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Non-R&D, interactive learning and economic performance: Revisiting innovation in small and medium enterprises

Jörg Thomä[a,#], Volker Zimmermann[b]

a Institute for Small Business Economics at the Georg-August-University Goettingen, Heinrich-Düker-Weg 6, 37073 Göttingen, Germany
b KfW Bankengruppe, Frankfurt a.M.

Abstract:

In the present paper, various groups of innovating German SMEs are empirically identified according to their use (or non-use) of in-house R&D, their reliance on external sources of knowledge, and the degree of internal interactive learning that they employ. In order to account for non-R&D innovation activities, we apply the STI/DUI concept as a theoretical starting point. This distinguishes between (1) the science, technology, innovation (STI) mode with its strong emphasis on formal processes of in-house R&D and (2) the doing, using, interacting (DUI) mode with its focus on experience-based knowledge and interactive learning. On this basis, the empirical results indicate that three groups associated with different modes of learning and innovation exist within the German SME sector: the supplier-dependent DUI group, the customer-oriented DUI group and the STI/DUI group. The corresponding findings confirm that SMEs innovate differently depending on the specificities of their knowledge environments. In order to evaluate this in terms of innovation policy, we examine how these learning modes among innovating SMEs relate to overall company performance. Our main observation is that each learning mode is likely to positively affect performance, at least to some degree. There is no difference in economic performance between the three learning modes as long as non-high-growth SMEs are considered. Hence, in large parts of the SME sector, it is economically rational to choose a non-R&D-oriented mode of learning and innovation. The paper concludes with some policy implications of these findings.

JEL: M21, O32, O38

Keywords: Modes of learning, R&D, Non-R&D innovation, Interactive learning, SMEs

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Corresponding author. joerg.thomae@wiwi.uni-goettingen.de

1 Introduction

There is no doubt that investment in research and development (R&D) is a key driver of innovation at the firm level. In this context, policy-makers frequently consider that small and medium enterprises (SMEs) play a paramount role in the technological progress of the economy. This is typically associated with concerns that systematic disadvantages related to in-house R&D may prevent smaller firms from fully realising their innovative potential, which in turn justifies R&D policy measures specifically addressing SMEs (Shapira 2010; Bennett 2014). In fact, over the years a number of studies examining the Schumpeterian hypothesis concerning the relationship between firm size and innovation have identified several advantages of large firms in terms of in-house R&D activity (for an overview, see e.g. Cohen 1995; Acs and Audretsch 2005). For example, due to capital market imperfections, it is often more difficult for SMEs – in comparison with their larger counterparts – to acquire finance for risky R&D projects. In addition, owing to their general lack of resources, smaller firms are less able to generate economies of scale and scope in conducting R&D. Moreover, the limited customer base of smaller firms can make it more challenging for them to appropriate sufficient profits from R&D-based innovations to cover the high fixed costs of antecedent investments. Finally, R&D-performing SMEs can be more vulnerable compared with large firms, in terms of being less able to spread the risk accompanying innovation over many simultaneous R&D projects.

However, despite these potential disadvantages, a large number of SMEs do innovate (OECD 2010). Moreover, with respect to innovation, there is strong diversity among smaller firms. While a notable proportion of SME innovation undoubtedly depends on in-house R&D activity (especially in high-technology contexts), the innovation strategies of smaller firms are often characterised by attributes that extend beyond R&D (see e.g. Baldwin and Gellatly 2003; de Jong and Marsili 2006). This is the case – for example – when SMEs closely interact with their customers and exploit certain advantages associated with a smaller firm size. They may compensate for their lack of R&D by offering a superior differentiation between existing products through a focus on personalised service or providing a fast, flexible and incremental adjustment of product quality to individual customer needs. According to classical theoretical literature on small firm innovation (see Rothwell and Zegveld 1982; Rothwell 1989; Nooteboom 1994), such advantages of non-R&D-performing SMEs are largely behavioural and closely related to informal interaction within and outside the firm. Examples include greater internal flexibility, a lack of internal bureaucracy, greater efficiency of internal communication and the competences acquired from learning with external contacts such as customers and suppliers (e.g. in terms of specialisation or customisation).

While literature of SMEs has long recognised the aspect of innovation that extends beyond R&D, this topic has only been brought to the attention of a wider audience of scholars in recent years (Lee and Walsh 2016). A growing number of empirical studies point to the significant amount of non-R&D innovation occurring in European countries (e.g. Arundel et al. 2008; Barge-Gil et al. 2011; Lopez-Rodriguez and Martinez-Lopez 2017). Among this research, one specific strand refers to innovation in low- and medium-technology industries, where most of the firms are SMEs. A key insight issuing from these studies is that non-R&D activities such as design, prototyping, the use of advanced machinery and equipment, training or marketing are suitable variables in explaining innovation under conditions of less R&D-oriented knowledge environments (see Heidenreich 2009; Santamaría et al. 2009; Kirner et al. 2009; Hervas-Oliver et al. 2011; Hervas-Oliver et al. 2012). A second strand of literature with specific relevance to the present paper is more narrowly concerned with the innovation performance of non-R&D SMEs (see Rammer et al. 2009; Moilanen et al. 2014; Hervas-Oliver et al. 2014; Hervas-Oliver et al. 2016). One key outcome of these studies is that the use of management practices to foster both interactive learning within the firm (notably through organisational methods related to human resources and team work) and external knowledge inflows (e.g. from interaction with suppliers, customers, competitors or scientific institutions) has a strong impact on the innovative success of those smaller firms that do not carry out formal R&D. It is even shown that the innovation performance of non-R&D SMEs can be quite similar to that of R&D performers if these interactive mechanisms are integrated and combined effectively. This provides empirical evidence of the theoretical claim that innovating SMEs can compensate for their lack of in-house R&D capacities by placing a strong emphasis on interactive learning.

Hence, there is some support for the policy recommendations proposed by Ortega-Argilés et al. (2009). According to these authors, in light of the heterogeneity among innovating SMEs, "a targeted R&D policy addressed to particular sub-groups of SMEs" should be preferred to a "general-purpose erga omnes" R&D policy (ibid. p. 9). Moreover, in their view, relying solely on in-house R&D is not enough to foster innovation activity in the SME sector. This is not only due to the fact that innovation in smaller firms often occurs without R&D activity, but also that even R&D-intensive SMEs in high-technology sectors need to take non-R&D sources of innovation into account to be successful. Ortega-Argilés et al. (2009) therefore plead for a more comprehensive approach to innovation policy in terms of European SMEs, which complements classical R&D measures with non-R&D-related policy actions aimed at supporting interactive learning and innovation in smaller firms (e.g. by facilitating easier access to external knowledge, supporting the use of new organisational practices within firms, and fostering external partnerships).

In order to implement such a policy, policy-makers must have a broad and systemic understanding of innovation in smaller firms. They should especially be aware of the fact that interactive learning plays a significant role in SME innovation, irrespective of whether it occurs in R&D-performing or non-R&D-active SMEs. The present paper aims to contribute to a better understanding of this in two major ways. First, we empirically identify different groups of innovating German SMEs according to their use of in-house R&D and their reliance on various forms of interactive learning. The STI/DUI concept introduced by Jensen et al. (2007) serves as a theoretical framework (see Table 1), according to which there are two ideal modes of learning at the level of the innovating firm: (1) the science, technology, innovation (STI) mode with its strong emphasis on formal processes of in-house R&D to produce explicit and global knowledge, and (2) the doing, using, interacting (DUI) mode with its focus on the experience-based (tacit) knowledge that emerges from interaction between people and departments within companies and between companies and their external environments. Underlying the STI/DUI concept is the 'system of innovation' approach, according to which, instead of overly focusing on in-house R&D, "the interaction between people, firms, and other actors […] [is] the key to developing new knowledge and transforming it into successful innovation" (Parrilli et al. 2016, p. 199).

Table 1 Two ideal modes of learning at the level of the innovating firm

STI mode	DUI mode
• Formal learning of science and technology within R&D departments	• Experience-based learning from informal problem-solving communication, including experimentation and trial and error
• Production and use of explicit and global knowledge with a focus on know-why and know-what	• Overall importance of locally embedded tacit knowledge, with high priority given to know-how and know-who
• R&D cooperation with universities and other external scientific institutions	• Collaboration with customers, suppliers and competitors
• Fostering of learning by relying on commonly shared scientific principles and research practices	• Fostering of learning by building up internal interaction structures (e.g. use of project teams, problem-solving groups or job and task rotation)
• Higher levels of technological innovativeness	• Incremental improvement of existing products and processes; close link to non-technological innovation (organisation and marketing)
• Scientifically-educated workforce	• Vocationally-trained workforce
• Example: R&D-intensive SMEs in high-technology sectors	• Example: Innovating SMEs in low- and medium-tech industries

Source: Own compilation based on Jensen et al. (2007); Apanasovich (2016); Thomä (2017).

The body of literature on the STI/DUI concept has markedly increased in recent years (e.g. Chen et al. 2011; Asheim and Parrilli 2012; Fitjar and Rodríguez-Pose 2013; González-Pernía et al. 2015; Herstad et al. 2015; Parrilli and Alcalde Heras 2016; for comprehensive literature reviews, see Parrilli et al. 2016 or Apanasovich 2016). There are also some studies on this topic adopting a specific SME perspective (e.g. Parrilli and Elola 2012; Thomä 2017). This seems reasonable as – in light of the above discussion – one could easily argue that innovation in SMEs vis-à-vis large firms is relatively more strongly focused on the DUI mode of learning. Thus, in particular the STI/DUI concept bears the potential to account for the strong diversity among innovating SMEs when it comes to R&D and interactive learning (which – as noted above – is the primary interest of our paper). While identifying different modes of learning among innovating German SMEs, the present paper adds to the STI/DUI literature in several ways. For example, in order to examine DUI types of interactions, we not only focus on customers, suppliers and competitors, but also the role played by other external sources of interactive learning (e.g. the visit of trade fairs). On the other hand, internal interaction between people and departments of the firm is not only measured by the use of human resource or teamwork practices (as – for example – by Jensen et al. 2007). Instead, we investigate the effectiveness of interactive learning within the firm directly by examining the degree to which internal innovation-oriented collaboration occurs. Finally, to offer another example, the present study uses a number of novel variables that lie at the heart of what is known as the German Mittelstand (Pahnke and Welter 2018) to profile the identified modes learning (i.e. the role of craft skills in less R&D-oriented knowledge environments or the close link between vocational education and training and the widespread occurrence of DUI learning among German SMEs).

Second, a natural question arising from a policy perspective is how the identified modes of learning increase the economic performance of innovating SMEs. This is because the justification for public policy intervention in support of smaller firms ultimately relates to final objectives such as competitiveness or job growth (Storey 2005). However, empirical evidence on the economic effects of STI and DUI learning modes is scarce, as almost all studies in this field stop at the level of innovation as an intermediate indicator of overall firm performance (e.g. by measuring sales generated from new-to-market products). The main finding here is that firms combining the STI mode with DUI mode learning achieve a higher level of technological innovativeness than those that focus on only one learning mode (for an overview, see Apanasovich 2016). However, to our knowledge, until now only Nunes and Lopes (2015) have examined the direct relationship between different learning modes and the overall economic performance of firms. Based on a sample of Portuguese firms and by accounting for the growth of company turnover, their results show that innovating firms combining STI and DUI drivers with each other are likely to have a stronger economic performance. The present paper adds to this discussion. Three performance indicators are used in the present study (sales growth, employment growth and change in labour productivity). Moreover, we investigate overall firm performance not only at the average impact level, but also at various performance percentiles.

The rest of the paper is organised as follows. Section 2 presents our data set on innovating SMEs and discusses the baseline variables in light of the literature. The first part of the empirical analysis is conducted in Section 3, in which cluster analysis is employed to identify different modes of learning regarding R&D and interactive learning. As a next step, in Section 4, we use ordinary least squares and quantile regression methods to investigate how the identified learning modes relate to the economic performance of innovating SMEs. Section 5 summarises the results and concludes with implications for policy and research.

2 Data set and baseline variables

2.1 Data

We use data from the 2017 survey wave of the KfW SME panel ("KfW-Mittelstandspanel"), a representative survey of German SMEs conducted by the KfW Bankengruppe on an annual basis. The target population comprises all small and medium-sized enterprises of the German economy with annual turnover of up to EUR 500 million. The population of the 2017 survey wave was drawn as a stratified random sample. The variables used for stratification were industry classification (manufacturing, construction, retail, wholesale, services, others), firm size (six employment size classes), region (East or West Germany) and participation in a government support programme for SMEs conducted by the KfW Bankengruppe. The response rate of the survey wave 2017 was about 22%, whereby 11,043 firms returned a questionnaire. The reference period covered is 2014 to 2016 (for more details, see Schwartz 2017).

The KfW SME panel offers detailed information on German SMEs, enabling in-depth analysis of their economic behaviour (e.g. regarding the number of employees, investment or finance). One section of the questionnaire is regularly dedicated to the topic of innovation. Several questions concerning companies' innovation process are asked every year to respondents (e.g. on innovations introduced in the last 3 years, shares of turnover from product innovations or the use of R&D), all of which fully comply with the Oslo Manual guidelines (OECD/Eurostat 2005). In addition, information is collected in individual survey waves on special innovation topics of interest. For example, in 2017, a number of questions on interactive learning were included.

A distinct advantage over comparable datasets (notably the German contribution to the Community Innovation Surveys, CIS) is the inclusion of micro enterprises with five or fewer employees, which form the bulk of the German SME sector in terms of company numbers. Another advantage of the KfW SME panel compared with the German CIS is its broad sectoral coverage, since no industries are excluded ex ante from the panel due to lower R&D intensities. Owing to these two advantages, we are able to draw a more complete picture of the German SME sector in terms of innovation, especially when it comes to DUI learning in less R&D-oriented knowledge environments.

At the starting point of the empirical analysis, we restricted the data set in two ways. First, observations from firms with more than 499 full-time employees are removed to ensure that we retain our focus on the SME sector. Second, since we are interested in the learning modes of innovating SMEs, the data set is confined to the subsample of companies that introduced innovations during the reference period. In accordance with the Oslo Manual (OECD/Eurostat 2005), a company is classified as innovative if it has introduced new or significantly improved products or services (product innovation) and/or if it has implemented new or significantly improved production or delivery methods (process innovation) during the 2014-2016 period.

In the first part of the empirical analysis (Section 3), the sample size amounts to n = 2,776. These innovating SMEs are grouped by means of cluster analysis to identify their mode learning. The regression models in the second part of the empirical analysis (Section 4) combine these clustering results with information on three performance indicators as dependent variables and several control variables. The number of observations available at this stage lies between 2,300 and 2,500 firms, depending on which performance indicator is examined.

2.2 Baseline variables

Table 2 provides descriptive statistics for the baseline variables used to cluster innovating SMEs according to their mode of learning. As noted above, our interest lies on the role of R&D as a typical indicator of the STI mode and the use of various forms of interactive learning. Consequently, the first clustering variable measures whether an innovating SME conducted in-house R&D during the reference period. In our sample, this is true for about 39% of observations.

Table 2 Descriptive statistics of the baseline variables used in the cluster analysis

	Mean	S.D.	Min	Max
In-house R&D-activity[a]	0.39	0.49	0	1
Use of external sources for innovation[b]				
Customers/users/clients	0.74	0.44	0	1
Competitors	0.37	0.48	0	1
R&D service providers/consultancy firms/marketing firms	0.16	0.37	0	1
Trade press	0.36	0.48	0	1
Trade fairs	0.48	0.50	0	1
Suppliers of inputs, materials, components	0.38	0.48	0	1
Universities and other public research institutions	0.16	0.36	0	1
Innovation-oriented exchanges internal to the firm[c]				
Maintaining informal contacts within the firm	3.67	1.12	1	5
Ideas and concepts relevant to innovation are communicated openly within the firm	3.73	1.09	1	5
Joint development of innovation goals and strategies	3.36	1.18	1	5
Mutual support in the case of problems with innovation projects	3.50	1.14	1	5
Regular meetings among managerial staff to discuss issues related to innovation	3.68	1.18	1	5
Joint workshops in the context of innovation projects	2.58	1.28	1	5
Staff exchange programmes between departments in the context of innovation projects	2.05	1.24	1	5

Note: The total number of observations amounts to 2,776 companies in each case, since the sample of the final cluster solution presented in Table 3 was taken as a basis for calculating the descriptive statistics.

[a] Survey question: "Did your enterprise conduct in-house R&D in the years 2014 to 2016 (continuously or occasionally)?"

[b] Survey question: "Which of the following external sources have contributed to your innovations activities in the years 2014 to 2016 (i.e. to find ideas, to realise innovation projects or to launch innovations on the market)?"

[c] Survey question: "To what degree did innovation-oriented interactions occur within your enterprise in the years 2014 to 2016? (1= 'very low' to 5 = 'very high')"

One set of dummy variables refers to interactions between responding SMEs and a variety of external sources of innovation. With this information, we aim to account for the key notion underlying the STI/DUI concept that interactive learning is crucial for understanding innovation and that this takes place in a broader institutional and systemic context (Asheim and Parrilli 2012). Formal collaborations with universities, other public research institutes, technology centres or consultancy firms are classified by previous studies as STI types of interactive learning (see e.g. Chen et al. 2011; Fitjar and Rodríguez-Pose 2013; González-Pernía et al. 2015; Parrilli and Alcalde Heras

2016). The new knowledge produced by these science-related actors is often analytical (codified) and explicit. It can constitute a major source of innovation for firms, regardless of whether they perform in-house R&D or not. However, it has to be noted that such inter-institutional links to science-related actors often also involve tacit know-how flows (e.g. through face-to-face contacts or staff exchanges; see Howells 1996). Interaction within the supply chain (i.e. with suppliers and customers) or to competitors in the same industry or sector are used by previous studies as DUI indicators (ibid.). The interactive learning occurring between companies and such non-scientific actors is assumed to continuously generate experience-based (tacit) knowledge that drives creative problem-solving and incremental improvements of existing products and processes.

As expected, innovation in the German SME sector most frequently arises from interaction with customers ('customers/users/clients'; see Table 2). 74% of responding firms reported that this external source of DUI learning stimulated their innovation activities during the reference period. Among the respondents of our sample, the second most widely-used external source of innovation is visiting trade fairs (48%), followed by suppliers, competitors and trade press reading as further learning stimuli. We also expect these four sources to be DUI drivers. The least commonly-reported source on average is learning by interacting with 'R&D service providers/consultancy firms/marketing firms' and 'universities and other public research institutions', with 16% in each case. Both sources should be strongly related to the STI mode of learning. This result reflects the low R&D orientation in the majority of innovating SMEs (on this issue, see Section 1).

Based on a second set of variables, the degree of innovation-oriented interactions within the firm is measured on an ordinal scale (see Table 2). In the STI/DUI literature, such exchanges that take place between people and departments within the boundaries of the firm are also used as indicators of DUI mode learning (see e.g. Jensen et al. 2007; Nunes and Lopes 2015; Parrilli and Elola 2012). This is reasonable as all of them involve intra-firm flows of tacit knowledge at individual, group or departmental levels (Howells 1996). Seven areas of internal interaction are examined (Table 2). According to the descriptive results, an intra-firm innovation culture characterised by open communication about new ideas and approaches to solving problems is most strongly emphasised by innovating SMEs. Closely related to this is the fact that the degree of interactive learning through informal contacts within the firm and through regular meetings among managerial staff also tends to be relatively high. By contrast, 'joint workshops in the context of innovation projects' and 'staff exchange programmes between departments in the context of innovation projects' are less commonly used on average. The most likely explanation for this is that these two areas of interaction only come into consideration in the relatively small group of larger SMEs, as these innovating firms are already organised by functional departments as a result of their growth.

3 Identifying different modes of learning among innovating SMEs

3.1 Preparing clustering variables

In preparation of the cluster analysis, the two variable sets on interactive learning are compressed into distinct factors by means of factor analysis. Accordingly, we aim to create clustering variables that are more robust than the originals. Moreover, doing so seeks to avoid the negative impact of multicollinearity on the cluster analysis results (Hair et al. 1998). The latent root criterion is used to decide on the number of factors to extract. It represents the most commonly-used technique for this purpose. Thus, only factors with eigenvalues greater than one are retained. Regarding the seven dummies of the first variable set on interactive learning, this criterion – based on a polychoric correlation matrix – leads to a three-factor solution. Accordingly, three types of interactive learning between innovating SMEs and their external environment can be distinguished (see Table A1 in the Appendix).

The first factor is marked by high loadings on suppliers, trade fairs and trade press (Table A1). These three sources of innovation are all related to the use of certain industry knowledge holding relevance in the business environment of a company. It is thus labelled 'learning from specific industry knowledge'. The reliance on customers (respectively users or clients) and competitors as sources of innovation instead loads significantly on Factor 2. This type of interactive learning relates to the ongoing need for the majority of SMEs to remain competitive through customer-oriented innovation. In this case, the fruitful interplay between the natural strive for competitiveness and the satisfaction of customer needs leads to the continuous introduction of new or improved products or processes. The second factor is summarised under the heading 'learning from market competition'. Factor 3 shows high loadings on 'R&D service providers/consultancy firms/marketing firms' and 'universities or other public research institutions'. Here, learning from scientific knowledge increases the innovativeness of SMEs, and thus the third factor is labelled as 'learning from scientific knowledge'.

Regarding this first variable set, a prior application of Bartlett's test of sphericity confirms that it is appropriate to apply factor analysis (Chi-square = 712.67, $p < 0.000$). This test is used to check whether there is sufficient correlation among the variables used for structure detection. Another measure to ensure the appropriateness of factor analysis is the Kaiser-Meyer-Olkin Measure of Sampling Adequacy. The lower the corresponding index, the lower the intercorrelations among the variables used for factor analysis. In case of the first variable set, the

KMO amounts to 0.56, which is quite low but still acceptable in terms of common guidelines (Hair et al. 1998). However, the later cluster analysis requires differentiated variables for clustering that are as distinctive as possible. Sets of original variables that are less distinctive (i.e. not highly correlated) thus deteriorate the quality of the cluster solution (ibid.). Accordingly, a trade-off is required between the need to compress correlated variables by means of factor analysis to avoid the negative impact of multicollinearity on the cluster analysis results and the need to minimise the deteriorating effect of less distinctive clustering variables on the quality of the cluster solution. In trying to find this compromise, we decided not to use metric factor scores on the first variable set for clustering (i.e. weighted variables of each factor computed for each respondent), because this would increase the effect of lower distinctiveness. Instead, based on the factor scores, three dummy variables are created that measure whether the relevance of the corresponding factors is higher than the sample average in the individual case. According to this, Factor 1 (learning from specific industry knowledge) holds above-average importance for 43.0% of innovating SMEs. The corresponding shares of Factor 2 (learning from market competition) and Factor 3 (learning from scientific knowledge) amount to 57.0% and 34.3%. The results of the later cluster analysis confirm that this methodological procedure leads to a superior cluster solution than when metric factor scores are used.

In case of the variable set on innovation-oriented exchanges that are internal to the firm, a two-factor solution is found, explaining 67.8% of the variance (see Table A2 in the Appendix). The first factor accounts for the bulk of the variance. It is characterised by high loadings on the maintaining of informal contacts, the open discussion of innovation-related ideas and concepts, the joint development of innovation goals and strategies, the mutual support in case of problems and the regular occurrence of meetings among managerial staff to discuss issues related to innovation. Factor 1 thus refers to the overall degree of (informal) interaction among the staff of innovating SMEs, as is labelled as ‘learning from interaction between people within the firm or a specific department’. On the other hand, the conduct of joint workshops and the existence of staff exchange programmes both load significantly on Factor 2. We suppose that the second factor refers to interactive learning that takes place between different departments of larger SMEs. In fact, the results of the following empirical analysis support this assumption (see Section 3.2), allowing Factor 2 to be summarised under the heading ‘learning from interaction across departments’. The results of Bartlett’s test of sphericity (8224.53, $p < 0.000$) and the Kaiser-Meyer-Olkin Measure (KMO = 0.86) are both highly satisfactory. Therefore, in case of the variables on innovation-oriented exchanges that are internal to the firm, we decided to use metric factor scores (standardised to zero mean and a standard deviation of one) as variables for clustering.

3.2 Cluster analysis

Based on the factor analysis results, we are now equipped with six variables than can be used to identify different modes of learning among innovating SMEs.2 A hierarchical clustering procedure is carried out by using Ward’s method with squared Euclidian distances. The corresponding results strongly point to a three-cluster solution. This can already be seen by a visual inspection of the corresponding dendrogram (see Fig. A1 in the Appendix). The additional use of two cluster stopping rules also clearly suggests a three-group solution (see Table A3 in the Appendix).

The final cluster solution is presented in Table 3. All clustering variables significantly differ across the three groups, which confirms that they are distinctive. The first group of innovating SMEs comprises 42.62% of the total sample. It is marked by above-average levels of learning from market competition and learning from interaction between people within the firm or a specific department. On the other hand, the use of external scientific knowledge sources and the relevance of in-house R&D are below the sample average. This indicates that person-embodied know-how and informal processes of interactive learning play a paramount role in Cluster 1 in terms of innovation. Regarding the underlying learning process, we interpret that SMEs in the first group try to stay ahead of their competitors by incrementally improving products and processes to meet consumer needs. This leads to a continuous learning with experience-based knowledge accumulated by the people of the firm (i.e. ‘learning from market competition’). Apparently, this is likely to succeed if this also involves a high degree of interaction within the firm, as such a learning culture increases employee involvement in innovation activities. Accordingly, tacit knowledge can be acquired and transferred more effectively inside the firm at individual or group levels (i.e.

[2] The six variables are in-house R&D activity, learning from specific industry knowledge, learning from market competition, learning from scientific knowledge, learning from interaction between people within the firm or a specific department, and learning from interaction across departments.

'learning from interaction between people within the firm or a specific department'). The first cluster of innovating SMEs thus close resembles the idealised conception of DUI mode learning discussed in Section 1. Accordingly, it is named the 'customer-oriented DUI group'.

Table 3 Cluster solution: mean values of the clustering variables and statistical significance of cluster differences (N = 2,776)

	Total	Cluster (1)	(2)	(3)	Chi-square
Use of external sources for innovation (above-average importance of factors 1/0 in %)					
Learning from specific industry knowledge	42.98	43.11	48.46	39.92	10.73*
Learning from market competition	57.02	61.96	38.29	61.32	98.51*
Learning from scientific knowledge	34.26	28.57	32.12	41.84	44.72*
Degree of innovation-oriented exchanges internal to the firm (factor scores[a])					
Learning from interaction between people within the firm or a specific department	0.01	0.63	-1.22	-0.03	1293.53*
Learning from interaction across departments	0.00	-0.62	-0.54	1.00	1665.04*
In-house R&D activity in %	38.72	37.95	18.33	50.38	156.57*
Share of sample in %	100.0	42.62	19.85	37.54	
Cluster label		Customer-oriented DUI group	Supplier-dependent DUI group	STI/DUI group	

[a] Factor scores are standardised to a mean of 0 and standard deviation of 1.

* report a significance level of 1% (Exchanges internal to the firm: Kruskal-Wallis test with ties; Use of external sources for innovation and in-house R&D activity: Pearson's chi-square test)

A specific feature of the second cluster – comprising 19.85% of innovating SMEs in the total sample – is the almost complete lack of own in-house R&D (see Table 3). Learning from external scientific knowledge also takes place at a below-average level. While this would indicate a close proximity to the DUI mode, at the same time the impetus for innovation less often comes from market-driven interaction with customers. Moreover, interactive learning among people and departments within the firm is weakly developed. Both observations would speak against the possession of strong DUI mode competencies. However, in Cluster 2, innovation activities tend to be connected with other DUI-related knowledge sources, namely learning from specific industry knowledge. SMEs in the second cluster tend to depend on suppliers, visiting trade fairs and reading the trade press when it comes to innovation (e.g. for gaining new ideas, following the latest trends and innovations, finding information to solve specific problems or generating new inter-firm contacts). Therefore, the second cluster is labelled as the 'supplier-dependent DUI group'.

The third cluster – referred to as the 'STI/DUI group' – comprises 37.54% of the total sample. The innovating SMEs in this group share a strong emphasis on STI mode learning. Performing in-house R&D as well as learning from external scientific knowledge is vital for them to achieve innovative results. At the same time, the result of Thomä (2017) is confirmed, namely that – at the firm level – the STI mode is unlikely to be integrated alone without complementing this with DUI mode competencies. Moreover, interactive learning with customers is also an important driver of innovation in the case of Cluster 3 (i.e. 'learning from market competition'). Learning from interaction between people within the firm or a specific department is holding average importance, while learning from interaction across departments is clearly above average. Along with the strong focus on in-house R&D, this provides the first hint that firms in Cluster 3 are larger in size than those in the first and second clusters, probably allowing them to introduce innovations with a higher degree of novelty by relying on their own technological competencies.

In order to assess the predictive validity of the derived cluster solution, variables are needed that have a theoretically-based relationship with the identified modes of learning but have not previously been used to identify the clusters (Hair et al. 1998). For this purpose, we use information on the responding firms' intensities of R&D and total innovation expenditure, their company size in terms of employee numbers and the industry sector to which they belong. Descriptions of these validating variables are shown in Table A4 in the Appendix. The cluster solution is considered distinctive if these validating variables significantly vary across the three groups of innovating SMEs. According to the within-cluster results in Table 4, this is indeed the case.

Table 4 Predictive validity of the cluster solution[a]

	Total	Cluster			
		Customer-oriented DUI group	Supplier-dependent DUI group	STI/DUI group	Chi-square
R&D expenditure/turnover in %	1.73	1.07	0.38	3.21	151.32*
Total innovation expenditure/turnover in %	3.82	4.22	2.03	4.34	105.37*
Firm size					
Microenterprise	34.19	37.45	43.01	25.82	
Small-sized enterprise	42.40	44.55	38.11	42.23	
Medium-sized enterprise	23.41	18.01	18.87	31.96	93.39*
Industry sector					
Manufacturing	33.11	34.74	25.05	35.51	
Construction	9.04	8.88	12.16	7.58	
Trade	27.41	28.74	31.94	23.51	
Services	28.35	25.53	28.31	31.57	
Others	2.09	2.11	2.54	1.82	40.71*

* report a significance level of 1% (Kruskal-Wallis test with ties, Pearson's chi-squared test)

[a] Within-cluster results are provided, i.e. the percentage share per cluster is shown. For example, the R&D expenditure as a share of turnover amounts to 1.07% in case of Cluster 1 (Customer-oriented DUI group).

As expected, the expenditure on in-house R&D in relation to a firm's turnover is highest in the STI/DUI group. The corresponding measure of intensity amounts to 3.21%, which is clearly above the average level of 1.73% (see Table 4). With respect to the intensity of total innovation expenditure, it is interesting to observe that the customer-oriented DUI group reaches the same percentage level as the STI/DUI group (4.22% vs. 4.34%). Total innovation expenditure is the sum of all expenditures for innovation activities. Apart from in-house R&D, it includes further types of expenditures (e.g. acquisition of external R&D services, acquisition of machinery and equipment, industrial design, industrial engineering and tooling up, innovation-related training and marketing activities, etc.). Accordingly, while the intensity of in-house R&D expenditure in the customer-oriented DUI group reaches an appreciable level with 1.07%, innovation activities extending beyond in-house R&D account for the major share of innovation expenditure in the first cluster. Despite starting from a lower level, something similar is true in the case of the supplier-dependent DUI group. In this group of innovating SMEs, the intensity of in-house R&D expenditure only amounts to 0.38%, while the total innovation expenditure intensity is about 2 %. Hence, also in case of the second cluster, innovation expenditure mostly relates to activities other than in-house R&D. Exactly the opposite is true for the STI/DUI group, in which a relatively small share of expenditure on non-R&D innovation inputs3 is complemented by a strong emphasis on in-house R&D expenditure.

The diverse role played by resource-intensive R&D in the innovation processes of SMEs is also reflected by significant differences in the firm size structures of the three learning modes (Table 4). Larger SMEs – i.e. medium-sized enterprises with 50 to 499 employees, which should have fewer resource constraints in general – make up a

[3] The share of non-R&D innovation expenditure in case of the STI/DUI group would probably be even smaller if the acquisition of extramural R&D could be excluded (i.e. the purchase of R&D services from public or private research institutions or other companies).

relatively large share of the R&D-oriented STI/DUI group (almost one-third of companies). In the customer-oriented DUI group with its still-appreciable intensity of in-house R&D, the majority of enterprises are small-sized, with between 10 and 49 employees. On the other hand, the almost complete absence of in-house R&D in the supplier-dependent DUI group is related to the fact that microenterprises – with up to 9 employees – account for the largest share of this cluster.

In light of the differences in knowledge bases of industrial sectors (Malerba and Orsenigo 1997; Malerba 2002), a further validating variable measures the industry composition of the three clusters (Table 4). Relatively large shares of manufacturing SMEs characterise both the customer-oriented DUI group as well as the STI/DUI group (34.74% and 35.51%). On the other hand, the supplier-dependent DUI group shows an above-average concentration on construction and wholesale/retail trade sectors (12.16% und 31.94%). This partly explains the important role played by suppliers, trade fairs and trade magazines as sources for innovation in this group of SMEs. Especially in construction and trade sector industries, small businesses often serve as intermediate users transferring new products developed by large suppliers (producers or manufacturers) to other firms or end customers. Often, this goes hand in hand with making minor improvements or adaptations to existing products to meet specific demand requirements. Moreover, their feedback on user experience often helps suppliers to improve their products and process or develop entirely new solutions. Accordingly, firms in the supplier-dependent DUI group are important in terms of technology diffusion and incremental innovation.

The final step of the cluster analysis (after the three learning modes have been identified and their predictive validity has been confirmed) is to profile the different groups of innovating SMEs on additional variables that are likely to predict cluster membership (Hair et al. 1998). Table 5 presents across-cluster results, as we expect causality to run from these profiling variables to the belonging to a particular cluster. For this purpose, the differences between the across-cluster percentages and the expected frequency distribution are shown. The corresponding results provide further hints regarding the practical significance of the derived cluster solution. Descriptions of the profiling variables are shown in Table A4 in the Appendix.

The first profiling variable measures whether a responding SME belongs to the skilled crafts sector. This sector constitutes a large part of the German Mittelstand, as it is dominated by a large number of small businesses from a variety of industries. In case of craft-based SMEs, a close link to the DUI mode of learning can be expected, since a core feature of craft knowledge is its tacit nature (Sennett 2009) and given that craft firms typically operate in more traditional, less R&D-intensive manufacturing and service industries. Our empirical results lend some support to this hypothesis (see Table 5): craft-based SMEs are more likely to be members of the customer-oriented and the supplier-dependent DUI groups, while they are less likely to be found in the STI/DUI group.

With two additional profiling variables, we account for the phenomenon that DUI mode learning is deeply rooted in the German innovation system due to the key importance that vocational education and training holds for skill formation in Germany (see Thomä 2017). Accordingly, innovating SMEs that place a strong emphasis on vocational qualifications should be more likely to concentrate on the DUI mode of learning (see Section 1). Indeed, this is exactly what we observe: firms in the customer-oriented and the supplier-dependent DUI groups show the highest propensity to have only non-academic employees, whereas innovating SMEs having no employees with a university degree are relatively seldom found in the STI/DUI group. To make this picture complete, we also examine the qualification degree of company owners. As expected, in case of company owners with advanced vocational qualification (such as those of master craftsmen, foremen, certified industrial supervisors), it is more likely that the corresponding companies are members of Cluster 1 or 2 (see Table 5).

Table 5 Profiling of the cluster solution[a]

	Cluster			
	Customer-oriented DUI group	Supplier-dependent DUI group	STI/ DUI group	Chi-square
Craft-based SMEs	+2.4	+2.8	-5.2	16.07*
No employees with university degree	+1.8	+7.0	-8.8	64.86*
Company owner with advanced vocational qualification	+3.0	+3.7	-6.7	15.45*
Export market activities	+1.2	-6.0	+4.8	71.27*
Regional business focus	-4.7	+10.4	-5.7	58.20*
Degree of innovation				
New products with higher innovativeness	+0.1	-6.2	+6.1	11.54*
New processes with higher innovativeness	+0.1	-14.5	+14.4	30.79*
Learning from failure culture	+3.4	-6.6	+3.2	48.13*
Management practices to stimulate innovation				
Material incentives for employees to actively contribute to innovation efforts	-3.1	-3.6	+6.7	39.50*
Non-material incentives for employees to actively contribute to innovation efforts	+3.3	-3.9	+0.7	17.57*
Integration of innovation success indicators into targets agreed with employees	-4.0	-5.5	+9.6	27.66*
Organisational measures to ensure efficient use of existing know-how	-2.6	-3.4	+6.0	34.76*
Measures to find, promote and keep innovation-related personnel	-3.0	-5.6	+8.6	27.23*
Delegation of decision-making powers in innovation projects	+0.9	-4.7	+3.9	16.52*

* report a significance level of 1% (Pearson's chi-squared test)

[a] Across-cluster results are provided, i.e. the observed frequency distribution of firms across clusters minus the expected frequency in percentage points is shown.

The degree of technological innovativeness and the spatiality of learning and knowledge are other dimensions on which STI and DUI modes are expected to vary (see Section 1). In this regard, the customer-oriented DUI group occupies a middle position between the supplier-dependent DUI group and the STI/DUI group (Table 5). SMEs that compete in international markets and those with higher degrees of technological innovativeness are most likely to be a member of the third cluster. By contrast, both types of companies are much less inclined to be found in the second cluster. This means that the supplier-dependent DUI group is largely composed of incremental innovators with a focus on local or regional markets. Hence, the middle position of the customer-oriented DUI group implies that the first cluster – despite being less R&D intensive – has an appreciable propensity to include SMEs that are particularly innovative and competitive (nonetheless, which is lower than in the STI/DUI group).

Where the customer-oriented DUI and the STI/DUI groups hardly differ is the probability of having a culture of learning from mistakes (Table 5). Such a failure culture refers to the degree of trial-and-error learning and experimentation within the firm. Experience-based knowledge generated through experimentation and trial and error are core elements of DUI mode innovation (Asheim and Parrilli 2012; also see Table 1 in Section 1). This is another hint that innovating SMEs in the first cluster can compensate (at least to some degree) for their lack of in-house R&D by having distinct DUI mode competencies. In this context, it is interesting to observe that companies that intentionally promote employee involvement in innovation through management practices are especially likely to be in the STI/DUI group. There is only one exception to this finding: innovating SMEs that provide non-material incentives for employees to engage in innovation (e.g. public acknowledgements, time and space for experimentation or constructive criticism when mistakes are made) are most likely to be a member of the customer-oriented

DUI group. These results are probably linked to the firm size differences between Cluster 1 and 3 (see Table 4). The larger-sized SMEs in the STI/DUI group have more resources available to stimulate employee-driven innovation, including financial rewards. However, due to organisational hierarchies and bureaucracies related to their larger firm size, the corresponding firms may also be obliged to use a broad set of management practices if they want to ensure that their employees are still effectively involved in innovation. By contrast, in the case of the smaller-sized SMEs of the customer-oriented DUI group, the typical advantages that small innovating firms have in terms of internal communication may come to fruition (see Section 1). Hence, in the first cluster it is probably sufficient to rely on non-material incentives for employees to build up a failure culture as a ground for DUI innovation, whereas in the third group a broader set of management practices is required for this aim.

4 The link to economic performance

In this section, we examine the link between learning modes and the overall economic performance of innovating SMEs. Three performance indicators are used (see Table 6). The first one measures the percentage of sales growth between 2015 and 2016. As a second indicator of performance, the percent change in employment from 2014 to 2016 is calculated. The third dependent variable refers to the growth in labour productivity, which is measured by calculating sales per full-time employee for 2015 and 2016. The reader should note that we only have cross-sectional data, as questions on interactive learning were included only once in the KfW SME panel (see Section 2.1). However, in each questionnaire of the KfW SME panel, responding companies are asked to give information on their sales and their number of employees for different years, which enables us to calculate the mentioned performance indicators.

Table 6 Descriptive statistics of the dependent variables used in in the performance analysis

Dependent Variable	Variable description	Mean	S.D.
Sales growth	Change in sales from 2015 to 2016 in %	10.30	46.98
Employment growth	Change in the number of full-time employees from 2014 to 2016 in %	12.24	37.61
Change in labour productivity	Change in sales per full-time employee from 2015 to 2016 in %	6.77	39.44

As a first step, the average relationship between the learning modes identified in Section 3 and the three performance indicators is estimated by means of ordinary least squares (OLS) regression. The STI/DUI group is used as the reference group. The corresponding results are presented in Table 7. Each regression model includes several control variables to account for potential confounding factors. For example, this holds for the potential impact of firm size and firm age. The engagement in competitive export markets, the share of academic workforce and the respondent's industry sector are used as further controls. Finally, in order to control for any structural bias, four binary variables indicate whether the legal form of a company implies limited liability to the owners, whether a company is autonomous in terms of shares or voting rights, whether a respondent's company locates in East Germany and whether it had received any subsidies through a government support programme conducted by the KfW Bankengruppe. Descriptions of the control variables are shown in Table A5 (see Appendix).

Table 7 Performance analysis - results from OLS regression

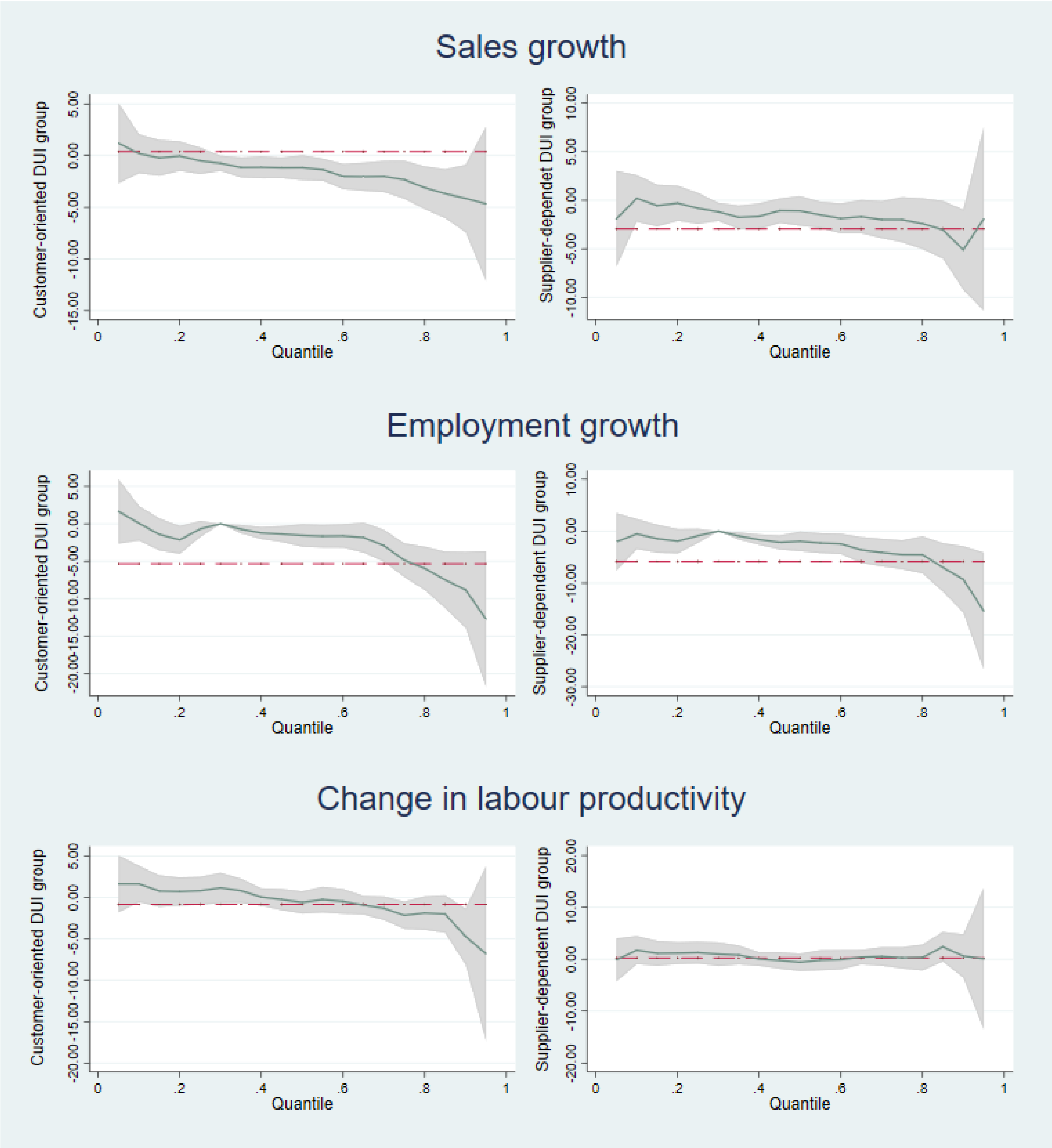
	Sales growth	Employment growth	Change in labour productivity
Customer-oriented DUI group	0.388 (1.93)	-5.339 (1.58) ***	-0.840 (1.74)
Supplier-dependent DUI group	-2.941 (1.70) *	-5.857 (2.12) ***	0.244 (2.19)
STI/DUI group	Left out	Left out	Left out
Log (employees)	-3.627 (1.01) ***	-3.680 (0.99) ***	-2.567 (0.774) ***
Log (firm age)	-7.013 (1.39) ***	-8.719 (1.24) ***	-4.484 (1.08) ***
Share of academic work-force	0.132 (0.073) *	0.030 (0.036)	0.038 (0.05)
Export activities	-2.663 (2.33)	0.884 (1.68)	-3.180 (1.78) *
Manufacturing	Left out	Left out	Left out
Construction	-1.528 (2.74)	1.354 (2.61)	-3.666 (2.45)
Trade	-4.614 (2.25) **	2.025 (2.030)	-6.615 (1.74) ***
Services	-4.225 (2.99)	-2.675 (2.17)	-2.971 (2.48)
Other sectors	21.661 (28.45)	-5.997 (4.50)	10.877 (18.11)
Limited liability	4.523 (2.26) **	1.805 (2.38)	0.957 (2.16)
Non-autonomous enter-prise	2.826 (2.79)	2.619 (2.00)	0.903 (1.89)
East Germany	-5.126 (2.43) **	-5.028 (1.65) ***	-1.736 (1.85)
Subsidy status	1.454 (2.04)	1.334 (1.711)	1.883 (1.62)
Intercept	42.489 (7.05) ***	53.10 (5.92) ***	31.53 (5.61)
F-statistic	3.50 ***	8.03 ***	3.00 ***
Number of observations	2,356	2,487	2,327

*** report a significance level of 1%, ** of 5% and * of 10%; Robust standard errors in parentheses

The OLS results indicate that on average the customer-oriented DUI group does not significantly underperform compared with the STI/DUI group in terms of sales growth and change in labour productivity (Table 7). Hence, the less R&D-oriented SMEs of the first cluster are largely found to be similarly able to increase their economic performance compared with the R&D-performing SMEs of the third group. The only exception is employment growth. In this case, firms in the customer-oriented DUI group significantly fall behind their counterparts in the STI/DUI group on average. Regarding the supplier-dependent DUI group, the picture looks slightly different. Now, in addition to a lower degree of employment growth, the overall sales performance of the second cluster is lower than that of the STI/DUI group (albeit results are only statistically significant at the 10% level). In the case of labour productivity, no significant differences are found between the supplier-dependent DUI group and the reference group.

As noted above, the OLS regression results only refer to the average response of the performance indicators to the independent variables. Consequently, they only provide a partial view on the relationship between learning modes and economic performance of innovating SMEs. To overcome this limitation, as a second step, quantile regression for the same set of dependent and independent variables is performed at a number of percentiles of the performance distribution. Hence, learning mode effects are estimated at different points of the empirical distribution of the three performance indicators. Accordingly, we are able to account for the fact that the relationship between learning modes and economic performance may be very different among high-performing SMEs compared with firms at the bottom or the middle of the performance distribution. Quantile regression results for the learning mode variables are shown in Fig. 1.

Fig. 1 Performance analysis - results from quantile regression



Note: The STI/DUI group served as a reference in each case.

Fig. 1 illustrates how the learning mode effects vary across different quantiles of the performance distribution (fluctuating solid line) and how this relates to the OLS estimate, i.e. the average effect (horizontal dashed line). The confidence intervals around the quantile regression coefficients are also shown (grey area). It is important to interpret the coefficients of the quantile regressions in reference to the zero line and the OLS estimate. The greater the distance to the zero line, the stronger the magnitude of economic performance at the corresponding quantile. A parallel comparison to the OLS estimate shows how considerably this performance effect differs from the average response in each case. Statistical significance can be visually checked, whereby a quantile regression coefficient is statistically significant when its confidence interval does not intersect with the zero line.

The results of the quantile regression for the sales growth indicator are presented in the upper part of Fig. 1. Almost up to the 60th percentile (which corresponds to growth rates of above 5%; see Table A6 in the Appendix), there is virtually no difference between the customer-oriented DUI group and the STI/DUI group in terms of sales performance. Only when growth rates exceed this level, the innovating SMEs in the first cluster increasingly fall behind the R&D-performing SMEs in the third cluster. The sales performance of companies in the supplier-dependent DUI group starts to be significantly lower compared with the reference case at the level of zero growth (i.e. about the 30th percentile, See Table A6). The magnitude of this effect tends to grow with larger quantiles. However, statistical significance remains at a constant low level across the performance distribution (see Fig. 1). This confirms the OLS results of Table 7, according to which the lower average sales performance of the supplier-dependent DUI group being measured only holds weak statistical significance.

The middle part of Fig. 1 displays the results of the quantile regression for employment growth. It is striking that the employment performance of both the customer-oriented DUI and the supplier-dependent DUI groups is rather similar to that of the STI/DUI group up to moderate single-digit growth rates (i.e. around the 60th percentile; see Table A6). However, when employment growth rises to double-digit rates, the performance of less R&D-oriented SMEs in the first and second clusters sharply drops (see Fig. 1). Hence, the significant negative OLS effect (see Table 7) primarily results from the fact that the employment growth of the customer-oriented DUI and the supplier-dependent DUI groups strongly decreases at higher quantiles of the performance distribution. Most likely, SMEs only consider hiring new personnel after a certain sales level has been reached. Germany's less flexible labour market probably plays a role in this context. In light of relatively strong job protection rules, it is likely that many firms are cautious about recruitment. Accordingly, when sales volumes increase, available human resource capacities are fully utilised first before new employees are hired.

The quantile regression results on labour productivity complement this picture (see. Fig. 1). Regarding this performance indicator, the customer-oriented DUI group starts to lag behind the STI/DUI group around the 70th percentile. However, this effect remains relatively weak with low statistical significance. In case of the supplier-dependent DUI group, no statistically significant difference compared with the STI/DUI group can be observed across the whole performance distribution. Hence, there is some empirical evidence that the less R&D-oriented SMEs in the first and second clusters are – at least mainly – not less productive than R&D performers in the third cluster.

5 Conclusion

Theoretically, there are two ideal-type modes of learning at the firm level. The "science, technology and innovation" (STI) mode is characterised by distinct in-house R&D competencies that are combined with scientific knowledge from universities and other external research institutions to generate innovations with high degrees of novelty. In the "doing, using and interacting" (DUI) mode, the focus is on experience-based knowledge and collaboration with customers, suppliers or competitors rather than in-house R&D activities. DUI learning often results in incremental innovation instead of disruptive innovation. Moreover, interaction between people and departments within the firm holds particular relevance for innovation success in the DUI mode.

In the present paper, the STI/DUI concept has been transferred to the German Mittelstand (Pahnke and Welter 2018) by empirically examining the use of R&D and interactive learning among innovating SMEs. Our special interest has focused on the many less R&D-intensive innovators in the small business sector not least to provide a better understanding of the DUI mode. According to our results, there are three modes of learning. On one side of the spectrum, there is the supplier-dependent DUI group, reflecting SMEs that almost entirely innovate without internal R&D and focus on minor improvements of existing products and processes. Based on vocational qualifications, they are able to respond to innovation impulses from suppliers, trade fairs or the trade press. We assume that the members of the supplier-dependent DUI group hold key importance to the successful diffusion of new technologies and the introduction of incremental innovations. A typical example of this learning mode are micro-enterprises in construction and trade sectors that make their own modifications to existing products or help producers and manufacturers to develop new ideas based on their user experience.

On the other side of the spectrum is the STI/DUI group. Through distinct R&D competencies and the intensive use of external scientific knowledge sources (i.e. universities, other public research institutions, R&D service providers, etc.), the corresponding SMEs are in a position to actively pursue STI innovation, often resulting in new products and processes with a high degree of novelty. We assume that these firms are often technology leaders in their field. At the same time, our results indicate that innovation activities in this group also depends on DUI mode competencies. Experience-based knowledge gained from interactive learning with the customer side represents a further innovation driver for those firms. Innovation-oriented exchanges within the firm are correspondingly pronounced, because only in this way can the various experiences of the company's employees stimulate each other to come up with creative solutions. Since many companies in the STI/DUI group are larger SMEs, interactive learning often takes place across departmental boundaries. Moreover, these firms try to foster innovation-related interaction among their employees by a number of management practices. A typical example of this mode of learning are R&D-intensive SMEs from manufacturing and service industries.

Positioned somewhere between these two modes is the customer-oriented DUI group. These are SMEs that already have certain competencies in in-house R&D but still primarily focus on non-R&D innovation. Tacit knowledge continuously being generated from personal interaction with customers is the major source of innovation in case of this learning mode. We therefore assume that the members of the customer-oriented DUI group have distinct competencies to solve customer specific problems. In contrast to the supplier-dependent DUI group, the corresponding SMEs have an established culture of experimentation and learning from failure. On this basis, they are proactive and can innovate on their own initiative, which in certain respects makes them similar to the STI/DUI group (for example, the intensity of total innovation expenditure is the same for both groups). As a result, in addition to incremental modifications, innovations in the customer-oriented DUI group are often already associated with higher degrees of novelty. The practical skills and experienced-based knowledge of vocationally-trained workers also plays an important role in this context. A typical example of this learning mode are small craft-based SMEs that concentrate on niche markets and their capacity for customisation to compensate for disadvantages associated with small size.

These findings show that SMEs innovate differently depending on their mode of learning. In order to evaluate this in terms of innovation policy, information on the relationship between the learning mode of a firm and its economic performance is required. As a main result, we observe that each learning mode is likely to positively affect performance, at least to some degree. However, as expected, higher R&D intensities make it more likely that SMEs grow at rapid rates. Members of the two less R&D-oriented groups perform quite similar to the R&D-intensive firms of the STI/DUI group at lower and middle levels of the performance distribution, while they fall behind them at higher growth rates. This is particularly true in the case of employment growth. Hence, there is no difference in economic performance between the three learning modes as long as non-high-growth SMEs are considered. In large parts of the SME sector, performing in-house R&D is thus neither an advantage nor disadvantage in terms of overall company performance. We interpret this result as an economic rationale at the level of the firm for choosing a non-R&D-oriented mode of learning and innovation.

Regarding implications for policy-makers, one might argue that the most efficient way to increase the economic performance of SMEs in the customer-oriented and the supplier-dependent DUI groups through innovation is to foster their investments in in-house R&D. Such policy measures might be effective to some extent, especially when an unconditional tax subsidy for R&D is actually introduced (which is currently under discussion in Germany). However, if it is too narrowly focused on R&D, such a policy approach would ignore the competitiveness of innovating SMEs in the two less R&D-oriented learning modes. Respective SMEs innovate in a way that is economically viable under the conditions of their low- or moderate-growth markets. Under such circumstances, the promotion of technology adoption and diffusion – for example – may be a much more promising policy objective than seeking to increase SME performance by heavily supporting R&D investments. Hence, in order to account for the different learning modes of innovating SMEs, policy-makers need to not only focus on in-house R&D, but they should also place an emphasis on upgrading the general innovative capabilities of smaller firms.

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Appendix

Table A1 Factor analysis on the use of external sources for innovation (principal component factoring based on polychoric correlations, varimax rotated factor loadings)

	Factor 1	Factor 2	Factor 3
Customers/users/clients	-0.061	0.856	0.018
Competitors	0.379	0.660	-0.029
R&D service providers/consultancy firms/marketing firms	0.000	-0.409	0.592
Trade press	0.759	0.031	0.093
Trade fairs	0.783	0.152	0.067
Suppliers of inputs, materials, components	0.592	-0.232	-0.419
Universities and other public research institutions	0.060	0.068	0.821
Interpretation:	Learning from specific industry knowledge	Learning from market competition	Learning from scien-tific knowledge
Proportion of variance accounted for:	24.1%	20.3%	17,3%

Note: The factor analysis is based on observations of 3,207 companies who provided full information on the corresponding variables. The sample size of the later cluster analysis only amounts to n = 2,776 (see Table 3). The reason is that not all respondents provided full information on all clustering variables.

Table A2 Factor analysis on the degree of innovation-oriented exchanges internal to the firm (principal component factoring, varimax rotated factor loadings)

	Factor 1	Factor 2
Maintaining informal contacts within the firm	0.737	0.047
Ideas and concepts relevant to innovation are communicated openly within the firm	0.846	0.099
Joint development of innovation goals and strategies	0.797	0.267
Mutual support in the case of problems with innovation projects	0.831	0.224
Regular meetings among managerial staff to discuss issues related to innovation	0.702	0.316
Joint workshops in the context of innovation projects	0.317	0.760
Staff exchange programmes in the context of innovation projects	0.073	0.866
Interpretation:	Learning from in-teraction between people within the firm or a specific department	Learning from interaction across depart-ments
Proportion of variance accounted for:	45.5%	22.3%

Note: The factor analysis is based on observations of 2,857 companies who provided full information on the corresponding variables. The sample size of the later cluster analysis only amounts to n = 2,776 (see Table 3). The reason is that not all respondents provided full information on all clustering variables.

Fig. A1 Dendrogram for Ward cluster analysis

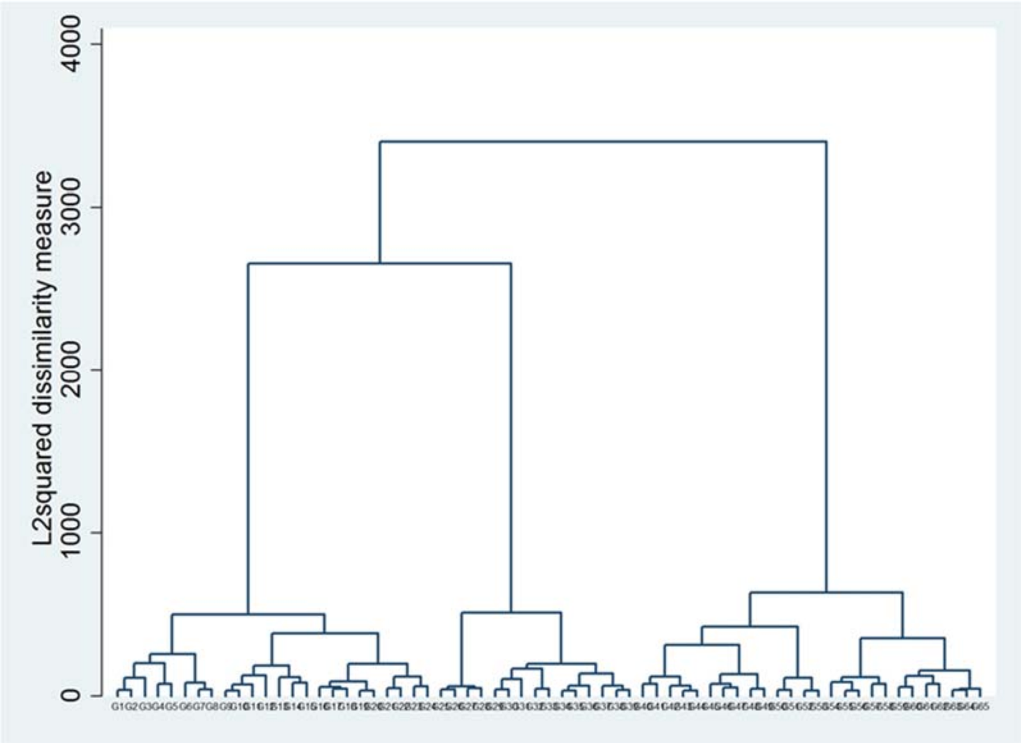

Table A3 Results from cluster-analysis stopping rules used to determine the number of clusters after Wards's method is carried out

Number of clusters	Calinski/Harabasz pseudo-F index	Number of clusters	Duda-Hart index	
			Je(2)/Je(1)	Pseudo T-squared
2	738.21	1	0.7898	738.21
3	829.52	2	0.6884	783.86
4	651.12	3	0.8515	181.36
5	555.44	4	0.7486	184.37
6	503.03	5	0.8696	177.09
7	465.57	6	0.7784	156.57
8	438.69	7	0.8302	147.69
9	418.78	8	0.7934	127.11
10	402.00	9	0.7520	115.40

Note: In case of both rules, larger values indicate more distinct clustering. Exceptions are the pseudo-T-squared values included in the Duda-Hart index. Here, smaller values indicate more distinct clustering

Table A4 Description of variables used for validating and profiling the cluster solution

Variable	N	Description
R&D expenditure/turnover in %	2,544	Total R&D expenditure as a share of turnover
Total innovation expenditure/turnover in %	2,479	Total innovation expenditure as a share of turnover
Firm size		
Microenterprise	949	Firm has 9 or less fulltime employees
Small-sized enterprise	1,177	Firm has between 10 and 49 fulltime employees
Medium-sized enterprise	650	Firm has between 50 and 499 fulltime employees
Industry sector		
Manufacturing	919	Firm belongs to manufacturing industries
Construction	251	Firm belongs to construction industries
Trade	761	Firm belongs to trade industries
Services	787	Firm belongs to service industries
Others	58	Firm belongs to other industries
Craft-based SMEs	2,735	1 if firms belongs to the German skilled crafts sector, 0 otherwise
No employees with university degree	2,656	1 if firm has no employees holding a university degree (incl. universities of applied sciences and "Berufsakademien"), 0 otherwise
Company owner with advanced vocational qualification	2,609	1 if a firm's company owner has passed an advanced vocational training certificate (Meister-/ Techniker-abschluss) as highest qualification degree, 0 otherwise
Export market activities	2,739	1 if firm had any exports, 0 otherwise
Regional business focus	2,739	1 if firm only served local or regional markets within a range of about 50 km, 0 otherwise
Learning from failure culture	2,741	1 if the degree of trial-and-error learning internal to the firm is high or very high, 0 otherwise
Degree of innovation		
New products with higher innovativeness	2,304	1 if firm introduced product innovations that had not yet been supplied to the respective market segment, 0 otherwise
New processes with higher innovativeness	1,878	1 if firm introduced process innovations that had not yet been introduced by competitors, 0 otherwise
Management practices to stimulate innovation		
Material incentives for employees to actively contribute to innovation efforts	1,039	Firm used material incentives for employees to engage in innovation
Non-material incentives for employees to actively contribute to innovation efforts	912	Firm used non-material incentives for employees to engage in innovation
Integration of innovation success indicators into targets agreed with employees	490	Innovation success indicators are part of employee's target agreements
Organisational measures to ensure efficient use of existing know-how	1,093	Organisational measures are taken to ensure efficient use of existing know-how (e.g. team work, innovation circles, employee suggestion systems etc.)
Measures to find, promote and keep innovation-related personnel	532	Measures are taken to find, promote and keep innovation-related personnel
Delegation of decision-making powers in innovation projects	678	Delegation of decision-making powers is used in the conduct of innovation projects

Table A5 Descriptive statistics of control variables used in the regression analysis (taken from the OLS-regression on the sales growth indicator)

Continuous variables	Description	Mean	S.D.
Employees	Number of full-time employees in 2014	40.5	63.7
Firm age	Years since market entry at the time of survey	40.8	45.0
Share of academic workforce	Share of employees holding a university degree (incl. universities of applied sciences and "Berufsakademien")	17.9	25.9
Categorical variables	Description		Percentage
Customer-oriented DUI group	Firm belongs to the Customer-oriented DUI group		49.1
Supplier-dependent DUI group	Firm belongs to the Supplier-dependent DUI group		19.7
STI/DUI group	Firm belongs to the STI/DUI group		31.2
Export activities	1 if firm had any exports, 0 otherwise		53.1
Manufacturing	Firm belongs to manufacturing industries		34.5
Construction	Firm belongs to construction industries		9.1
Trade	Firm belongs to trade industries		27.3
Services	Firm belongs to service industries		27.2
Other sectors	Firm belongs to other industries		1.9
Limited liability	1 if firm's legal form implies limited liability of the owners, 0 otherwise		69.3
Non-autonomous enterprise	1 if other companies have a stake of 25% or more of the firm's capital or voting rights, 0 otherwise		16.3
East Germany	1 if firm is located in East Germany, 0 otherwise		31.5
Subsidy status	1 if firm received KfW subsidies, 0 otherwise		64.0

Table A6 Percentiles of the three performance indicators

	Sales growth	Employment growth	Change in labour productivity
10^{th} percentile	-9.4%	-11.1%	-14.3%
20^{th} percentile	-3.1%	-4.0%	-7.8%
30^{th} percentile	0%	0%	-3,9%
40^{th} percentile	2.6%	0%	-0,1%
50^{th} percentile	5.0%	4.4%	1.8%
60^{th} percentile	7.7%	8.3%	4.9%
70^{th} percentile	11.1%	13.5%	8.1%
80^{th} percentile	16.7%	21.3%	12.9%
90^{th} percentile	25.2%	38.6%	23.7%