Volkswirtschaftliches Institut für Mittelstand und Handwerk an der Universität Göttingen

ifh Working Paper No. 24*/2020

Does Personality Matter? Small Business Owners and Modes of Innovation

Petrik Runst[a], Jörg Thomä[a, b]

[a] *Institute for Small Business Economics at the Georg-August-University Goettingen, Heinrich-Düker-Weg 6, 37073 Göttingen, Germany*

Abstract:

The DUI (learning by doing-using-interacting) mode offers a promising theoretical framework to explain why many small and medium-sized enterprises (SMEs) are successful in innovation without research and development (R&D) efforts. In this context, we argue that – because of the informal, person-centered, and interactive nature of the DUI mode – small business owners should be in a key position to trigger DUI learning processes at the company level. Based on a large SME data set from Germany, we show empirically that Big Five personality traits of small business owners positively affect self-selection into DUI-based innovation in less R&D-intensive SMEs. That is, companies operating largely under the DUI mode seem to benefit in particular from certain owners' personality characteristics. In addition, we present novel evidence that complementarities between different Big Five traits exist in terms of self-selection into the DUI mode, thereby pointing to the role of certain personality prototypes. The paper concludes with implications for policy and further research.

JEL: O31; O32; D91

Keywords: modes of innovation; non-R&D innovation; Big Five personality traits; personality prototypes; SMEs

* Updated version of a working paper published in 2020 with the title "Small Business Owners as Gatekeepers of Knowledge? Personality Traits and Modes of Innovation."

[b] Corresponding author: joerg.thomae@wiwi.uni-goettingen.de.

1. Introduction

The role played by in-house research and development (R&D) in innovation in small and medium-sized enterprises (SMEs) is a matter of ongoing debate. It can be argued that smaller firms face systematic disadvantages in R&D compared to larger firms, which may prevent smaller firms from realizing their innovative potential (Acs and Audretsch 2005; Cohen 1995; Nooteboom 1994; Ortega-Argilés et al. 2009; Rothwell 1989). However, the assumption that R&D is a pivotal source of innovation is brought into question by the fact that many SMEs are successful in innovation despite low or nonexistent R&D activity (Baldwin and Gellatly 2003; de Jong and Marsili 2006; Hervas-Oliver et al. 2011; Hewitt-Dundas 2006; Rammer et al. 2009).

It has been shown that external knowledge inflows from customers or suppliers (e.g., Hervas-Oliver et al. 2011; Hervas-Oliver et al. 2014; Moilanen et al. 2014), the use of innovative management practices (e.g., Hervas-Oliver et al. 2016; Rammer et al. 2009; Thomä and Zimmermann 2020), or the human capital of owners, managers, and employees (e.g., Andries and Czarnitzki 2014; McGuirk et al. 2015) can at least partially compensate for a lack of R&D in innovating SMEs. In addition, non-R&D-intensive SMEs can exploit increased flexibility in responding to fast-changing market conditions, efficient and informal internal communication networks, or their capacity for customization (Nooteboom 1994; Rogers 2004; Rothwell 1989).

The literature on business innovation modes – with its distinction between the doing-using-interacting (DUI) and the science-technology-innovation (STI) modes (see Apanasovich 2016; Jensen et al. 2007; Parrilli and Alcalde Heras 2016) – provides a useful framework to conceptualize these ostensibly unrelated findings on the surprising innovation success of non-R&D-intensive SMEs. The DUI mode perspective, in particular, can be brought to bear fruitfully on this innovation puzzle. It emphasizes innovation activities that are strongly influenced by experience-based know-how embodied in people and shaped by informal processes of interactive learning within and outside the firm, thereby explaining the absorptive capacity of non-R&D-intensive SMEs (Alhusen and Bennat 2020; Parrilli and Elola 2012; Thomä and Zimmermann 2020).

However, much remains unknown about the DUI mode of learning in non-R&D-intensive SMEs. One key aspect of DUI revolves around the small business owner, who can be regarded as a main driver of SME innovation (Nooteboom 1994). Smaller firms exhibit a distinct "orientation towards personal values and goals, and relatively unstructured procedures and relations, with an emphasis on oral rather than written communication, and scope for improvisation and spontaneity" (Nooteboom 1994, p. 331). In such an environment, owners are often solely responsible for all day-to-day operations. Accordingly, innovation processes in SMEs should be strongly shaped by the personal characteristics of the owner. Several strengths that are typically associated with innovating SMEs (such as flexibility, efficient communication, or customization) are directly linked to the way in which the owner, with his or her unique characteristics, shapes the organizational culture of the firm (Nooteboom 1994; Rothwell 1989). However, the previous literature on business innovation modes remains silent on the relationship between the owner's character and innovation activity at the company level.

Against this background, we suggest that the personality characteristics of the owner are instrumental in explaining a smaller firm's self-selection into the DUI mode of innovation. Due to the informal, person-centered, and interactive nature of the DUI mode of innovation, owners should be in a key position to trigger DUI learning in smaller firms. A broad sample of German SMEs serves as a basis for the empirical analysis. In this way, we contribute to the literature by providing a novel explanation for the innovation success of non-R&D-intensive SMEs. We argue that previous explanations are valid, but they represent various aspects of the DUI mode of innovation, which should therefore be regarded as the main driver of learning and innovation in less R&D-oriented SMEs. Thus, to address the corresponding innovation puzzle, one needs to answer the question of why some SMEs develop DUI competencies, whereas others do not. This article aims to fill this gap in the literature by suggesting that the owner's unique character, as measured by the Big Five personality traits (Costa and McCrae 1995; Digman 1990) and prototypes (Asendorpf et al. 2001; Gerlach et al. 2018; Specht et al. 2014), can explain self-selection into the DUI mode, and should therefore be seen as an important driver of innovation success in non-R&D-intensive SMEs.

The remainder of this paper is structured as follows. Section 2 provides the theoretical background of our study, followed by a presentation of our data and preparation of variables (Section 3). The empirical results are discussed in Section 4, after which the final section concludes by pointing out implications for policy and future research.

2. Theoretical Background

2.1. Does an Owner's Personality Affect Self-Selection into the DUI Mode of Innovation?

There are two ideal, typical modes of innovation at the company level. The STI mode is based on in-house R&D, scientifically trained personnel, and external sources of codified, scientific knowledge. The DUI mode is marked by experience-based know-how embodied in people and informal, interactive processes of non-R&D learning (see Jensen et al. 2007; Parrilli and Alcalde Heras 2016). Empirical research on the STI/DUI concept acknowledges that actual innovation practices of firms are usually based on a mix of STI and DUI factors. Hence, depending on the nature of this mix, groups of innovating firms can be classified along different points on the DUI-STI continuum, thereby accounting for the stark heterogeneity among innovating SMEs (see Alhusen and Bennat 2020; Apanasovich et al. 2016; Parrilli and Elola 2012; Parrilli and Radicic 2020; Thomä and Zimmermann 2020).

The DUI mode of innovation is particularly relevant here, as it is directly linked to the specificities of less R&D-oriented knowledge environments that are typical for so many innovating SMEs (e.g., distinct learning from customers and suppliers, informal interaction structures among employees, or a strong reliance on experience-based, practical knowledge; Kirner et al. 2015; Thomä 2017). In this regard, one advantage of the DUI perspective is that it captures the organizational dimension of firm-level innovation (Jensen et al. 2007; Parrilli and Alcalde Heras 2016). An organizational culture of learning that emerges as a by-product of daily operations forms the internal foundation of the DUI mode, implying that an innovating firm with strong DUI competencies is an ideal example of a learning organization (Asheim and Parrilli 2012).

Against this background, we expect the personality characteristics of the small business owner to exert a major influence on a firm's self-selection into the DUI mode. The owner's key role in triggering DUI learning can be explained by Cohen and Levinthal's (1989, 1990) model of "absorptive capacity". It reflects the ability of a firm to identify, absorb, and exploit external knowledge, whereby the important role of human resources, external and internal interactions, and organizational learning is acknowledged (Lane et al. 2006). In this context, Cohen and Levinthal (1990) point to the relevance of certain individuals – so-called "gatekeepers" – who are key drivers of their firm's absorptive capacity (and hence its success at innovation). They argue that an organization's absorptive capacity depends on the gatekeeper's capabilities in terms of external knowledge sourcing and efforts to foster knowledge dissemination within the firm, thereby fully acknowledging the know-how of those employees to whom the external knowledge is transmitted. Thus, a knowledge gatekeeper, with his or her unique characteristics, is instrumental in the emergence of all key components of the DUI mode (i.e., experience-based know-how plus interactive learning within and outside the firm).

Hence, it is but one step to suspect that the small business owner's (Big Five) personality traits (see Table 1 and Section 2.2) not only affect the kinds of external DUI-type knowledge sources that he or she selects but also influences the kinds of internal DUI interaction among people of the firm that he or she inspires and initiates. For example, owners who display extroversion and openness to experience may be more likely to monitor their external environment for novel ideas from customers or suppliers. They will also engage in within-firm communication more frequently, thereby laying the foundation for more frequent interactions and exchange of information among employees, a prerequisite for DUI learning (Jensen et al. 2007). If such an owner displays openness toward new ideas, employees will be more forthcoming with suggestions, expressing themselves more freely, again fostering one basic tenet of the DUI mode: the generation of an innovation-friendly learning environment (Sung and Choi 2009; Zhao and Seibert 2006).

Table 1. Definition of the Big Five traits

	Explanation
Extraversion	Preference for social interaction; social skills, such as communication
Agreeableness	Likely to defer to others in the face of social conflict; forgiving attitudes; belief in cooperation; careful to use inoffensive language
Conscientiousness	Achievement orientation and a diligent work ethic; involves long-term planning, efficient actions, and attention to detail
Neuroticism (opposite: Emotional stability)	Likely to be moody and anxious or to experience feelings of sadness, hopelessness, or guilt; more vulnerable to stressors
Openness to experience	Preference for novelty and variety, as opposed to routine and repetition; tend to have an active imagination

Moreover, if the owner is more agreeable and emotionally stable, social interactions, which are critical for DUI-based innovation, will be more enjoyable for employees, and therefore more likely to occur. Agreeableness enhances cooperative relationships within firms, as it implies that the owner trusts his or her employees, appreciates their ideas, and generally fosters communication or mutual support between employees. Emotionally stable business owners who are self-confident and resilient should be more likely to think positively about their tasks and other people. Moreover, employees are probably more likely to support innovative changes within their working environment when their owner-manager's personality radiates calmness and optimism (Sung and Choi 2009; Zhao and Seibert 2006).

Conscientiousness relates to a small business owner's task performance in terms of organization, self-discipline, and goal accomplishment. While being negatively correlated with individual creativity and innovativeness (Marcati et al. 2008), a higher degree of conscientiousness may be rather helpful for owners when organizational processes must be adapted to make valuable external knowledge applicable within the firm (i.e., the internal foundation of the DUI mode). This should hold true especially because effective employee engagement in innovation requires clear workplace goals set by the management (Billett 2012).

Another central component of the DUI mode can be found in knowing-how and knowing-who (Jensen et al. 2007), both of which are likely to be influenced by the owner's personality. The degree of employees' knowing-how will be positively affected by the quantity and quality of interactive learning processes that the owner triggers. In addition, localized knowledge divided among employees needs to be connected on the company level to transform individual absorptive capacity into organizational absorptive capacity. Therefore, knowing-who represents an important bridge between the various practical and specialized competencies of individual employees. Thus, more openness and extroversion on the part of the owner will give rise to employees' increasing capacity to know-how and know-who.

2.2. Empirical Research on the Big Five Personality Traits and Firm-Level Innovation

Innovation research increasingly shows the critical role of key individuals as a driver of the innovation success of SMEs (e.g., Ahn et al. 2017; Andries and Czarnitzki 2014; McGuirk et al. 2015). Evidence on the psychological underpinnings of such a person-centered approach to innovation is still scarce (Marcati et al. 2008). A standard approach in the psychology literature to measure the basic personality traits of individuals is the Big Five Inventory (BFI). It was created as a 44-item questionnaire to measure the five personality traits of extraversion, agreeableness, conscientiousness, neuroticism (or emotional stability as its opposite pole), and openness (John et al. 1991). According to John et al. (2008), there is a broad consensus in the field of psychology that the Big Five "can represent the various and diverse systems of personality description in a common framework" (John et al. 2008, 116).

Previous research has already established robust empirical links between the Big Five and entrepreneurship, that is, the propensity to start a business (e.g., Caliendo et al. 2014; Ciavarella et al. 2004; McCrae and Costa 2008; Obschonka and Stuetzer 2017; Zhao and Seibert 2006; Zhao et al. 2010). The only previous empirical study that hints at a relationship between the Big Five personality traits and innovation (as opposed to entrepreneurship) is that of Marcati et al. (2008). Based on a small sample of SME owners, the authors examine "the degree of creativity in the cognitive style, that is, the way individuals mentally process information, take decisions, and solve problems" (Marcati et al. 2008, 1581). In other words, creativity is portrayed as a component of human character, classifying individuals on a continuum ranging from adaptive (if an individual's action remains in line with existing rules and methods) to creative (if an individual transcends existing patterns of action). The authors find that openness and extraversion correlate with two psychological measures of innovativeness. These findings are limited in two major ways. First, the suggestive evidence is based on a very small sample (N = 181) of Italian firms and does not consider any other control variables on the firm level. Second, innovativeness is measured as a purely psychological construct. Therefore, it does not measure actual innovation outcomes at the firm level. We seek to rectify these problems and address the corresponding blind spot in the literature by applying Marcati et al.'s insights to a large data set of SMEs to test whether the Big Five personality characteristics of small business owners indeed affect DUI-based innovation in less R&D-intensive SMEs.

2.3. From Personality Traits to Prototypes?

The preceding paragraph already implies that several Big Five traits may be complementary, in the sense that certain synergies between personality traits exist in the context of innovation. For example, although emotional stability and openness to experience may affect DUI learning separately, the combination of a high degree of emotional stability and openness could conceivably exceed the sum of the two separate effects. In other words, the mutual interplay of several traits could be more important than the effects of single traits. Person-oriented analyses from the psychology literature – as opposed to trait-based analyses – focus on such configurations within an individual to describe distinct personality types (Asendorpf et al. 2001; Boehm et al. 2002; de Fruyt et al. 2002; Herzberg and Roth 2006; Meeus et al. 2011; Robins et al. 1996; Schnabel et al. 2002; Specht et al. 2014), thereby overcoming the traditional variable-focused perspective of research on the Big Five model. Most studies find that there are three replicable prototypes at the individual level: resilients, over-controllers, and under-controllers, although some studies indicate the existence of additional types (see Gerlach et al. 2018; Herzberg and Roth 2006).

Resilience refers to the ability "to respond flexibly, rather than rigidly to changing situational demands, particularly stressful situations. Control refers to the tendency to contain versus express emotional and motivational impulses (strong control vs. weak control)" (Asendorpf et al. 2001, 175). Both over- and under-controllers are related to lower levels of resiliency. Over-controllers display a tendency toward being inhibited, shy, having lower social self-esteem, and more loneliness. Under-controllers display a tendency toward a higher rate of antisocial behavior and lower popularity (Asendorpf et al. 2001, 175). As the resilient type tends to display high values in all Big Five traits, we hypothesize that this type will be more likely to self-select into the DUI mode. The underlying assumption is that an owner's personality prototype may be better suited to examine how the psychological basis of a small business owner's character is related to innovation outcomes in non-R&D-intensive SMEs.

3. Data and Methods

3.1. Data Set

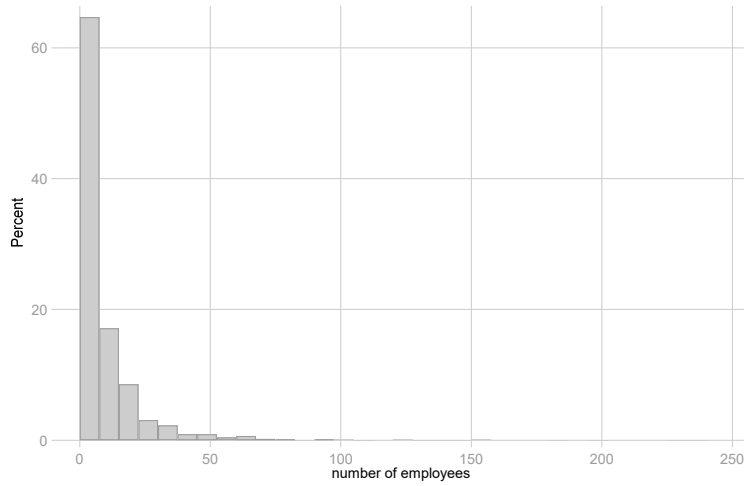
In January 2019, we sent out a questionnaire to 17,000 companies. In cooperation with the three chambers of skilled crafts in the German state of Saxony, we drew a stratified random sample from the population of all officially registered craft SMEs1 located in the state of Saxony, using the variables trade group (seven groups) and local region (three chamber districts) for the purpose of stratification. We strove to obtain a minimum number of 30 replies for each sampling cell (7 × 3): main construction trades, finishing trades, trades for industrial needs, automobile trades, foodstuffs trades, health trades, and trades for private needs, for the three regions.

Our focus on the skilled crafts sector ensures that the sample mostly comprises less R&D-intensive SMEs, as German craft enterprises typically operate in less R&D-intensive manufacturing and services industries (Thomä 2018). As expected, the main survey round did not yield 30 completed questionnaires in all regions in the case of

[1] Defined according to the SME definition set by the European Union (i.e., an upper threshold of 249 employees).

smaller sectors (e.g., health, foodstuffs). In these cases, a follow-up telephone survey was conducted to increase response rates. Moreover, we randomly drew additional companies from the official registries in the case of health trades to send out a second wave of questionnaires. Overall, we received 1,928 replies, which equals a relatively high response rate of 11.3%. As intended, our sample mostly contains smaller-sized SMEs (see Figure 1). The vast majority of companies have less than 20 employees.

Figure 1. Histogram of company size in the sample



Firms were asked whether they had brought to market new or significantly improved products or services or introduced new or significantly improved processes during the past three years. In line with the latest version of the Oslo Manual (OECD and Eurostat 2018), we also asked whether they had implemented innovation-related digitalization measures in the past three years regarding improved internal business processes, the development of new products or services, new business models, improved production or service provision, or the acquisition of new customer bases. If any of the former questions was answered affirmatively, we coded our innovation variable as one, and zero otherwise. In our sample, the former holds true for about 64% of survey respondents. Descriptive statistics can be found in Table A1 in the appendix.

The questionnaire also solicited information on the existence of in-house R&D activity during the previous three years. Apart from this, it included twelve Likert-type questions (five-point scale) on the importance of several non-R&D sources of innovation, such as employee creativity, the scope for employees to develop new ideas, learning from customers, suppliers, universities, and so on, which will enter into our cluster analysis regarding modes of innovation (see Section 3.2).

In addition, the survey contained a brief, ten-item construct of the Big Five personality traits on a seven-point Likert scale (see Rammstedt and John 2007), which was generated to allow the inclusion of personality aspects in cross-disciplinary research settings. The BFI-10 scales retain significant levels of reliability and validity compared with longer versions such as the BFI-44 (Rammstedt and John 2007). In the present paper, in each case exactly two items are utilized to generate one of the trait variables on a fourteen-point scale. These five variables are used in a cluster analysis concerning potential personality prototypes among small business owners.

3.2. Overview of Methods

In a first step, we employ cluster analysis techniques to generate our main dependent variable (modes of innovation) and our key explanatory variable (personality prototypes). In a second step, we run multinomial probit regressions to test the hypothesized relationship.

As factorized variables lead to more robust clustering than using original items (Hair et al. 1998), we condense the twelve variables on sources of innovation to a four-factor solution (see Table 2), which accounts for 65% of the total variance. Both Bartlett's test of sphericity (chi square distribution = 5697.0, $p < 0.001$) and the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO = 0.802) suggest that the twelve items are sufficiently correlated to apply factor analysis. We employ the latent root criterion (eigenvalue > 1) as well as parallel analysis (Horn 1965) via a scree plot, which represents an improvement over the eigenvalue rule (Humphreys and Montanelli 1975).

We follow Thomä and Zimmermann (2020) by employing hierarchical clustering to generate modes of innovation as well as assigning one such mode to each innovating firm. The clustering variables are the existence of in-house R&D and the metric factor scores of our factor variables on non-R&D sources of innovation (standardized to a mean of 0 and a standard deviation of 1). Ward's algorithm with squared Euclidean distance is used as the measure of similarity, as it represents the most widely used hierarchical clustering method in this field. A visual inspection of the dendrogram and two-cluster stopping rules (Calinski/Harabasz pseudo-F index and Duda-Hart index) are used to decide the number of clusters.

Analogous to the clustering of innovation sources, personality traits can also be grouped into certain combinations of traits that frequently occur within individuals. Distinct trait combinations – or "personality prototypes" – have been detected by means of cluster analysis in the realm of psychology (see Asendorpf et al. 2001; Boehm et al. 2002; de Fruyt et al. 2002; Herzberg and Roth 2006; Schnabel et al. 2002; Specht et al. 2014). We follow Herzberg and Roth (2006) by applying Ward's hierarchical cluster analysis based on the Big Five traits followed by a nonhierarchical (k-means) cluster analysis to optimize the cluster solution.2 When using general samples of the population, most studies yield the three prototypes of resilients, over-controllers, and under-controllers. Resilient types tend to display relatively high scores on all of the Big Five traits, but slight variations exist across studies. Under-controllers score particularly low on conscientiousness and agreeableness, and over-controllers tend to be introverted, less emotionally stable, and more conscientious.

4. Results

4.1. Factor Analysis

The four external innovation sources of (1) trade press/media/internet, (2) trade fairs, (3) chambers/trade associations/guilds, and (4) laws/regulations load highly on the first factor. Learning from producers/suppliers also shows a relatively strong loading in this case (see Table 2). Hence, we label the first factor as "applied external knowledge" (F1). This result shows that companies that seek information on recent technological or organizational developments in specialized journals also seem to search for relevant business information at trade fairs, they utilize the consulting services provided by their chamber, and they are alert to new regulatory requirements. Factor 1 therefore points to a certain openness toward application-oriented industry knowledge.

In contrast, the variables of employee creativity and scope for employees to develop new ideas as well as – to a lesser extent – hiring new staff load on the second factor (F2), which we label "internal experiential knowledge." Hence, companies that rely on their employee's creativity to generate innovative ideas also seem to grant a higher degree of employee autonomy. Companies scoring high on the second factor are likely characterized by flat hierarchies and flexible organizational structures, which is contrasted with centrally coordinated innovation activities in which employees execute a previously laid out plan.

---

[2] We did not perform this two-step procedure in the case of innovation sources (see above). Hierarchical clustering without additional k-means achieved more distinct groups with respect to the R&D variable. As the varying importance of in-house R&D lies at the heart of the STI/DUI concept, we refrained from nonhierarchical clustering there.

Table 2. Loadings from principal component factoring after varimax rotation (non-R&D sources of innovation)

Variable	F 1 Applied external knowledge	F 2 Internal experiential knowledge	F 3 External STI knowledge	F 4 Value chain knowledge	*Unique-ness*
Employee creativity	0.12	0.92	0.07	0.08	0.13
Scope for developing new ideas	0.09	0.91	0.12	0.13	0.13
Customers/clients	0.04	0.20	0.02	0.81	0.31
Suppliers/producers	0.34	0.08	0.08	0.67	0.43
Competitors	0.15	0.12	0.28	0.69	0.41
Hiring new staff	-0.02	0.39	0.56	0.27	0.46
Universities/other research institutions	0.13	0.10	0.86	0.08	0.23
R&D service providers/consultancy firms/marketing firms	0.24	0.08	0.82	0.06	0.26
Trade press/media/internet	0.73	0.18	0.17	0.12	0.39
Trade fairs	0.67	0.15	0.23	0.08	0.47
Chambers/trade associations/guilds	0.70	0.11	0.20	0.14	0.43
Laws/regulations	0.59	0.06	0.08	0.28	0.56

Note: Only factor loadings > 0.3 are displayed here.

The third factor (F3; "external STI knowledge") shows high factor loadings on the variables (1) hiring of new staff, (2) universities/other public research institutes, and (3) external R&D service providers/consultancy firms/marketing firms. We interpret this factor as signifying the degree of external STI-based interaction, where the latest science-based knowledge is absorbed by (1) hiring key employees (likely university graduates), (2) engaging external R&D services or consultancy firms, or (3) cooperating with universities, which we would mostly expect to see in larger SMEs. Finally, the fourth factor (F4) elucidates the fact that SMEs often access external (DUI-based) knowledge through the value chain (Haus-Reve et al. 2019; Fitjar and Rodríguez-Pose 2013; Paton and McLaughlin 2008). Companies that receive innovation stimuli from customers also receive them from suppliers as by observing competitors. Hence, the fourth factor is labeled "value chain knowledge."

4.2. Cluster Analysis: Modes of Innovation

According to the four-cluster solution (Table 3), companies in the first cluster (C1) are marked by a below-average share of in-house R&D and they are very unlikely to source external STI knowledge. This prompts us to assume that the DUI mode holds particular importance for companies in C1. Indeed, companies in C1 are likely to learn from applied external knowledge, as factor F1 lies almost one standard deviation above the mean, with a strong reliance on experiential employee knowledge. This relatively high degree of openness is validated by the higher degree of innovation-related cooperation in comparison to groups C2 and C3. Therefore, the first cluster is labeled the "open DUI group."

The second group of companies (C2) also rely strongly on experiential knowledge but are much less open to external sources of applied external knowledge. No strong emphasis on in-house R&D can be observed. Value chain knowledge seems to play a certain role, whereas companies relatively seldom use external STI knowledge. Moreover, innovation cooperation with external partners rarely takes place in this group of SMEs. Thus, C2 can also be understood as resembling the DUI mode of innovation, although such firms are much more inward-focused than those in C1. Therefore, we label the second group the "closed DUI group."

Firms in C3 are innovative, even though they do not report being strongly stimulated by any of the sources of innovation in the questionnaire. In fact, they do not rely on internal experiential knowledge, which is more than one standard deviation below the mean, whereas they score about average regarding applied external knowledge and STI sources of external knowledge. However, there is evidence in C3 of some influence of value chain knowledge on innovation, which brings the corresponding firms closer to the DUI mode, even though the absolute effect size is low. Finally, in-house R&D holds practically no importance in the third group. Firms in C3 are also much smaller in size than those of the other three groups. We label C3 as "low learning," following Thomä (2017), whose cluster solution of innovation modes yields a group with similar characteristics. The impact of value chain knowledge can be interpreted as an indicator of DUI innovation. It can be surmised that the smaller firms in this group have taken their very first steps in developing DUI competencies. On the other hand, the fact that no single factor seems to influence the innovation activity in this group in a quantitatively significant manner points to the existence of unknown factors that drive this mode of innovation.

Table 3. Four-cluster solution (modes of innovation)

		C1	C2	C3	C4		
	Overall mean	**Open DUI**	**Closed DUI**	**Low learning**	**STI/DUI**	***Chi2***	
		Cluster solution in terms of the clustering variables					
In-house R&D	0.199	0.159	0.194	0.070	0.281	37.187	***
Applied external knowledge (F1)	0.068	0.848	-0.902	-0.091	0.284	409.159	***
Internal experiential knowledge (F2)	0.122	0.505	0.624	-1.439	0.273	418.520	***
External STI knowledge (F3)	0.083	-0.817	-0.451	-0.249	1.063	629.502	***
Value chain knowledge (F4)	0.048	-0.282	0.113	0.161	0.147	29.921	***
		Validating the cluster solution					
Number of employees	12.522	9.792	14.585	6.591	15.296	71.695	***
Over-all technical state of the plant and	2.300	2.344	2.432	2.418	2.136	22.058	***
Innovation cooperation with external	0.100	0.115	0.045	0.058	0.143	20.141	***
N	1,038	226	242	172	398		

Note: The table displays mean values of the factor variables (F1–F4), additional company characteristics for validation, and statistical significance of cluster differences (*** significance level of 1 percent, Kruskal-Wallis test with ties, Pearson's chi square test). Factors F1–F4 have a mean value close to zero and a standard deviation of one.
[a] From 1 (state-of-the-art) to 5 (completely out-of-date).

Finally, firms in C4 share a relatively strong emphasis on in-house R&D. Moreover, they are positively affected by all factors on non-R&D sources of innovation. They display some DUI characteristics as they have an above-average likelihood of relying on internal experiential knowledge and they are somewhat open to applied external knowledge, although both aspects are less developed compared to the open DUI group (C1). Moreover, firms in cluster C4 also receive some external stimuli through value chain knowledge. However, apart from the relatively strong emphasis on in-house R&D, the most distinctive characteristic of C4 can be found in its considerable reliance on external STI knowledge, because factor F3 is more than one standard deviation above the mean. Both aspects indicate a particularly high level of technological innovativeness, which is validated by the fact that firms in C4 are the largest in size on average and are most likely to report being engaged in innovation-related activities. Against this background, the fourth group is labeled the "STI/DUI group."

4.3. Cluster Analysis: Personality Prototypes

Our analysis yields a three-cluster solution found in previous studies (Asendorpf et al. 2001; Meeus et al. 2011; Specht et al. 2014). C2, the largest group in our sample (N = 633), can be interpreted as the resilient prototype. The defining features of the resilient prototype are its above-average trait scores. As Table 4 shows, C2's trait

scores are particularly high, except for agreeableness. Given that prototype solutions tend to vary slightly across samples in the psychology literature, the evidence nevertheless clearly points toward an interpretation as the resilient prototype. It also has to be kept in mind that our sample deviates from the general population in the sense that our focus is restricted to the subgroup of company owners. C3 can be identified as over-controllers. Over-controllers tend to display very low scores on extraversion and lower scores on emotional stability but score relatively high on conscientiousness, resembling the trait scores for C3. The similarity in the openness score in C2 (resilient) and C3 (over-controlling) has also been found in other studies (Asendorpf et al. 2001; Specht et al. 2014). The remaining cluster (C1) is interpreted as under-controllers, who score relatively low on conscientiousness, agreeableness, emotional stability, and openness.

Table 4. Three-cluster solution (personality prototypes)

	Overall mean	**C1 Under-controllers**	**C2 Resilient**	**C3 Over-controllers**	***Chi2***	
		Cluster solution in terms of the clustering variables				
Extraversion	9.48	8.56	11.86	7.65	943.86	***
Agreeableness	8.31	7.98	7.81	9.31	134.74	***
Conscientiousness	12.06	10.88	13.07	12.20	326.56	***
Emotional stability	9.63	8.67	10.58	9.59	193.199	***
Openness to experience	9.55	6.68	11.11	11.00	989.33	***
		Validating the cluster solution				
Innovation[a]	0.67	0.63	0.70	0.67	6.00	**
Product innovation	0.22	0.19	0.25	0.21	7.03	**
Process innovation	0.23	0.19	0.25	0.25	8.05	**
N	*N* = 1,751	602	633	516		

Note: The table displays mean values for the Big Five variables (each of which ranges from 1–14) and statistical significance of cluster differences (***significance level of 1 percent, **significance level of 5 percent, Kruskal-Wallis test with ties, Pearson's chi square test).
[a] Introduction of product innovations and/or process innovations and/or innovation-related digitalization measures.

4.4. Multinomial Probit Regressions

We perform multinomial probit regressions to determine the relative likelihood of falling into a particular mode of innovation instead of the category of noninnovative firms. Our dependent variable is categorical in nature. Companies fall into the base category if they are noninnovative according to the innovation definition given in Subsection 3.1 (i.e., the dependent variable "innovation" equals 0). The remaining categories signify our innovation mode clusters (C1–C4); that is, in each case, the dependent variable "innovation" equals 1. We regress this categorical variable against the personality trait variables (or the personality prototypes), in addition to a number of covariates.

The multinomial probit coefficients are reported in Table 5. Column (1) displays a positive and significant coefficient for the "resilient" -prototype. Thus, an owner with this personality is more likely to self-select into the open DUI group instead of the baseline group. Over-controllers also show a higher relative likelihood to be found in the open DUI group, rather than not being innovative (albeit to a lesser degree than resilient owners). The stronger effect of an owner's personality type in the open DUI group supports our assumption that the personality of small business owners is strongly related to self-selection into the DUI mode of innovation.

In specifications 5 to 8, we replace personality prototypes with the separate Big Five traits. Again, we find evidence of a relationship between personality and self-selection into a specific innovation mode. However, the results are much weaker, which speaks in favor of using a prototype approach. We observe that an owner's emotional stability and openness make it more likely for the corresponding firm to be found in the open DUI group instead of not being innovative. Extraversion tends to increase the likelihood of being in the closed DUI group and the STI/DUI group (compared to the noninnovative group), albeit with relatively low statistical significance. Finally, emotional stability also tends to increase the relative likelihood of being in the STI/DUI group.

Table 5. Multinomial probit coefficients (dependent variable: mode of innovation; baseline variable: noninnovative firms)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Open DUI	*Closed DUI*	*Low learning*	*STI/DUI*	*Open DUI*	*Closed DUI*	*Low learning*	*STI/DUI*
Under-controlled	-	-	-	-				
Resilient	0.399**	0.074	-0.020	0.189				
Over-controlled	0.307**	0.128	0.127	0.112				
Extraversion					0.025	0.039*	0.013	0.045*
Agreeableness					0.016	0.028	0.023	0.016
Conscientiousness					-0.021	-0.020	0.033	-0.016
Emotional stability					0.056**	0.015	0.002	0.045*
Openness					0.047**	0.033	-0.017	0.035
Log (employees)	0.262***	0.387***	-0.116	0.456***	0.259***	0.386***	-0.120	0.455***
Above regional sales	0.250**	0.403***	0.301**	0.312**	0.271**	0.408***	0.304**	0.322***
Owner with university degree	-0.018	0.013	0.253	0.090	-0.020	0.009	0.268	0.085
Very low competition	-	-	-	-	-	-	-	-
Low competition	0.108	0.083	0.004	0.543***	0.097	0.070	-0.001	0.537***
Medium competition	0.168	0.335**	0.337*	0.805***	0.176	0.336**	0.337*	0.819***
High competition	0.279	0.288	0.387*	0.869***	0.288	0.294	0.405*	0.879***
Increase of revenue	0.391***	0.301*	0.291*	0.502***	0.424***	0.298*	0.276*	0.507***
Rationalization/lower costs	0.784***	0.649***	0.521***	0.460***	0.785***	0.647***	0.518***	0.461***
Technological modernization	0.421***	0.379***	0.471***	0.475***	0.422***	0.379***	0.482***	0.473***
Renewal/expanding the product range	0.491**	0.394*	0.322	0.852***	0.482**	0.367*	0.342	0.827***
Environmental protection	0.093	0.050	-0.045	0.500**	0.062	0.016	-0.058	0.461**
Regulatory compliance	-0.031	0.082	-0.165	0.163	-0.002	0.094	-0.157	0.187
Trade groups	yes	yes	yes	yes	yes	yes	yes	yes
Age	-0.009	-0.018***	-0.025***	-0.022***	-0.009	-0.018**	-0.026***	-0.022***
Constant	-1.649***	-1.236***	-0.386	-1.356***	-2.529***	-1.989***	-0.916	-2.399***
N	1434	1434	1434	1434	1434	1434	1434	1434

*$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Although the coefficients in Table 5 must always be interpreted with reference to the baseline group, the marginal effects of the multinomial probit coefficients show the impact of a variable on the absolute likelihood of falling into the corresponding group. These are reported in Table 6. Columns 1 to 5 show that companies led by resilient owners are 5.6 percentage points more likely in absolute terms to be found in the open DUI group (for over-controlling owners, plus 3.7%). Again, this finding supports our above assumptions regarding the significant role of personality in the context of the DUI mode of innovation.

In specifications 6 to 10, we turn to individual Big Five personality traits. Again, we find that emotional stability and openness are positively associated with the open DUI mode. A high degree of conscientiousness and less openness make it more likely to be included in the low learning group. Finally, we do not find any association between separate Big Five traits and the likelihood of being in the closed DUI or the STI/DUI group.

The coefficients of the covariates are in line with our expectations (see Table 6). There is a clear effect of firm size on STI/DUI innovation. Moreover, a company's innovativeness decreases if customers are located in a purely regional context, as firms with sales at the state, national, or international levels are less likely to be found in the noninnovative group. We find that the higher the degree of competitive pressure, the higher the likelihood of STI/DUI innovation. This may be a hint that SMEs choose to invest in resource-intensive R&D primarily in the face of fierce competition. As expected, a number of investment motives are positively related to innovativeness (e.g., increase of revenue, rationalization/lower costs, technological modernization). Finally, there is a plausible age effect, whereby older firms are more likely to be found in the noninnovative group, and younger firms tend to be in the low learning or STI/DUI groups.

Overall, our findings show that a certain combination of personality traits, such as the resilient prototype, makes it more likely that the owner self-selects into the DUI mode of innovation, particularly in the case of the open DUI group. Hence, the personal characteristics of small business owners indeed play a role in terms of non-R&D-intensive innovation. The robustness of this finding is confirmed by a binary probit framework that we conducted with standard errors clustered by municipality (see Table A2 in the appendix). In this case, the binary information on the basis of the innovation variable (1 = innovative; 0 = noninnovative; see Table A1) is regressed against the five personality trait variables (and the three personality prototypes), in addition to a number of covariates.

Table 6. Marginal effects after multinomial probit (dependent variable: mode of innovation)

	(1) *Noninnovative*	(2) *Open DUI*	(3) *Closed DUI*	(4) *Low learning*	(5) *STI/DUI*	(6) *Noninnovative*	(7) *Open DUI*	(8) *Closed DUI*	(9) *Low learning*	(10) *STI/DUI*
Under-controlled	-	-	-	-	-					
Resilient	-0.043	0.056**	-0.011	-0.020	0.019					
Over-controlled	-0.041	0.037*	0.003	0.003	-0.002					
Extraversion						-0.008*	0.000	0.003	-0.001	0.006
Agreeableness						-0.005	0.000	0.003	0.002	0.000
Conscientiousness						0.002	-0.003	-0.003	0.006*	-0.002
Emotional stability						-0.008*	0.007**	-0.002	-0.003	0.006
Openness						-0.007	0.005*	0.003	-0.006*	0.004
Log (employees)	-0.069***	0.010	0.037***	-0.049***	0.071***	-0.068***	0.009	0.037***	-0.049***	0.070***
Above regional sales	-0.080***	0.005	0.038**	0.015	0.023	-0.082***	0.007	0.037**	0.014	0.024
Owner with university degree	-0.021	-0.015	-0.009	0.032	0.012	-0.021	-0.015	-0.009	0.035	0.010
Very low competition	-	-	-	-	-	-	-	-	-	-
Low competition	-0.054*	-0.010	-0.016	-0.019	0.099***	-0.051*	-0.011	-0.017	-0.019	0.098***
Medium competition	-0.112***	-0.031	0.003	0.009	0.130***	-0.113***	-0.030	0.002	0.008	0.132***
High competition	-0.123***	-0.015	-0.014	0.012	0.141***	-0.125***	-0.015	-0.015	0.014	0.141***
Increase of revenue	-0.097***	0.023	0.004	0.006	0.065**	-0.098***	0.029	0.002	0.003	0.064**
Rationalization/lower costs	-0.151***	0.075***	0.049**	0.021	0.006	-0.149***	0.075***	0.048**	0.020	0.006
Technological modernization	-0.111***	0.022	0.014	0.029	0.046**	-0.111***	0.022	0.013	0.031	0.045*
Renewal/expanding the product range	-0.138***	0.018	-0.004	-0.007	0.132***	-0.134***	0.018	-0.008	-0.002	0.127***
Environmental protection	-0.046	-0.011	-0.022	-0.027	0.106***	-0.038	-0.013	-0.025	-0.026	0.101***
Regulatory compliance	-0.007	-0.013	0.011	-0.030	0.039	-0.012	-0.010	0.010	-0.031	0.042
Trade groups	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Age	0.005***	0.001	-0.001	-0.002**	-0.003**	0.005***	0.001	-0.001	-0.002**	-0.003**
N	1434	1434	1434	1434	1434	1434	1434	1434	1434	1434

*$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2 in the appendix displays the marginal effects for this set of probit regressions. All main results are robust to model specification, and unreported marginal effects obtained through logit and ordinary least squares regressions are almost identical to those reported here. As can be seen, the Big Five characteristics of extraversion and openness affect the likelihood of firm-level innovation positively and significantly across specifications 1 to 3, and the effect sizes are considerable. Similarly, openness to experiences also positively affects the dependent variable across specifications. We find the same effect size as in the case of extraversion. Although the Big Five trait of emotional stability is also positively related to innovation, it is only statistically significant in the full specification (specification 3). As expected, the personality prototype – notably the resilient type – exerts a considerable influence on the binary outcome variable (specification 6).

5. Conclusion

The innovation success of less R&D-intensive SMEs is a matter of ongoing debate. Previous studies attribute small firms' innovation performance to external knowledge inflows, innovation management tools, the owner's human capital, increased flexibility in responding to market conditions, efficient and informal internal communication networks, or their capacity for customization. We argue that many of these ostensibly unrelated findings can be usefully subsumed under the theoretical framework of the DUI innovation mode. Companies with well-developed DUI competencies exhibit the very characteristics that have been found to be determinants for innovative success in less R&D-intensive SMEs. In fact, DUI companies have been called ideal examples of a learning organization (Asheim and Parrilli, 2012).

Nevertheless, the DUI mode remains underexplored. In particular, the relationship between the SME owner, who is responsible for all day-to-day activities in smaller firms, his or her personality characteristics, and non-R&D-based sources of innovation, has been mostly overlooked. Our results support the notion that the small business owner's personality drives firm-level innovation, for example, by shaping the learning culture within the firm. Most importantly, individuals with certain personality characteristics are more likely to source such external knowledge inputs that are critical to DUI-based innovation (e.g., customer or supplier knowledge) and facilitate the emergence of internal interaction structures as a key foundation of the DUI mode. By applying the well-known Big Five personality model to the topic of firm-level innovativeness, it becomes clear that self-selection into innovation modes is not tied only to separate personality traits of the owner (such as openness or extraversion); instead, the empirical analysis shows that complementarities between different personality characteristics exist (personality prototypes). Accordingly, our paper contributes to the innovation mode and Big Five personality literature, in addition to the more general literature on non-R&D innovation, by showing how innovating SMEs can effectively compensate for a lack of in-house R&D capacity.

One potential limitation of our paper is that, despite our efforts to create a random data set (see Section 3.1), the data may suffer from selection bias. In particular, one may wonder why the overall conscientiousness score of survey participants appears to be quite high on average (see Table 4). An obvious explanation could be that owners who are more conscientious are more likely to fill out and send back a questionnaire. If this is true, less diligent and less organized persons (so-called under-controllers) may be underrepresented in our data set. We cannot fully rule out this point, but we argue that the specific subgroup of owners/entrepreneurs is likely to have a higher conscientiousness score than other population groups to keep their businesses running. The results of Zhao and Seibert (2006) and Zhao et al. (2010) point in this direction. However, further empirical research is required to validate this argument.

With respect to policy implications, our results provide a hint that policy makers aiming to support SME innovation should pay attention to the psychological basis of a firm's absorptive capacity. Personality traits are relatively constant and stable over time. Nevertheless, entrepreneurship education programs targeting potential founders may offer tailor-made courses that take into account specific personality characteristics, raising awareness of their own strengths (which can be further developed) and weaknesses (which can be compensated for). Moreover, although we cannot evaluate the cost-benefit ratio of such support measures, our results may provide policy makers with a justification for technology transfer activities, because small business owners who are receptive and willing to learn may still require some outside impetus to identify relevant knowledge sources in their external environment. Given the existing framework of innovation support structures, the organizational component of innovation in smaller firms may also attract the attention of policy makers. Support programs that target innovating SMEs often pay strong attention to a smaller firm's access to financial resources. Our results imply that an alternative approach could support smaller firms in implementing DUI mode learning (e.g., by guiding them to use human resource management tools or teamwork practices) to develop organizational absorptive capacity.

Future research that focuses on the examination of more specific personality characteristics than the broader Big Five traits/prototypes (such as risk-taking, self-efficacy, need for achievement, or internal locus of control;

see, e.g., Obschonka and Stuetzer 2017) may provide additional insights into the psychological basis of self-selection into modes of innovation. A closely related avenue for future research refers to the characterization of innovation modes itself. Based on our data, it was not possible to comprehensively interpret the "low learning group." Further research on this issue is necessary to understand better the learning mechanisms in this group of firms.

Acknowledgments

As part of the project "The skilled crafts sector in Saxony: An Analysis of its structure and potential," our research was funded by the Saxon State Ministry for Economic Affairs, Labour and Transport. We gratefully acknowledge the cooperation with the three crafts chambers in the German state of Saxony. Moreover, we would like to thank Dr. Till Proeger for detailed comments that helped us to improve the manuscript.

References

Acs, Z. J., & Audretsch, D. B. (2005). Innovation and technological change. In: Acs, Z. J., & Audretsch, D. B. (Eds), *Handbook of entrepreneurship research. An interdisciplinary survey and introduction* (pp. 55-79). New York: Springer.

Ahn, J. M., Minshall, T., & Mortara, L. (2017). Understanding the human side of openness: the fit between open innovation modes and CEO characteristics. *R&D Management, 47*(5), 727-740.

Alhusen, H., & Bennat, T. (2020). Combinatorial innovation modes in SMEs: mechanisms integrating STI processes into DUI mode learning and the role of regional innovation policy, *European Planning Studies*, https://doi.org/10.1080/09654313.2020.1786009.

Andries, P., & Czarnitzki, D. (2014). Small firm innovation performance and employee involvement. *Small Business Economics: An Entrepreneurship Journal, 43*(1), 21–38.

Apanasovich, N. (2016). Modes of Innovation: A Grounded Meta-Analysis. *Journal of the Knowledge Economy, 7*(3), 720-737.

Apanasovich, N., Alcalde Heras, H., & Parrilli, M. D. (2016). The impact of business innovation modes on SME innovation performance in post-Soviet transition economies: The case of Belarus. *Technovation, 5*7-58, 30–40.

Asendorpf, J. B. (2002). Editorial: The Puzzle of Personality Types. European *Journal of Personality, 16*(S1), S1-S5.

Asendorpf, J. B., Borkenau, P., Ostendorf, F., & van Aken, M. A. G. (2001). Carving personality description at its joints: Confirmation of three replicable personality prototypes for both children and adults. *European Journal of Personality, 15*(3), 169-198.

Asheim, B. T., & Parrilli, M. D. (2012). Introduction: Learning and Interaction — Drivers for Innovation in Current Competitive Markets. In: Asheim, B.T., Parrilli, M.D. (Eds.), *Interactive learning for innovation. A key driver within clusters and innovation systems* (pp. 1-29). Palgrave London: Macmillan UK.

Baldwin, J. & Gellatly, G. (2003). *Innovation strategies and performance in small firms*. Cheltenham, UK and Northampton, Massachusetts, USA: Edward Elgar.

Billett S. (2012) Explaining Innovation at Work: A Socio-Personal Account. In: Høyrup S., Bonnafous-Boucher M., Hasse C., Lotz M., Møller K. (Eds.), *Employee-Driven Innovation* (pp. 92-107). London: Palgrave Macmillan.

Boehm, B., Asendorpf, J. B., & Avia, M. D. (2002). Replicable types and subtypes of personality: Spanish NEO-PI samples. *European Journal of Personality, 16*(S1), S25-S41.

Caliendo, M., Fossen, F., & Kritikos, A. S. (2014). Personality characteristics and the decisions to become and stay self-employed. *Small Business Economics, 42*(4), 787-814.

Ciavarella, M. A., Buchholtz, A. K., Riordan, C. M., Gatewood, R. D., & Stokes, G. S. (2004). The Big Five and venture survival: Is there a linkage?. *Journal of Business Venturing, 19*(4), 465-483.

Cohen, W. (1995). Empirical studies of innovative activity. In: Stoneman, P. (Ed.), *Handbook of the economics of innovation and technological change* (pp. 182-264). Oxford UK, Cambridge USA: Blackwell.

Cohen, W., & Levinthal, D. A. (1989). Innovation and Learning: The Two Faces of R&D. *Economic Journal, 99*(397), 569-596.

Cohen, W., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, (35)*1, 128-152.

Costa, P. T., & McCrae, R. R. (1995). Domains and facets: Hierarchical personality assessment using the Revised NEO Personality Inventory. *Journal of Personality Assessment, 64*(1), 21–50.

Digman, J. M. (1990). Personality structure: Emergence of the five-factor model. *Annual Review of Psychology, 41*, 417–440.

Fitjar, R. D., & Rodríguez-Pose, A. (2013). Firm collaboration and modes of innovation in Norway. *Research policy, 42*(1), 128-138.

de Fruyt, F., Mervielde, I., & van Leeuwen, K. (2002). The consistency of personality type classification across samples and five-factor measures. *European Journal of Personality, 16*(S1), S57-S72.

Gerlach, M., Farb, B., Revelle, W., & Amaral, L. A. N. (2018). A robust data-driven approach identifies four personality types across four large data sets. *Nature human behaviour, 2*(10), 735-742.

Haus-Reve, S., Fitjar, R. D., & Rodríguez-Pose, A. (2019). Does combining different types of collaboration always benefit firms? Collaboration, complementarity and product innovation in Norway. *Research Policy, 48*(6), 1476-1486.

Hervas-Oliver, J.-L., Albors Garrigos, J., & Gil-Pechuan, I. (2011). Making sense of innovation by R&D and non-R&D innovators in low technology contexts: A forgotten lesson for policymakers. *Technovation, 31*(9), 427-446.

Hervas-Oliver, J.-L., Sempere-Ripoll, F., & Boronat-Moll, C. (2014). Process innovation strategy in SMEs, organizational innovation and performance: A misleading debate? *Small Business Economics, 43*(4), 873-886.

Hervas-Oliver, J.-L., Boronat-Moll, C., & Sempere-Ripoll, F. (2016). Does management innovation pay-off in SMEs? Empirical evidence for Spanish SMEs. *Small Business Economics, 47*(2), 507–533.

Herzberg, P.Y., & Roth, M. (2006). Beyond resilients, undercontrollers, and overcontrollers? An extension of personality prototype research. *European Journal of Personality, 20*(1), 5-28.

Hewitt-Dundas, N. (2006). Resource and capability constraints to innovation in small and large plants. *Small Business Economics, 26*(3), 257-277.

Hofstee, W. K. B. (2002). Types and variables: towards a congenial procedure for handling personality data. *European Journal of Personality, 16*(S1), S89-S96.

Horn, J. L. (1965). "A rationale and test for the number of factors in factor analysis". *Psychometrika, 30*(2), 179-185.

Humphreys, L. G., & Montanelli, R. G. Jr. (1975). An investigation of the parallel analysis criteria on for determining the number of common factors. *Multivariate Behavioral Research, 10*(2), 193-205.

Jensen, M. B., Johnson, B., Lorenz, E., & Lundvall, B. Å. (2007). Forms of knowledge and modes of innovation. *Research Policy, 36*(5), 680-693.

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). *The Big Five Inventory-Versions 4a and 54.* Berkeley, CA: University of California, Berkeley, Institute of Personality and Social Research.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. *Handbook of personality: Theory and research, 3*(2), 114-158.

de Jong, J., & Marsili, O. (2006). The fruit flies of innovations: A taxonomy of innovative small firms. *Research Policy, 35*(2), 213-229.

Kirner, E., Som, O., & Jäger, A. (2015). Innovation Strategies and Patterns of Non-R&D-Performing and Non-R&D-Intensive Firms. In: Som O., Kirner E. (Eds.), *Low-tech Innovation* (pp. 91-111). Cham: Springer International Publishing, https://doi.org/10.1007/978-3-319-09973-6_7.

Lane, P. J., Koka, B. R., & Pathak, S. (2006). The Reification of Absorptive Capacity: A Critical Review and Rejuvenation of the Construct. *Academy of Management Review, 31*(4), 833-863.

Marcati, A., Guidoa, G., & Peluso, A. M. (2008). The role of SME entrepreneurs' innovativeness and personality in the adoption of innovations. *Research Policy, 37*(9), 1579-1590.

McCrae, R. R., & Costa, P. T., Jr. (2008). The five-factor theory of personality. In: John, O.P., Robins, R.W., Pervin, L.A. (Eds.), *Handbook of personality: Theory and research* (pp. 159-181). NY: Guilford Press.

McGuirk, H., Lenihan, H., & Hart, M. (2015). Measuring the impact of innovative human capital on small firms' propensity to innovate. *Research Policy, 44*(4), 965-976.

Meeus, W., Van de Schoot, R., Klimstra, T., & Branje, S. (2011). Personality types in adolescence: change and stability and links with adjustment and relationships: a five-wave longitudinal study. *Developmental psychology, 47*(4), 1181-1195.

Moilanen, M., Østbye, S., & Woll, K. (2014). Non-R&D SMEs: External knowledge, absorptive capacity and product innovation. *Small Business Economics, 43*(2), 447-462.

Nooteboom, B. (1994). Innovation and diffusion in small firms: Theory and evidence. Small Business Economics, 6(5), 327-347.

Obschonka, M., & Stuetzer, M. (2017). Integrating psychological approaches to entrepreneurship: the Entrepreneurial Personality System (EPS). *Small Business Economics, 49*(1), 203-231.

Ortega-Argilés, R., Vivarelli, M., & Voigt, P. (2009). R&D in SMEs: A paradox? *Small Business Economics, 33*(1), 3-11.

Parrilli, M. D., & Radicic, D. (2020). STI and DUI innovation modes in micro-, small-, medium- and large-sized firms: distinctive patterns across Europe and the U.S.. *European Planning Studies*, https://doi.org/10.1080/09654313.2020.1754343.

Parrilli, M. D., & Alcalde Heras, H. (2016). STI and DUI innovation modes: Scientific-technological and context-specific nuances. *Research Policy, 45*(4), 747-756.

Parrilli, M. D., & Elola, A. (2012). The strength of science and technology drivers for SME innovation. *Small Business Economics, 39*(4), 897-907.

Paton, R. A., & McLaughlin, S. (2008). Services innovation: Knowledge transfer and the supply chain. *European Management Journal, 26*(2), 77-83.

Rammer, C., Czarnitzki, D., & Spielkamp, A. (2009). Innovation success of non-R&D-performers: Substituting technology by management in SMEs. *Small Business Economics, 33*(1), 35-58.

Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of research in Personality, 41*(1), 203-212.

Robins, R. W., John, O. P., Caspi, A., Moffitt, T. E., & Stouthamer-Loeber, M. (1996). Resilient, overcontrolled, and undercontrolled boys: Three replicable personality types. *Journal of Personality and Social psychology, 70*(1), 157.

Rogers, M. (2004). Networks, firm size and innovation. *Small business economics, 22*(2), 141-153.

Rothwell, R. (1989). Small Firms, Innovation and Industrial Change. *Small Business Economics, 1*(1), 51–64.

Schnabel, K., Asendorpf, J. B., & Ostendorf, F. (2002). Replicable types and subtypes of personality: German NEO-PI-R versus NEO-FFI. *European Journal of Personality, 16*(S1), S7-S24.

Specht, J., Luhmann, M., & Geiser, C. (2014). On the consistency of personality types across adulthood: Latent profile analyses in two large-scale panel studies. *Journal of personality and social psychology, 107*(3), 540-556.

Sung, S. Y., & Choi, J. N. (2009). Do Big Five Personality Factors Affect Individual Creativity? the Moderating Role of Extrinsic Motivation. *Social Behavior and Personality, 37*(7), 941-956.

Thomä, J. (2017). DUI mode learning and barriers to innovation—A case from Germany. *Research Policy, 46*(7), 1327-1339.

Thomä, J. (2018). Handwerksunternehmen und handwerkliche Qualifikationen – empirische Hinweise zur Rolle des Handwerks im Innovationssystem. *Göttinger Beiträge zur Handwerksforschung, Heft 23*, Göttingen.

Thomä, J., & Zimmermann, V. (2020). Interactive learning — The key to innovation in non-R&D-intensive SMEs? A cluster analysis approach. *Journal of Small Business Management, 58*(4), 747-776.

Zhao, H., & Seibert, S. E. (2006). The big five personality dimensions and entrepreneurial status: a meta-analytical review. *Journal of applied psychology, 91*(2), 259-271.

Zhao, H., Seibert, S. E., & Lumpkin, G. T. (2010). The relationship of personality to entrepreneurial intentions and performance: A meta-analytic review. *Journal of management, 36*(2), 381-404.

Appendix A

Table A1. Descriptive statistics

Variable name	Mean	SD	Variable name	Mean	SD
Binary variables on innovation			*Investment motives*		
Innovation[a]	0.639	0.481	Increase of revenue	0.195	0.396
Modes of innovation			Rationalization/lower costs	0.211	0.408
Noninnovative	0.361	0.481	Technological modernization	0.351	0.477
Open DUI	0.137	0.344	Renewal/expanding the product range	0.109	0.312
Closed DUI	0.148	0.355	Environmental protection	0.084	0.277
Low learning	0.106	0.308	Regulatory compliance	0.123	0.328
STI/DUI	0.248	0.432			
Personality prototypes			*Trade groups*		
Undercontrolled	0.354	0.478	Main construction	0.252	0.252
Resilient	0.351	0.477	Finishing trades	0.151	0.358
Overcontrolled	0.296	0.457	Industrial needs	0.154	0.361
			Cleaners	0.025	0.156
Personality traits			Automobile	0.144	0.352
Extraversion	9.422	2.51	Foodstuff	0.105	0.306
Agreeableness	8.285	2.348	Health	0.056	0.23
Conscientiousness	11.98	2.178	Private needs	0.113	0.317
Emotional stability	9.63	2.409			
Openness	9.517	2.802			
Employees	10.096	19.288	*Competitive pressure*		
Above regional sales	0.583	0.493	Very low	0.218	0.218
Owner with university degree	0.22	0.414	Low	0.244	0.43
Age	54.035	9.234	Medium	0.374	0.484
			High	0.164	0.37
N	1434				

Note: Table A1 summarizes all variables based on the sample of the Multinomial probit regression (N = 1434; see tables 5 and 6)

[a] i.e. product innovation and/or process innovation and/or innovation-related digitalization measures.

Table A2. Marginal effects after Probit regression (binary dependent variable: 'innovation'[a])

	(1)	(2)	(3)	(4)	(5)	(6)
Extraversion	0.011***	0.013***	0.008*			
Agreeableness	-0.006	-0.001	0.002			
Conscientiousness	-0.008	-0.007	-0.000			
Emotional stability	0.005	0.004	0.008*			
Openness	0.011**	0.012***	0.008*			
Under-controlled				-	-	-
Resilient				0.066***	0.072***	0.054**
Over-controlled				0.040	0.047*	0.046*
Log(employees)		0.008***	0.004**		0.008***	0.004**
Above regional sales			0.092***			0.091***
Owner with university degree			0.022			0.022
Very low competition			-			-
Low competition			0.060**			0.061**
Medium competition			0.129***			0.128***
High competition			0.124***			0.123***
Increase of revenue			0.114***			0.115***
Rationalization/lower costs			0.142***			0.143***
Technological modernization			0.121***			0.122***
Renewal/Expanding the product range			0.140***			0.146***
Environmental protection			0.025			0.031
Regulatory compliance			0.029			0.025
Main construction		-	-		-	-
Finishing trades		0.006	0.011		0.005	0.009
Industrial needs		0.087***	0.061*		0.084**	0.056*
Cleaners		-0.170**	-0.107		-0.183**	-0.120
Automobile		0.190***	0.153***		0.184***	0.148***
Foodstuff		0.060	0.071*		0.056	0.067
Health		0.176***	0.156***		0.176***	0.153***
Private needs		0.023	0.065*		0.032	0.068*
Age			-0.004***			-0.004***
N	1726	1681	1602	1726	1681	1602

Notes: *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; [a] i.e. product innovation and/or process innovation and/or innovation-related digitalization measures