally involved in the innovation activities of their firm, which allows a deeper understanding of the individual innovation contributions of the VET workforce. Moreover, the data allow us to distinguish between IVETs and HVETs, 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 of a business innovation processes. Since the BIBB/BAuA employment surveys are a representative data set, it is also possible to examine the possible influence of firm size in a differentiated manner, as we also have information on the size of the firm of an employed person. All in all, this dataset allows for a more nuanced examination of the role and contributions of the VET workforce in the context of firm-level innovation 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 potential advantages for a company in terms of innovation, which should be particularly prevalent in the context of manufacturing industries. Toner (2010) was the first to describe this in detail, focusing on the role of skilled production workers and, in particular, craftsmen and technicians. For the Australian case, he argues 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 skills, and participating in incremental innovation. Following on from this, Toner (2010) sees a key role for the VET system in terms of technology diffusion throughout the economy.

Building on Toner's (2010) seminal contribution, studies have extended these theoretical considerations and focus on the specific skills of the VET workforce, emphasising 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 (e.g. Ruth and Deitmer 2010; EFI 2014). This 'mutual understanding' can promote intra-firm knowledge exchange (i.e. learning by interaction) between the R&D department and other parts of the company, such as production and marketing (Flåten et al. 2015; Backes-Gellner and Lehnert 2023). This is particularly likely to be the case in countries with established dual VET systems, such as Germany, where, on the one hand, apprentices learn "on the job" during their apprenticeship and thus start to acquire experiential knowledge about internal business processes, which they later deepen as skilled production workers. On the other hand, this practical knowledge is complemented by the formal knowledge acquired in vocational schools, resulting in a mix of practical and theoretical-abstract knowledge that favours innovation-promoting interaction with academically trained personnel – i.e. the group of university graduates (Ruth and Deitmer 2010; Thomä 2017).

Due to their skills, members of the VET workforce are able to contribute to creative problem solving and to cope 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; Thomä 2017). Their experience-based knowledge is particularly important at the interface between incremental product improvement, production technology, plant, machinery and process planning (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. In this way, its members actively contribute to process and product innovation, as has already been shown empirically in studies of manufacturing SMEs from Spain (Albizu et al. 2017; Brunet Icart and Rodríguez-Soler 2017). The emergence of such innovation contributions by the VET workforce is facilitated by a learning-friendly design of workplaces, which are geared towards interaction, opportunities for learning through 'trial and error' and strong individual responsibility, thus offering a high degree of scope for creativity to unfold (Flåten et al. 2015; Matthies et al. 2023).

In this context, we argue that it is useful to distinguish the roles and contributions of different subgroups of the VET workforce with respect to the phase of the innovation process. In the case of Germany, individuals with higher VET qualifications such as master craftsmen or technicians (i.e. HVETs) are a relevant source of a firm's absorptive capacity (Hirsch-Kreinsen 2008; Hirsch-Kreinsen, 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 the firm’s innovation process in interaction with university graduates such as scientists and engineers (Bolli et al. 2018; Mason et al. 2020). Moreover, this innovation-promoting interplay between HVETs and university graduates should also be linked to the fact that HVETs in particular can play a mediating 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, HVETs possess both a high level of scientific-theoretical knowledge related to new innovative ideas and the in-depth practical experience needed to implement them (e.g. with regard to production processes, prototyping or the necessary equipment and machinery), which enables them to mediate and translate between different qualification groups within the company, especially in the case of manufacturing industries. For example, in their role as first-line managers or as process developers, they can orchestrate the exchange of knowledge between scientists in the R&D department and skilled production workers on the shop floor, thus reducing the coordination and communication costs that arise from such interaction due to conflict, mistrust or misunderstanding (Finegold and Wagner 1998; Mason 2000; Kirner and Som 2015; Bolli et al. 2018; Weidner et al. 2022). For this reason, we expect HVETs to be important "boundary spanners" (Weidner et al. 2022) between the different levels of education involved in the invention and implementation phases of a firm’s innovation process, helping to unlock the innovation-enhancing benefits of educational workforce diversity (Østergaard et al. 2011). This leads us to formulate two hypotheses:

H1: Both university graduates and HVETs contribute significantly to the invention phase of firm-level innovation.

H2: HVETs are boundary spanners between different educational levels and are therefore an essential prerequisite for realising the benefits of educational workforce diversity in innovating firms.

Compared to HVETs, we expect IVETs to be more involved in the implementation phase of a firm's innovation process (Mason et al. 2020). IVETs should be strongly involved in the implementation of technological and organisational innovation outputs because they work directly with the innovation-relevant machines, equipment or materials (Toner 2010). On the shop floor, however, they often have to perform routine tasks as skilled production workers (Pfeiffer 2018), which is why we expect fewer creative innovation contributions overall compared to the group of HVETs. Nevertheless, the feedback from IVETs to upstream business units such as the R&D department, derived from the application experience they have gained through learning by doing and using experience, should provide important impetus for incremental improvements and modifications (EFI 2014; Thomä 2017; Mason et al. 2020). Our third hypothesis is therefore:

H3: IVETs contribute mainly to the implementation phase of the firm's innovation process.

Moreover, empirical results on educational workforce diversity (Bolli et al. 2018; Mason et al. 2020) lead us to expect that the innovation contributions of the VET workforce can complement those of university graduates in different ways. In this context, the influence of the organisational framework, as expressed by the size of an innovating firm, is still unclear. As mentioned above, the innovation participation of the VET workforce has so far been empirically demonstrated using the example of manufacturing SMEs (Albizu et al. 2017; Brunet Icart and Rodríguez-Soler 2017). However, the benefits of educational diversity may be more pronounced in the workforce of large manufacturing 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 known in economic research that increasing firm size is associated with an increasing division of labour among the individuals working there (Groenewegen 2016). Against this background, it is not surprising that innovation activities at the firm level are also characterised by a certain allocation of tasks (Chakrabarti and Hauschildt 1989) – and that this is likely to be driven by firm size. Indeed, one of the key innovation advantages of large firms is precisely that they have many highly and differently qualified specialists in different innovation-related fields (Nooteboom 1994; Rothwell 1989; Jensen et al. 2007), which increases the likelihood of an innovation-enhancing diversity between different qualification groups and departments within the firm. Smaller firms, on the other hand, have a higher degree of innovation activities carried out by one and the same person (e.g. the business owner, see Runst and Thomä 2022) due to a lower degree of division into departments and functional areas. The innovation-promoting diversity of different educational levels should therefore be more pronounced in larger firms. We therefore formulate a fourth hypothesis:

H4: The division of labour between the VET workforce and university graduates in the business innovation process is less pronounced in SMEs, so that the benefits of educational workforce diversity increase with firm size.

3. Data and Method

In order to examine the individual innovation contributions of the VET workforce, we use data from the 2006, 2012 and 2018 BIBB/BAuA Employment Surveys as an independently pooled cross-sectional data set.[1] These provides representative employment data from Germany that are collected jointly by the Federal Institute for Vocational Education and Training (BIBB) and the Federal Institute for Occupational Safety and Health (BAuA). The BIBB/BAuA Employment Surveys are conducted every six years and are based on random samples of the entire German labour force, defined as persons who work at least 10 hours per week and are older than 15 years. The surveys contain detailed information on the qualifications and working conditions of the respondents, providing a comprehensive and representative picture of aspects such as educational level, qualifications, tasks, knowledge requirements, working conditions, individual responsibilities or career changes. We restrict our sample to the working population aged 15-65 and focus on employed persons in manufacturing industries. Our sample contains nearly 13,500 observations. 55.1% of the respondents are IVETs, 12.0% HVETs and 22.7% are university graduates. Of the respondents, 52.9% work in SMEs and 47.1% in large firms. (Table 1).

To capture the invention phase, we use two different indicators of the input side of innovation. The first indicates how often a respondent researches, develops or designs something as part of his or her job, which we summarise under the term *R&D*[2]: 17.2% of respondents frequently carry out R&D themselves and 25.2% do so occasionally (Table 1). In addition, to cover participation in non-R&D-based innovation activities during the invention

[1] Data availability statement: This paper uses data from the BIBB/BAuA Employment Survey of the Working Population on Qualification and Working Conditions in Germany for the years 2006 (Hall and Tiemann 2021), 2012 (Hall et al. 2020a) and 2018 (Hall et al. 2020b). These surveys were conducted by the Federal Institute for Vocational Education and Training (BIBB), and the Federal Institute for Occupational Safety and Health (BAuA). The data access was provided via a Scientific-Use-File of the Data Research Centre at the Federal Institute for Vocational Training and Education (BIBB-FDZ).

[2] It should therefore be noted that, in line with Godin (2006), we also include design activities under the R&D label as an important interface between scientific and non-scientific activities.

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 – suggesting a relatively high level of creativity. This is true for 11.5% on a frequent basis ("Continuous innovator without R&D") and for 27.0% of respondents on an occasional basis ("Occasional innovator without R&D").

On the output side of innovation, in order to cover the implementation phase, we can distinguish between participation in product innovation activities and contributions to process innovation (see Table 1). In this respect, respondents were asked whether any innovative changes had taken place in their immediate working environment in the last two years. For product innovation, we distinguish between the use of new or significantly changed products or materials (39.4%) and the provision of new or significantly changed services (25.9%). In the case of process innovation activities, we have information on the introduction of new manufacturing or process technologies (51.7%), of new machines or equipment (53.8%) and of new organizational practices (48.1%).

Table 1. Descriptive statistics on core variables

	Description	**Mean**	**S.D.**
Dependent variables on innovation inputs			
Continuous R&D	1 if respondent is often involved in development/research/design at work	0.172	0.377
Occasional R&D	1 if respondent is sometimes involved in development/research/design at work	0.252	0.434
Continuous innovator without R&D	1 if respondent often improves existing processes or tries out something new at work (without carrying out R&D)	0.115	0.319
Occasional innovator without R&D	1 if respondent sometimes improves existing processes or tries out something new at work (without carrying out R&D)	0.270	0.444
Dependent variables on innovation outputs			
Products / materials	1 if new or significantly changed products or materials have been used in the respondent's immediate working environment in the last two years	0.394	0.489
Services	1 if new or significantly changed services have been provided in the respondent's immediate working environment in the last two years	0.259	0.438
Production / process technologies	1 if new production or process technologies have been introduced in the respondent's immediate working environment in the last two years	0.517	0.500
Machines / equipment	1 new machinery and equipment has been introduced into the respondent's immediate working environment in the last two years	0.538	0.499
Organizational practices	1 if the respondent's immediate working environment has undergone significant restructuring or reorganisation in the last two years	0.481	0.500
Explanatory variables			
IVETs	1 if completion of initial vocational education and training through a dual apprenticeship is the highest professional qualification	0.551	0.497
HVETs	1 if the completion of a higher vocational education and training programme (master craftsman, technician etc.) is the highest professional qualification	0.120	0.324
University graduates	1 if a university degree is the highest professional qualification	0.227	0.419
Sample structure			
SMEs	1 if the respondent's company has a workforce of between 1 and 249 persons	0.529	0.499
Large firms	1 if the respondent's company has a workforce of 250 persons or more	0.471	0.499

To conduct the empirical analysis, we estimate logistic regression models for the dependent variables of interest. The model equation is as follows:

$$Inno_{it} = \beta_0 + \beta_1\, IVETs_{it} + \beta_2\, HVETs_{it} + \theta X_{it} + \delta D_t + \epsilon_{i,t}$$

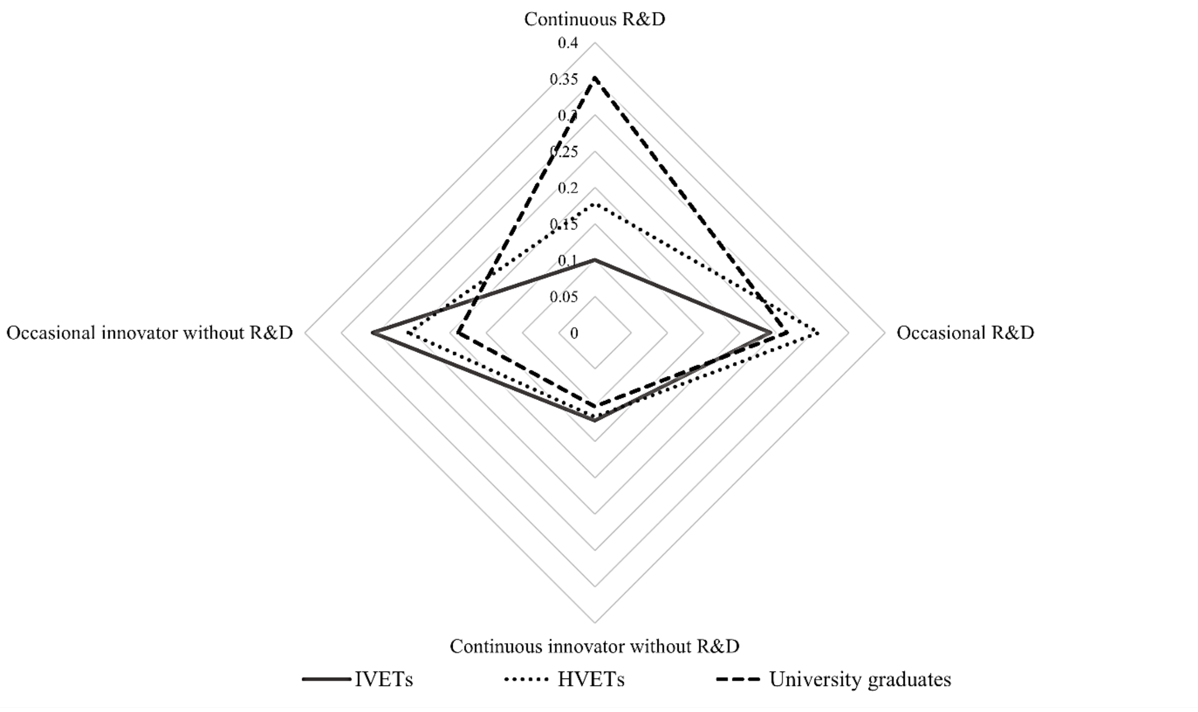
Inno refers to the various indicators of innovation input and output. *IVETs* and *HVETs* are the explanatory variables on the VET workforce, with university graduates being the reference case. As controls (*X*) we use variables on other qualification groups, firm size, manufacturing industry, age of the respondent, gender, nationality, and location in East Germany. Dummies for the survey years 2012 and 2018 are also included, with 2006 as the reference case and a subscript that reflects the cross-sectional dimension of our data (*D*).

The detailed regression results can be found in the appendix. In the following section, the predicted margins for IVETs, HVETs and university graduates being involved in the invention and implementation phases of business innovation are visualized in spider charts. In order to assess the statistical significance of these differences, the marginal effects for IVETs and HVETs are then reported in relation to university graduates. Finally, this differentiation by marginal effects is carried out again in separate regression models according to samples of SMEs and large firms in order to examine the possible division of tasks in innovation contributions between the VET workforce and university graduates in relation to firm size.

4. Results

4.1. Input side

Figure 1. Predicted margins for individual innovation contributions during the invention phase, differentiated by professional qualification



Notes: Based on logistic regression results for innovation inputs (full sample; see Table A2 in the appendix).

Figure 1 shows the predicted margins for innovation contributions at the invention stage (input side). As expected, university graduates are most likely to be involved in continuous R&D (35.1%). IVETs and HVETs have significantly lower probabilities in this respect, but the latter group falls behind to a lesser extent, suggesting a relatively higher involvement of HVETs in continuous R&D activities (see also Table 2). The picture is different for the other input indicators: in principle, the differences between university graduates and those with a VET qualification are now much less pronounced, suggesting a correspondingly higher level of innovation participation of IVETs and HVETs in these parts of the invention phase. Moreover, the VET workforce is now often even more likely to contribute to the input side of innovation than university graduates: For example, in the case of occasional

R&D and occasional non-R&D innovation, the probability is 4.1 % and 7.8 % higher for HVETs. On the other hand, IVETs are less likely to be involved in occasional R&D compared to university graduates. However, they are more likely to participate in continuous and occasional innovation activities without R&D than the reference group of university graduates (see Figure 1 and Table 2). In summary, we find evidence for the validity of H1, as both University graduates and HVETs contribute to the invention phase by participating in in-house R&D. HVETs are therefore an important player in the invention phase of firm-level innovation alongside university graduates. Interestingly, however, IVETs also appear to be active on the input side of innovation, especially in the context of non-R&D innovation activities, which argues against the assumption made in Hypothesis 3 that their involvement in business innovation is mainly found in the implementation phase.

Table 2. Marginal effects in comparison to university graduates for innovation inputs

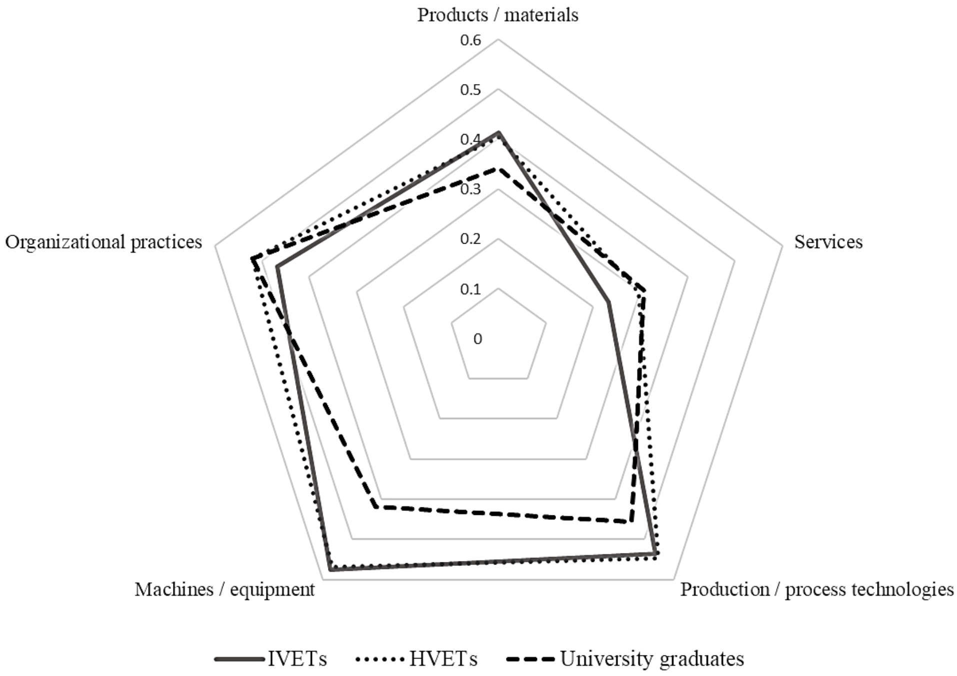
	Continuous R&D		Occasional R&D		Continuous innovator without R&D		Occasional innovator without R&D	
(1) Full sample								
IVETs	-0.205	***	-0.023	**	0.020	***	0.125	***
	(0.006)		(0.010)		(0.007)		(0.010)	
HVETs	-0.119	***	0.041	***	0.015		0.078	***
	(0.009)		(0.013)		(0.010)		(0.014)	
Baseline prob.	0.172		0.252		0.115		0.270	
(2) SMEs								
IVETs	-0.169	***	-0.035	**	0.036	***	0.081	***
	(0.009)		(0.014)		(0.011)		(0.015)	
HVETs	-0.095	***	0.009		0.042	***	0.039	*
	(0.012)		(0.018)		(0.014)		(0.021)	
Baseline prob.	0.152		0.253		0.104		0.269	
(3) Large firms								
IVETs	-0.240	***	-0.015		0.011		0.158	***
	(0.010)		(0.013)		(0.010)		(0.014)	
HVETs	-0.141	***	0.068	***	-0.008		0.105	***
	(0.014)		(0.017)		(0.015)		(0.020)	
Baseline prob.	0.194		0.250		0.127		0.262	
(4) SMEs vs. Large firms								
IVETs	chi2 = 6.90	***	chi2 = 1.06	n.s.	chi2 = 3.62	*	chi2 = 15.18	***
HVETs	chi2 = 2.10	n.s.	chi2 = 5.53	**	chi2 = 6.66	***	chi2 = 5.62	**

Notes: * p < 0.10, **p < 0.05, ***p < 0.01, n.s. > 0.10; Robust standard errors in parentheses; SMEs: the respondent's company has a workforce of between 1 and 249 persons; Large firms: the respondent's company has a workforce of 250 persons or more
(1) Full sample: Based on the results of the logistic regression in Table A2.
(2) SMEs: Based on the results of the logistic regression in Table A3.
(3) Large firms: Based on the results of the logistic regression in Table A4.
(4) Comparison of regression coefficients between the two firm size samples.

The lower participation of IVETs in continuous R&D is particularly pronounced in large firms – the corresponding coefficient difference between the two firm size samples is statistically significant (see Table 2). In large firms in particular, IVETs are therefore mainly active in the area of occasional innovation activity without R&D during the invention phase. On the other hand, occasional R&D and occasional non-R&D innovation activities are more likely to be carried out by HVETs working in large firm environments. Taken together, this suggests a certain division of labor in the invention phase of the innovation process in large firms with more than 250 employees, which is in line with hypothesis H4. As expected, this task allocation is less prevalent in SMEs. In addition, it is noticeable that the VET workforce in SMEs is more involved in the area of continuous innovation activity without R&D than in large firms, which may speak in favor of the importance of VET qualifications for the innovative capacity of smaller firms discussed above.

4.2. Output side

Figure 2. Predicted margins for individual innovation contributions during the implementation phase, differentiated by professional qualification



Notes: Based on logistic regression results for innovation inputs (full sample; see Table A5 in the appendix).

The results on the output side of the business innovation process – see Figure 2 and Table 3 – provide the counterpart to the picture of the invention phase discussed above. In the case of IVETs, it can be seen that they are significantly more involved in the implementation phase than university graduates. In line with hypothesis H3, they are significantly more often involved in the introduction of new production or process technologies (+8.1%), new machinery or equipment (+15.2%) and the application of new products and materials (+7.2%). On the other hand, they are less likely to be involved in service innovations (-7.2%) and new organizational practices (-5.2%), presumably because their activities at the shop floor mean that they have less direct contact with customers and are less involved in organizational management tasks. These findings complement the above results on the input side of the innovation process and argue for a certain division of tasks between IVETs and university graduates in the innovation process.

At the same time, there is some evidence that HVETs can indeed be an important interface for the innovation-promoting interplay between IVETs and university graduates in manufacturing firms. Their dotted line in the spider diagram in Figure 2 completely encloses the areas of activity of university graduates and IVETs in the implementation phase. Table 3 shows that HVETs are more likely than university graduates to be involved in the introduction of new products and materials, new production and process technologies and new machinery or equipment. At the same time, they do not lag behind university graduates when it comes to service innovation and new organizational practices. This suggests that, on the output side of innovation, HVETs are involved both in the practical implementation of new ideas and inventive steps and in guiding IVETs in this process, and that, in particular because of their similar involvement in new organizational practices as university graduates, they also take on more complex management and coordination tasks (see Figure 2 and Table 3). Taking into account the relatively strong involvement of HVETs in the invention phase (see section 4.1), there is therefore much to suggest that they can mediate and translate between the invention and implementation phases, and thus between university and IVETs, making them an important boundary spanner in the firm's innovation process. This supports hypothesis H2.

Table 3. Marginal effects in comparison to university graduates for innovation outputs

	Products / materials	Services	Production / process technologies	Machines / equipment	Organizational practices
(1) Full sample					
IVETs	0.072 ***	-0.072 ***	0.081 ***	0.152 ***	-0.052 ***
	(0.011)	(0.009)	(0.011)	(0.011)	(0.011)
HVETs	0.062 ***	-0.010	0.090 ***	0.146 ***	-0.000
	(0.015)	(0.013)	(0.015)	(0.015)	(0.015)
Baseline prob.	0.394	0.259	0.517	0.538	0.481
(2) SMEs					
IVETs	0.037 **	-0.082 **	0.005	0.099 ***	-0.059 ***
	(0.016)	(0.013)	(0.011)	(0.016)	(0.016)
HVETs	0.042 **	-0.018	0.027	0.092 ***	-0.004
	(0.021)	(0.018)	(0.022)	(0.022)	(0.021)
Baseline prob.	0.366	0.238	0.433	0.509	0.378
(3) Large firms					
IVETs	0.101 ***	-0.064 ***	0.136 ***	0.190 ***	-0.048 ***
	(0.015)	(0.013)	(0.014)	(0.014)	(0.015)
HVETs	0.074 ***	-0.007	0.129 ***	0.184 ***	-0.001
	(0.021)	(0.019)	(0.021)	(0.020)	(0.015)
Baseline prob.	0.425	0.282	0.604	0.571	0.597
(4) SMEs vs. Large firms					
IVETs	chi2 = 7.65 ***	chi2 = 1.80 n.s.	chi2 = 36.52 ***	chi2 = 20.28 ***	chi2 = 0.37 n.s.
HVETs	chi2 = 0.89 n.s.	chi2 = 0.22 n.s.	chi2 = 11.55 ***	chi2 = 10.56 ***	chi2 = 0.01 n.s.

Notes: * p < 0.10, **p < 0.05, ***p < 0.01, n.s. > 0.10; Robust standard errors in parentheses; SMEs: the respondent's company has a workforce of between 1 and 249 persons; Large firms: the respondent's company has a workforce of 250 persons or more

(1) Full sample: Based on the results of the logistic regression in Table A5.
(2) SMEs: Based on the results of the logistic regression in Table A6.
(3) Large firms: Based on the results of the logistic regression in Table A7.
(4) Comparison of regression coefficients between the two firm size samples.

The differentiation by firm size again suggests that the innovation-enhancing effects of educational workforce diversity are likely to be most pronounced in large firms (hypothesis H4). IVETs in large firm working environments are more likely to be involved in the introduction of new products and materials, new production and process technologies and new machinery / equipment than in SMEs. This complements the finding above that IVETs in large firms are less likely to be involved in continuous in-house R&D. Overall, this again points to a more pronounced division of tasks among the workforce the larger the firm. The situation is similar in case of HVETs. In the previous section, it was found that HVETs in large firms are more likely to participate in occasional R&D than in SMEs. The indicators for the implementation phase now show, consequently, that HVETs are more likely to be involved in the practical introduction of new production and process technologies and new machinery or equipment when they work in large firms.

5. Conclusion

This paper brings together the literature on the role of vocational education and training (VET) in SME innovation with studies on the innovation-promoting influence of educational workforce diversity by analyzing the individual innovation contributions of the VET workforce compared to university graduates such as scientists and engineers. For this purpose, individual-level data from manufacturing industries are used, distinguishing between persons with initial VET qualifications (i.e., 'IVETs' who have completed initial VET through a dual apprenticeship) and persons with higher VET qualifications (i.e., 'HVETs' such as master craftsmen or technicians).

The empirical results on various input and output indicators show that the VET workforce is not only involved in the implementation phase of the firm's innovation process, but also makes a significant contribution to the invention phase. While, as expected, university graduates clearly dominate the input side of innovation in the area of continuous research and development (R&D), the contribution of the VET workforce to occasional R&D and non-R&D related innovation inputs is relatively high. Moreover, HVETs are often involved not only in occasional R&D, but also to some extent in continuous R&D, which is why they can be expected to play an important role in the invention phase alongside university graduates, in creative steps such as exploring new ideas, solving problems, developing new prototypes, testing the feasibility of design options, etc. This finding is complemented by several indicators on the output side of the innovation process, thus completing the picture derived in the empirical analysis of this paper. As expected, there is a relatively high level of participation in innovation by the VET workforce in the implementation phase. Accordingly, in manufacturing industries, the introduction of new machines, equipment, production and process technologies, as well as the transfer of new or improved products and materials into practice, is largely in the hands of IVETs and HVETs.

Especially for IVETs, our analysis provides evidence in favor of a division of labor with university graduates. While they are much less involved in continuous R&D than university graduates, they not only make the above-mentioned contributions to other input activities in the invention phase, but their lower R&D activity is also compensated by their higher involvement in various areas of the implementation phase compared to university graduates. According to our results, such an allocation of tasks in the innovation process is more likely to occur in large firms which, due to their organizational structures and resource advantages, are better able to allow functional specialization and task-related differentiation among employees. This supports the present paper’s hypothesis that the benefits of educational workforce diversity in terms of innovation are more pronounced in larger firms.

With regard to the assumption that HVETs act as 'boundary spanners' in the firm’s innovation process, ensuring that effective interactive learning can take place between IVETs from production and university graduates from the R&D department, so that the benefits of educational workforce diversity can be realized, the present study has also found some initial empirical support. As the corresponding results show, HVETs operate in both worlds: they research, develop and work on new designs and prototypes, while at the same time they are heavily involved in the implementation phase of product and process innovations and also participate in the monitoring and management of accompanying organizational practices. This should enable them to speak the necessary "language" across functional boundaries, potentially making them an important link in manufacturing firms for the successful integration of different but complementary forms of knowledge and types of skills for the benefit of innovation. To validate this interpretation, however, more research is needed.

This leads to implications for policy making, management and further research. The observed contributions of the VET workforce to innovation shows once again the importance of a holistic approach to innovation policy, which takes into account the wide range of knowledge and learning components and thus goes beyond a classical linear understanding of innovation (Lewis 2023). With regard to the specific role of VET in the creation and diffusion of innovation, the core of such an approach would be to recognize and address the ways of learning and innovating that are anchored in the so-called Learning by Doing, Using and Interacting (DUI) mode. This mode goes beyond the narrow focus on R&D and codified scientific and technical knowledge and reflects the fact that application-oriented experiential knowledge and interactive learning in R&D, but above all beyond it, are often just as decisive for the success of innovation – and that VET qualifications in particular often form an important qualification basis for this (see e.g. Thomä 2017; Rupietta and Backes-Gellner 2019; Alhusen and Bennat 2021; Matthies et al. 2023). From an innovation system perspective, this also means that, especially in a regional context, policy should not only focus on universities and similar institutions for the training of highly qualified university graduates, but also take into account the role of VET institutions in the development of corresponding qualifications, which are often central to the DUI mode (Lund and Karlsen 2020; Hädrich et al. 2024; Friedrich and Kagel 2025). Particularly with regard to the promotion of VET in the context of innovation, this may also mean leaving the traditional field of innovation policy and addressing neighboring policy fields, for example by addressing the growing shortage of skilled workers in the area of VET qualifications in countries such as Germany through labor market measures, or by using education policy to seek and promote an 'optimal mix' of different, complementary levels of education, which will better enable companies to achieve an effective degree of educational workforce diversity (Bolli et al. 2018).

For managers, the findings of this paper suggest that firms should adopt an 'employee-driven innovation' management approach (Kesting and Parm Ulhøi 2010; Høyrup 2010, 2012). One of its key ideas is the active involvement of the entire firm’s workforce in the innovation process (i.e. not just the R&D department) in order to promote workplace learning in a broad sense. This includes stimulating and motivating the individual innovation contributions of employees with VET qualifications (e.g. by giving them personal freedom to make decisions and develop their own creativity) as well as promoting team-based innovation activities (e.g. by setting up R&D project teams consisting of university graduates and representatives of the VET workforce such as HVETs), conducting organizational innovations (e.g. measures to improve the organizational framework conditions for creative innovation contributions from non-R&D employees) or promoting the general learning and exchange culture of the company (McMurray et al. 2023). Such measures to promote interactive learning can also help innovating firms to cope with the potential coordination and communication costs of educational workforce diversity (e.g., those arising from misunderstandings between members of the VET workforce and university graduates).

One limitation of our paper is that, with the individual-level data available to us, we were only able to analyze the division of labor between the VET workforce and university graduates at the average level of manufacturing firms, and thus only obtained rather indirect indications of innovation-promoting interactions between these two levels of education. Future studies could build on this by combining individual-level and firm-level data – which could be either quantitative or qualitative – to investigate how this task allocation and the associated interactive learning actually takes place in individual firms. Another line of research would be to look more closely at whether the innovation benefits of educational workforce diversity are really only found in large firms, what determines this, and to what extent and under what conditions they might also apply to smaller firms. Finally, one of the hypotheses formulated in this paper, namely that HVETs are an important 'boundary spanner' in the innovation process of (large) manufacturing firms, needs to be examined in more detail in future studies than was possible within the framework of our empirical analysis.

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Appendix

Table A1. Descriptive statistics on control variables (N=13,487)

	Description	**Mean**
No professional qualification	1 if respondent has not acquired a professional qualification	0.07
Other professional qualification	1 if the respondent's highest level of professional qualification is not a dual apprenticeship, higher vocational education and training or a university degree	0.04
Age	Age of the respondent in years	44.40
Gender	Gender of the respondent (1=female, 0=male)	0.31
Nationality	Nationality of the respondent (1 = German as mother tongue, 0 = German not as mother tongue)	0.93
East	Federal state of the respondent (1=East Germany, 0 West Germany)	0.16
Firm size		
1 person	1 if there is 1 person working in the respondent's company	2.58
2 persons	1 if there are 2 persons working in the respondent's company	0.96
3-4 persons	1 if there are 3-4 persons working in the respondent's company	2.40
5-9 persons	1 if there are 5-9 persons working in the respondent's company	4.54
10-19 persons	1 if there are 10-19 persons working in the respondent's company	6.81
20-49 persons	1 if there are 20-49 persons working in the respondent's company	10.57
50-99 persons	1 if there are 50-99 persons working in the respondent's company	10.02
100-249 persons	1 if there are 100-249 persons working in the respondent's company	15.03
250-499 persons	1 if there are 250-499 persons working in the respondent's company	12.23
500-999 persons	1 if there are 500-999 persons working in the respondent's company	10.11
1,000 or more persons	1 if there are 1,000 or more persons working in the respondent's company	24.75
Manufacturing industry (*WZ 2003)*		
Food	1 if Food products and beverage	9.03
Tobacco	1 if Tobacco products	0.13
Textiles	1 if Textiles	1.94
Wearing	1 if Wearing apparel; dressing and dyeing of fur	0.84
Leather	1 if Leather and leather products	0.19
Wood	1 if Wood and wood products	1.93
Paper	1 if Pulp, paper and paper products; publishing and printing	1.57
Printing	1 if Publishing, printing and reproduction of recorded media	5.40
Coke	1 if Coke, refined petroleum products and nuclear fuel	0.22
Chemicals	1 if Chemicals, chemical products and man-made fibres	10.33
Rubber	1 if Rubber and plastic products	2.22
Glass	1 if Other non-metallic mineral products	1.91
Basic metal	1 if Basic metals	2.60
Fabricated metal	1 if Fabricated metal products, except machinery and equipment	12.20
Machinery	1 if Machinery and equipment	13.37
Computers	1 if Office machinery and computers	0.30
Electronics	1 if Electrical machinery and apparatus	8.65
Communication	1 if Radio, television and communication equipment and apparatus	2.49
Optics	1 if Medical, precision and optical instruments, watches, clocks	4.17
Automobile	1 if Motor vehicles, trailers and semi-trailers	15.95
Other transport	1 if other transport equipment	2.08
Furniture	1 if Furniture	2.03
Recycling	1 if Recycling	0.46
Survey year		
2006	1 if survey year is 2006	35.29
2012	1 if survey year is 2012	34.07
2018	1 if survey year is 2018	30.64

Table A2. Logistic regression on innovation inputs (Full sample)

	(1) Continuous R&D	(2) Occasional R&D	(3) Continuous innovator without R&D	(4) Occasional innovator without R&D
University graduates (Ref.)				
No professional qualification	-1.7938***	-0.5066***	0.1611	0.4191***
	(0.1348)	(0.1024)	(0.1234)	(0.0922)
Other professional qualification	-1.1598***	-0.1039	-0.1179	0.5288***
	(0.1447)	(0.1220)	(0.1684)	(0.1134)
IVETs	-1.6545***	-0.1237**	0.1948***	0.6583***
	(0.0578)	(0.0529)	(0.0717)	(0.0553)
HVETs	-0.9618***	0.2233***	0.1467	0.4105***
	(0.0758)	(0.0691)	(0.0993)	(0.0757)
1 person	0.7900***	0.1841	0.2907	-0.4330***
	(0.1540)	(0.1342)	(0.1799)	(0.1527)
2 persons	0.3401	-0.1835	-0.0355	-0.2280
	(0.2636)	(0.2232)	(0.3030)	(0.2173)
3-4 persons	0.4061**	0.1384	0.0088	-0.1162
	(0.1693)	(0.1385)	(0.1929)	(0.1376)
5-9 persons	0.3495**	0.0295	-0.2528	-0.1178
	(0.1393)	(0.1081)	(0.1605)	(0.1054)
10-19 persons	0.1873	-0.0713	-0.0718	0.1025
	(0.1263)	(0.0942)	(0.1305)	(0.0901)
20-49 persons	0.2401**	-0.0628	-0.2260*	0.0372
	(0.1048)	(0.0810)	(0.1174)	(0.0784)
50-99 persons	0.1902*	-0.1287	0.0250	-0.0282
	(0.1056)	(0.0825)	(0.1127)	(0.0807)
100-249 persons (Ref.)				
250-499 persons	0.0572	-0.1698**	0.2484**	0.0876
	(0.0999)	(0.0778)	(0.1027)	(0.0756)
500-999 persons	0.0127	-0.0855	0.0780	0.1350*
	(0.1053)	(0.0813)	(0.1119)	(0.0800)
1,000 or more persons	0.2490***	-0.1686**	0.2088**	0.0118
	(0.0843)	(0.0685)	(0.0925)	(0.0686)
Age	-0.0105***	-0.0124***	-0.0038	0.0075***
	(0.0023)	(0.0019)	(0.0027)	(0.0019)
Gender	-0.7942***	-0.7593***	0.2764***	0.6117***
	(0.0645)	(0.0507)	(0.0603)	(0.0438)
Nationality	-0.0467	0.1691**	0.0858	0.0623
	(0.0933)	(0.0837)	(0.1109)	(0.0814)
East	-0.3837***	-0.0693	-0.0420	-0.0005
	(0.0737)	(0.0563)	(0.0775)	(0.0549)
Manufacturing industries	Yes	Yes	Yes	Yes
2006 (Ref.)				
2012	0.1250**	-0.0063	0.0630	-0.0337
	(0.0613)	(0.0496)	(0.0678)	(0.0483)
2018	0.1287**	0.0181	0.1584**	-0.0642
	(0.0616)	(0.0513)	(0.0696)	(0.0512)
Constant	-0,7776***	-0,4258***	-2,4255***	-2,0575***
	(0,1934)	(0,1479)	(0,1996)	(0,1472)
N	13,487	13,487	13,487	13,487

Notes: * p < 0.10, **p < 0.05, ***p < 0.01; Robust standard errors in parentheses

Table A3. Logistic regression on innovation inputs (SME sample)

	(1) Continuous R&D	(2) Occasional R&D	(3) Continuous innovator without R&D	(4) Occasional innovator without R&D
University graduates (Ref.)				
No professional qualification	-1.6620***	-0.6323***	0.4589***	0.1604
	(0.1798)	(0.1376)	(0.1736)	(0.1243)
Other professional qualification	-1.0803***	-0.0700	0.0142	0.2914*
	(0.1954)	(0.1571)	(0.2372)	(0.1493)
IVETs	-1.4885***	-0.1903**	0.3891***	0.4218***
	(0.0850)	(0.0757)	(0.1193)	(0.0794)
HVETs	-0.8365***	0.0485	0.4583***	0.2042*
	(0.1107)	(0.1002)	(0.1549)	(0.1099)
1 person	0.7632***	0.1713	0.3867**	-0.4847***
	(0.1517)	(0.1350)	(0.1840)	(0.1526)
2 persons	0.3306	-0.1613	-0.0282	-0.2348
	(0.2579)	(0.2223)	(0.3045)	(0.2167)
3-4 persons	0.3981**	0.1308	0.0433	-0.1376
	(0.1769)	(0.1400)	(0.1964)	(0.1388)
5-9 persons	0.3392**	0.0318	-0.2530	-0.1285
	(0.1408)	(0.1097)	(0.1620)	(0.1066)
10-19 persons	0.1785	-0.0735	-0.0660	0.1009
	(0.1253)	(0.0954)	(0.1321)	(0.0895)
20-49 persons	0.2396**	-0.0665	-0.2240*	0.0357
	(0.1055)	(0.0818)	(0.1184)	(0.0785)
50-99 persons	0.1976*	-0.1373*	0.0217	-0.0331
	(0.1053)	(0.0831)	(0.1132)	(0.0807)
100-249 persons (Ref.)				
Age	-0.0094***	-0.0160***	-0.0052	0.0064**
	(0.0033)	(0.0026)	(0.0037)	(0.0026)
Gender	-0.9837***	-0.8320***	0.3066***	0.6800***
	(0.0923)	(0.0677)	(0.0850)	(0.0584)
Nationality	-0.1460	0.2274*	0.0550	0.1997*
	(0.1371)	(0.1193)	(0.1650)	(0.1179)
East	-0.3152***	-0.0776	-0.0619	-0.0346
	(0.0952)	(0.0722)	(0.1029)	(0.0697)
Manufacturing industries	Yes	Yes	Yes	Yes
2006 (Ref.)				
2012	0.0840	0.0259	0.0735	0.0010
	(0.0870)	(0.0679)	(0.0949)	(0.0649)
2018	0.1193	0.1042	0.1540	-0.0533
	(0.0888)	(0.0711)	(0.1010)	(0.0704)
Constant	-0.9528***	-0.2715	-2.5349***	-1.9619***
	(0.2594)	(0.1950)	(0.2747)	(0.1918)
N	7,131	7,131	7,137	7,137

Notes: * $p < 0.10$, **$p < 0.05$, ***$p < 0.01$; Robust standard errors in parentheses

Table A4. Logistic regression on innovation inputs (Large firm sample)

	(1) Continuous R&D	(2) Occasional R&D	(3) Continuous innovator without R&D	(4) Occasional innovator without R&D
University graduates (Ref.)				
No professional qualification	-1.9227***	-0.3985**	-0.0941	0.6594***
	(0.2119)	(0.1562)	(0.1865)	(0.1373)
Other professional qualification	-1.2058***	-0.2228	-0.1679	0.7592***
	(0.2185)	(0.1989)	(0.2457)	(0.1735)
IVETs	-1.7973***	-0.0810	0.1015	0.8516***
	(0.0808)	(0.0719)	(0.0920)	(0.0778)
HVETs	-1.0589***	0.3746***	-0.0687	0.5637***
	(0.1057)	(0.0951)	(0.1351)	(0.1071)
250-499 persons (Ref.)				
500-999 persons	-0.0488	0.0886	-0.1739	0.0547
	(0.1093)	(0.0862)	(0.1125)	(0.0831)
1,000 or more persons	0.1547*	0.0000	-0.0317	-0.0411
	(0.0901)	(0.0748)	(0.0941)	(0.0727)
Age	-0.0118***	-0.0080***	-0.0021	0.0088***
	(0.0034)	(0.0029)	(0.0038)	(0.0029)
Gender	-0.6105***	-0.6604***	0.2439***	0.5269***
	(0.0899)	(0.0772)	(0.0858)	(0.0658)
Nationality	0.0197	0.1241	0.0867	-0.0511
	(0.1309)	(0.1158)	(0.1504)	(0.1115)
East	-0.4817***	-0.0674	0.0101	0.0447
	(0.1199)	(0.0921)	(0.1166)	(0.0890)
Manufacturing industries	Yes	Yes	Yes	Yes
2006 (Ref.)				
2012	0.1681*	-0.0422	0.0606	-0.0754
	(0.0883)	(0.0735)	(0.0963)	(0.0725)
2018	0.1360	-0.0778	0.1619*	-0.0731
	(0.0863)	(0.0744)	(0.0963)	(0.0748)
Constant	-0.3574	-0.7334***	-2.2129***	-2.0733***
	(0.2863)	(0.2263)	(0.2920)	(0.2193)
N	6,350	6,335	6,343	6,350

Notes: * p < 0.10, **p < 0.05, ***p < 0.01; Robust standard errors in parentheses

Table A5. Logistic regression on innovation outputs (Full sample)

	(1) Products / materials	(2) Services	(3) Production / process technologies	(4) Machines / equipment	(5) Organizational practices
University graduates (Ref.)					
No professional qualification	0.2904***	-0.3696***	0.2655***	0.6837***	-0.4167***
	(0.0836)	(0.0930)	(0.0818)	(0.0835)	(0.0839)
Other professional qualification	0.1746	-0.3245***	0.2464**	0.6604***	-0.3485***
	(0.1091)	(0.1168)	(0.1059)	(0.1044)	(0.1067)
IVETs	0.3137***	-0.3824***	0.3499***	0.6653***	-0.2294***
	(0.0479)	(0.0505)	(0.0474)	(0.0472)	(0.0469)
HVETs	0.2710***	-0.0515	0.3903***	0.6375***	-0.0023
	(0.0654)	(0.0688)	(0.0657)	(0.0652)	(0.0650)
1 person	-0.8239***	-0.2190	-1.3690***	-0.9390***	-1.3850***
	(0.1420)	(0.1402)	(0.1417)	(0.1331)	(0.1455)
2 persons	-0.8571***	-0.1465	-1.0800***	-0.5099***	-1.4065***
	(0.2151)	(0.2117)	(0.2062)	(0.1907)	(0.2298)
3-4 persons	-0.4834***	0.0076	-0.8698***	-0.5319***	-1.0373***
	(0.1333)	(0.1409)	(0.1291)	(0.1269)	(0.1393)
5-9 persons	-0.4172***	-0.0918	-0.9020***	-0.5505***	-0.9734***
	(0.1010)	(0.1114)	(0.1000)	(0.0981)	(0.1034)
10-19 persons	-0.2426***	-0.0799	-0.7457***	-0.3621***	-0.7492***
	(0.0844)	(0.0962)	(0.0848)	(0.0838)	(0.0861)
20-49 persons	-0.2136***	-0.0320	-0.4198***	-0.1646**	-0.4514***
	(0.0732)	(0.0819)	(0.0715)	(0.0729)	(0.0714)
50-99 persons	-0.1312*	-0.0730	-0.1372*	-0.1083	-0.2439***
	(0.0739)	(0.0839)	(0.0721)	(0.0741)	(0.0713)
100-249 persons (Ref.)					
250-499 persons	-0.0097	0.0677	0.2563***	0.1329*	0.1760***
	(0.0690)	(0.0779)	(0.0690)	(0.0698)	(0.0671)
500-999 persons	-0.0050	-0.0803	0.2437***	0.0922	0.2119***
	(0.0730)	(0.0839)	(0.0727)	(0.0736)	(0.0712)
1,000 or more persons	0.0091	0.2237***	0.2754***	-0.0278	0.5626***
	(0.0611)	(0.0680)	(0.1404)	(0.0615)	(0.1443)
Age	-0.0049***	0.0045**	-0.0020	-0.0064***	-0.0021
	(0.0017)	(0.0019)	(0.0017)	(0.0017)	(0.0018)
Gender	-0.5063***	-0.1309***	-0.5242***	-0.8191***	-0.0764*
	(0.0422)	(0.0467)	(0.0411)	(0.0414)	(0.0412)
Nationality	-0.3374***	-0.2635***	-0.1402*	-0.1868**	-0.0268
	(0.0712)	(0.0776)	(0.0717)	(0.0739)	(0.0718)
East	0.0306	-0.1173**	-0.0228	0.1488***	-0.2862***
	(0.0509)	(0.0575)	(0.0501)	(0.0508)	(0.0504)
Manufacturing industries	Yes	Yes	Yes	Yes	Yes
2006 (Ref.)					
2012	-0.0653	-0.2008***	-0.1238***	-0.1866***	-0.2016***
	(0.0443)	(0.0491)	(0.0442)	(0.0441)	(0.0444)
2018	-0.0297	-0.2461***	-0.1932***	-0.1585***	-0.1438***
	(0.0463)	(0.0513)	(0.0461)	(0.0464)	(0.0462)
Constant	0.2280*	-0.6719***	0.2705**	0.6422***	0.2599**
	(0.1315)	(0.1459)	(0.1311)	(0.1320)	(0.1314)
N	13,304	13,252	13,337	13,386	13,430

Notes: * p < 0.10, **p < 0.05, ***p < 0.01; Robust standard errors in parentheses

Table A6. Logistic regression on innovation outputs (SME sample)

	(1) Products / materials	(2) Services	(3) Production / process technologies	(4) Machines / equipment	(5) Organizational practices
University graduates (Ref.)					
No professional qualification	0,1193	-0,6098***	-0,1805	0,2726**	-0,3799***
	(0,1146)	(0,1319)	(0,1124)	(0,1107)	(0,1138)
Other professional qualification	0,2320	-0,3442**	-0,0747	0,4759***	-0,2050
	(0,1411)	(0,1558)	(0,1398)	(0,1372)	(0,1408)
IVETs	0,1637**	-0,4607***	0,0234	0,4264***	-0,2633***
	(0,0712)	(0,0750)	(0,0691)	(0,0690)	(0,0692)
HVETs	0,1886**	-0,0999	0,1187	0,3986***	-0,0185
	(0,0961)	(0,1008)	(0,0941)	(0,0940)	(0,0947)
1 person	-0,8336***	-0,2086	-1,4364***	-0,9413***	-1,3654***
	(0,1428)	(0,1433)	(0,1415)	(0,1311)	(0,1461)
2 persons	-0,8547***	-0,1278	-1,0805***	-0,4775**	-1,3833***
	(0,2169)	(0,2170)	(0,2041)	(0,1887)	(0,2295)
3-4 persons	-0,4805***	0,0365	-0,8688***	-0,5151***	-1,0158***
	(0,1329)	(0,1429)	(0,1309)	(0,1262)	(0,1389)
5-9 persons	-0,4064***	-0,0656	-0,8916***	-0,5319***	-0,9716***
	(0,1006)	(0,1129)	(0,1004)	(0,0973)	(0,1046)
10-19 persons	-0,2332***	-0,0686	-0,7282***	-0,3333***	-0,7395***
	(0,0849)	(0,0970)	(0,0847)	(0,0834)	(0,0863)
20-49 persons	-0,2086***	-0,0244	-0,4115***	-0,1466**	-0,4494***
	(0,0731)	(0,0828)	(0,0716)	(0,0723)	(0,0719)
50-99 persons	-0,1287*	-0,0739	-0,1376*	-0,1000	-0,2456***
	(0,0737)	(0,0846)	(0,0719)	(0,0733)	(0,0719)
100-249 persons (Ref.)					
Age	-0,0068***	-0,0004	-0,0055**	-0,0096***	-0,0069***
	(0,0024)	(0,0027)	(0,0023)	(0,0023)	(0,0024)
Gender	-0,4470***	-0,2558***	-0,5244***	-0,7513***	-0,0677
	(0,0575)	(0,0646)	(0,0558)	(0,0553)	(0,0561)
Nationality	-0,2409**	-0,1327	-0,0441	-0,1640	0,0757
	(0,1021)	(0,1153)	(0,1027)	(0,1031)	(0,1042)
East	0,0713	-0,0989	-0,0646	0,2297***	-0,3388***
	(0,0648)	(0,0743)	(0,0638)	(0,0637)	(0,0665)
Manufacturing industries	Yes	Yes	Yes	Yes	Yes
2006 (Ref.)					
2012	-0,0816	-0,2187***	-0,1220**	-0,1585***	-0,2062***
	(0,0611)	(0,0684)	(0,0599)	(0,0597)	(0,0611)
2018	-0,0792	-0,2882***	-0,1598**	-0,1424**	-0,0655
	(0,0649)	(0,0734)	(0,0640)	(0,0638)	(0,0645)
Constant	0,3088*	-0,5124***	0,5972***	0,8952***	0,3631**
	(0,1729)	(0,1950)	(0,1720)	(0,1717)	(0,1739)
N	7,054	7,031	7,067	7,094	7,102

Notes: * p < 0.10, **p < 0.05, ***p < 0.01; Robust standard errors in parentheses

Table A7. Logistic regression on innovation outputs (Large firm sample)

	(1) Products / materials	(2) Services	(3) Production / process technologies	(4) Machines / equipment	(5) Organizational practices
University graduates (Ref.)					
No professional qualification	0,4376***	-0,1403	0,6868***	1,1494***	-0,5061***
	(0,1244)	(0,1340)	(0,1275)	(0,1308)	(0,1227)
Other professional qualification	-0,0159	-0,3512*	0,4760***	0,7617***	-0,5747***
	(0,1690)	(0,1815)	(0,1624)	(0,1629)	(0,1584)
IVETs	0,4302***	-0,3241***	0,5947***	0,8533***	-0,2061***
	(0,0643)	(0,0682)	(0,0635)	(0,0645)	(0,0639)
HVETs	0,3126***	-0,0348	0,5651***	0,8253***	-0,0046
	(0,0897)	(0,0950)	(0,0910)	(0,0916)	(0,0910)
250-499 persons (Ref.)					
500-999 persons	0,0093	-0,1379	-0,0009	-0,0308	0,0353
	(0,0766)	(0,0868)	(0,0772)	(0,0787)	(0,0745)
1,000 or more persons	0,0366	0,2050***	0,0506	-0,1535**	0,3964***
	(0,0659)	(0,0723)	(0,0666)	(0,0675)	(0,0649)
Age	-0,0025	0,0105***	0,0016	-0,0032	0,0041
	(0,0026)	(0,0029)	(0,0027)	(0,0027)	(0,0026)
Gender	-0,5760***	0,0202	-0,5203***	-0,9163***	-0,0820
	(0,0637)	(0,0676)	(0,0617)	(0,0631)	(0,0612)
Nationality	-0,4100***	-0,3726***	-0,2128**	-0,1766*	-0,1237
	(0,1002)	(0,1056)	(0,1046)	(0,1057)	(0,1009)
East	-0,0454	-0,1700*	0,0344	-0,0005	-0,2090***
	(0,0810)	(0,0920)	(0,0820)	(0,0828)	(0,0793)
Manufacturing industries	Yes	Yes	Yes	Yes	Yes
2006 (Ref.)					
2012	-0,0485	-0,1861***	-0,1323**	-0,2212***	-0,1992***
	(0,0652)	(0,0713)	(0,0666)	(0,0670)	(0,0653)
2018	0,0154	-0,2158***	-0,2324***	-0,1777***	-0,2265***
	(0,0663)	(0,0723)	(0,0672)	(0,0681)	(0,0665)
Constant	0,1335	-0,7272***	0,2915	0,5857***	0,2694
	(0,1970)	(0,2146)	(0,2008)	(0,2039)	(0,1952)
N	6,250	6,215	6,270	6,292	6,328

Notes: * p < 0.10, **p < 0.05, ***p < 0.01; Robust standard errors in parentheses