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ORIGINAL PAPER

Innovation ecosystem for smart product: empirical quantification of its key dimensions in SMEs of 21 European countries

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Abstract
This paper aims to quantify the innovation ecosystem model for allowing the development of smart products at the country level. In this regard, the research used an empirical approach to scale and validate the six dimensions of an innovation ecosystem model among the small and medium-sized enterprises of 21 European countries. The quantitative methods of panel data analysis and Pearson correlation tests between variables of the innovation ecosystem and smart products were considered to examine six research hypotheses. Three dimensions of the innovation ecosystem model, i.e., configuration, change, and capability, have enough effects to accelerate high levels of smart products in the small and medium-sized enterprises of European countries, supporting the external and internal economic partnerships of institutions and companies, cultural changes in functional status, and knowledge-based capabilities of technological skills in each ecosystem. In addition, hierarchical clustering analysis for the classification of the countries showed that some countries, e.g., the United Kingdom, Netherlands, Sweden, Switzerland, Germany, Denmark, France, and Norway, could support their powerful smart products for small and medium-sized enterprises at the national level due to their high mean innovation ecosystem values. Overall, the research can describe the managerial implications regarding the knowledge-based capabilities of the technological skills in each ecosystem to be utilized by managers and stakeholders in small and medium-sized enterprises.

Keywords Innovation ecosystems · Smart products · Small and medium-sized enterprises · European countries

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1 Introduction

In recent decades, the concept of innovation ecosystems (IEs) has become popular with a rapidly growing literature (i.e., Gomes et al. 2018), typically with a business and strategy origin and focus, in which the concept of innovation has been widely used with different qualifiers, such as national and sectoral innovation systems (Granstrand and Holgersson 2020). Recently, there has been attention given to IE approaches at various national and sectoral levels (e.g., Gawer and Cusumano 2014; Valkokari et al. 2017; Visscher et al. 2021). For example, in a production process, IE can use physical energy sources for power processes through value creation to renew energy (Shaw and Allen 2018). The dynamic nature of the innovative production process provides a perfect setting for examining the emergence of new entrepreneurship within an evolving IE (e.g., Khurana and Dutta 2021). Therefore, Lubik and Garnsey (2016) noted that an IE can create value from new science-based materials and products (Gomes et al. 2021), e.g., smart products (SPs). Benitez et al. (2020), Matt et al. (2021), and Benitez et al. (2021) developed frameworks for the IE concept by adopting SP, complementing the previous literature.

An SP is a data processing object with several interactive functions, combining physical and software interfaces (Nieminen et al. 1998). In recent research, Kahle et al. (2020) constructed an applicable model to reveal the role of IE in the SP setting, where there are significant technical challenges due to their innovative potential in each ecosystem (Adner and Kapoor 2016). Despite the old constrained definition of SP as a platform between users and designers (Vitali et al. 2017), scholars have recently noted that SP is a sensing and sustainable product that interacts with the environmental dimensions of physical, human, and cyberspace environments (e.g., Miranda et al. 2017; Zhang et al. 2019; Yin et al. 2020). In this regard, SP is individually a call for multiple technologies, such as developing, information, and intelligent technology. Hence, an integrative study on SP and IE is a novel method for understanding innovation-based innovative products, leading to better innovation performance and sustainability. In this regard, accelerating the development of innovative ecosystems in small and medium-sized enterprises (SMEs) could be significant for enhancing SPs (Yin et al. 2020).

As Yin et al. (2020) mentioned, a comprehensive investigation of IE and SP is lacking despite the literature on innovation and smartness (e.g., Tsujimoto et al. 2018; Liu et al. 2020). This subject indicates a need for further empirical investigation, especially regarding its applicability to cooperation between organizations (Oh et al. 2016; Ritala and Almpanopoulou 2017; Asplund et al. 2021).

Although the level of innovation ecosystems and econometric characteristics vary from country to country (ILO 2010), a new concept for IEs focused on SPs has grown in recent works. For example, Kahle et al. (2020) determined a six-dimensional framework (six-dimensional model) under the IE subject and called for future studies to indicate the differences in the development phases of SP through IE. In this regard, the structural models in innovation ecosystems have determined constitutive components but disagree on the relevant components, a main research gap (e.g., as elaborated by Klimas and Czakon 2022a; Bouncken and Kraus 2022). Regarding the extendibility of analysing the six-dimensional model, this paper attempts to respond to the call mentioned above, to research the relevant components of IE and to recognize the possible configurations for innovative ways in SMEs and ecosystems using quantitative data at the country level to detect the different phases of IE and SP between European countries. This fact was our main reason for considering the six-dimensional model.

Similarly, Stam (2013) and Szerb et al. (2019) analysed the relevance of quantitative ecosystems for regional and national performance. Rong et al. (2015) noted the need for SP development based on SME information in a given study case, calling for researchers to further investigate this topic via comparative cross-country analysis. There is a lack of composite data from SME collections in previous studies, and this paper offers the use of such big data from global databases at the national level. Understanding the IE ranking for SP among countries could aid in recognizing the development indicators of world innovation and smart databanks, such as the OECD and the World Bank.

Given the arguments mentioned above, this paper attempts to answer the following research question: by what means can we represent a systematic manner to evaluate the country-level effects of the dimensions of IE in the SP among the SMEs of different European countries? Hence, the main aim of this paper is to quantify the six dimensions of the innovation ecosystem model for allowing the development of smart products at the country level. On this basis, our research question and a research methodology to answer this question were developed to represent a quantitative approach (panel data analysis and hierarchical clustering analysis) using a statistical database of SMEs between 2015 and 2019. The research focuses on 21 European countries, categorized as advanced countries with considerable innovation levels among the world's countries. For instance, these countries (21 cases) have an average innovative business density of 5.8 registrations per 1,000 people.

In contrast, the EU region and the world have lower values of 3.7 and 1.4, revealing the high level of study areas in the innovation ecosystem. In this regard, our research contribution follows an empirical approach to scale and validate the six-dimensional IE model (after Kahle et al. 2020) through the development level of SP, which can be used for ranking European countries regarding their capacity at higher levels of both IE and SP in SMEs. We anticipate that the empirical research will support the positive effects of some IE dimensions (particularly the knowledge-based or technological-based dimensions) in the SP to offer a new perspective in the national context of the research.

Concentrating on the national dimension of IE is particularly useful because policies and the culture that tend to be activated at the national level influence the national context interestingly. Most studies focus on either the sectoral or national classification of IE. The sectoral classification of IE allows us to concentrate on the state-of-the-art sector and technology standards while concentrating on the national level, enabling us to understand the influence of culture and national policies on IE. Therefore, in this study, we focus on the national level of IE.

2 Literature review and development of hypotheses

2.1 Innovation ecosystem (IE)

An innovative ecosystem includes an innovative value proposition and its constellation of supporting agents (Jacobides et al. 2018). In this regard, innovative solutions connect people, organizations, and resources through an interactive ecosystem that enables value creation through cooperation, creativity, and exchange activities (Ruiz-Alba et al. 2021). IEs are multidimensional collaborative arrangements between actors and entities that orchestrate innovation, including smart technologies (Adner 2006; Reynolds and Uygun 2018; Yin et al. 2020). The literature on IE reveals a variety of settings and dimensions, such as a wide array of definitions of the term (Wei et al. 2020). For instanceKlimas and Czakon (2022b) noted that IE can be classified into five categories: life cycle, structure, innovation focus, scope of activities, and performance. Some scholars have also revealed that IE focuses on value creation (Gomes et al. 2018, 2021), coordinating small and medium-sized enterprises (SMEs) aligned with the technological perspective (Hekkert et al. 2007; Musiolik et al. 2012; Adner 2017).

Recently, a three-dimensional model covering actors, activities, and artefacts was developed by Granstrand and Holgersson (2020) and used in empirical studies by Dedehayir et al. (2022); Klimas and Czakon (2022a), which is a conceptual model to categorize products and technology under the artefact component. Technology, as a part of IE (Brown and Mason 2014; Carayannis et al. 2018), can introduce transformational business models and economic growth using the Internet of Things (IoT), artificial intelligence (AI), and digital transformation (Amitrano et al. 2018). Owing to the transformational aspect of IEs in different sectors, newer conceptual models have evolved by supposing more indicators and dimensions. For instance, Kahle et al. (2020) determined a six-dimensional (6D) framework, which originated from the research of Rong et al. (2015) and included 13 components of the IE for SP and corresponding questions (Table 1).

2.2 Smart product (SP)

SPs have three core components: physical, smart, and connectivity (Kahle et al. 2020). Due to the emergence of digitalization in manufacturing processes, SP is not limited to business-to-customer (B2C) products, which can be embedded with digital technology (Lerch and Gotsch 2015; Rymaszewska et al. 2017). Hence, the smartness of each product depends on its operation based on new technologies, such as the IoT, cloud computing, big data analytics, and artificial intelligence (Ardito et al. 2018; Frank et al. 2019). Several scholars have studied the various dimensions of SP development, such as the axiomatic design methodology (Rauch et al. 2016), the situation of Industry 4.0 (Nunes et al. 2017), conceptual design and implementation products (Filho et al. 2017), and the information technology (IT)-driven paradigm (Zheng et al. 2018).

Recently, SPs have benefitted from IT, ICT, and artificial intelligence (AI) paradigms, highlighting the scientific cooperation and information exchange among mul-

Table 1 The six dimensions and 13 components of the innovation ecosystems for smart products and corresponding questions after Kahle et al. (2020)

Dimension	Component	Corresponded questions
Context	Mission	Which companies think to gain benefit from the ecosystem?
	Barriers	Which barriers hinder the development of the ecosystem for smart products?
	Drivers	Which companies have driving forces to prompt the development of the ecosystem?
Construct	Actors	Which actors provide the ecosystem needs?
	Resources	Which technology is necessary to enable the ecosystem?
Configuration	External relationships	Which partnerships are established among the institutions to allow the development of smart products?
	Innovation partnership	Which partnerships are established among the companies to allow the development of smart products?
Cooperation	Governance	Which groups have the potential for leadership of the ecosystem?
	Absorptive capacity	Which companies have an awareness of the international need to develop smart products?
Change	Changes in the status quo	Which changes are necessary for the status quo to increase the level of an offering of smart products?
	Culture openness	Which companies are open to face with technological change?
Capability	Knowledge capabilities	Which companies have the necessary knowledge to develop smart products?
	Technological capabilities	Which companies have the technological capabilities to offer smart products?

tiple stakeholders to create shared values (Zhang et al. 2022). Furthermore, innovative technologies can provide alliances for smart products to connect the environment and exchange information with surrounding objects and people, enabling more innovative service delivery (Cheng et al. 2018; Zheng et al. 2018; Dalenogare et al. 2022).

2.3 IE and SMEs

I can draw on the expertise of knowledge creators (Clarysse et al. 2014); however, it is well known that SMEs are limited both geographically and technologically in terms of new knowledge (Lavie and Rosenkopf 2006; Asplund et al. 2021), such as smart and sensing products. Several smart solutions are complex and systemic, and single SMEs may lack all the required knowledge and capabilities to develop advanced products (Lerch and Gotsch 2015; Abramovici et al. 2016; Benitez et al. 2020).

According to the OECD (2021) and Eurostat (2022), SMEs are often referred to as the backbone of the European economy, providing a potential source for jobs and economic growth. SMEs are defined as those for which fewer than 250 people are employed. The five main classes are defined as [1] microenterprises: less than ten persons employed, [2] small enterprises: 10–50 persons employed, [3] medium-sized enterprises: 50–250 persons employed, [4] SMEs: 1-250 persons employed, and [5] large enterprises: 250 or more persons employed. In the European economy, SMEs play an important role in IE and SP due to their flexibility towards change. Hence, understanding how innovation practices improve the competitive advantages of SMEs is important because SMEs can collaborate in innovation to provide updated and customer-related solutions (Khan and Arshad 2019). In addition, specific requirements for SP must be met by SMEs due to their flexible advanced technology compared with that of large organizations (Adamik 2020).

2.4 Hypotheses

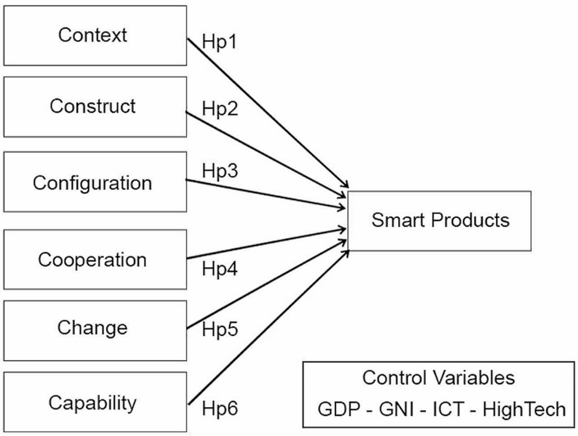
The hypotheses developed in our study are defined as a model, as shown in Fig. 1, which follows the IE model of Kahle et al. (2020). The six dimensions of IE (context, construct, configuration, cooperation, change, and capability) can be used to organize an SP platform for companies, facilitating the development of solutions by integrating different facilities. According to this IE model and its six dimensions, defined by Kahle et al. (2020) and Rong et al. (2015), six research hypotheses can be retained in this paper (see Table 1).

The first dimension of the IE model is 'context', which depends on the mission, barriers, and drivers of the innovative development of the ecosystem. In this regard, context can comprise technology improvements, customer demands, and various innovative potentials, such as hardware and robotics, IoT and sensors, cloud services, big data, and virtual analytics (Frank et al. 2019). In addition, communication difficulties and organizational and social barriers can hinder ecosystem development (Zhang et al. 2007; Kahle et al. 2020). In the first hypothesis, we can assume that the context dimension of the IE has sufficient potential, allowing products to become smart. Hence, the following hypothesis is retained:

H1: The context dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

The second dimension is 'construct', which focuses on the ecosystem's technological resources and provided actors. Moreover, the construct comprises different roles to support the ecosystem, such as government, universities, institutions, and entrepreneurs (Oh et al. 2016). In the second hypothesis, we can assume that the construct dimension of the IE has an important role in the ecosystem, conducting

Fig. 1 Research model



research and development to define technological standards for the development of a smart product (Kahle et al. 2020). Hence, the following hypothesis is retained:

H2: The construct dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

The third dimension is 'configuration', which addresses the external and internal economic partnerships in each ecosystem that the institutions and companies influence. This configuration provides innovation partnerships in SMEs, especially for developing complex solutions to sustain their competitive advantage (Gawer and Cusumano 2014). According to our third hypothesis, we can assume that the configuration dimension of IE is necessary for universities to build knowledge and develop smart industries and products (Kahle et al. 2020). Hence, the following hypothesis is retained:

H3: The configuration dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

The fourth dimension is 'cooperation', which depends on the ecosystem's governance leadership and international capacity. Cooperation also includes all the governance systems and coordination mechanisms of the ecosystem, such as absorptive capacity, which is the ability to cooperate and utilize extra knowledge (West and Bogers 2014). In the fourth hypothesis, we can assume that the cooperation dimension of the IE is the association of the companies receiving a demand for the development of a smart product (Kahle et al. 2020). Hence, the following hypothesis is retained:

H4: The cooperation dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

The fifth dimension is 'change', which relates to cultural changes needed to increase the functional status of the ecosystem. Changes are important for highlighting adaptations resulting from the renewal and coevolution of the ecosystem (Porter and Heppelmann 2014; Rong et al. 2015). According to our fifth hypothesis, we can assume that the change dimension of IE is necessary for SMEs to be open to changes in smart products, which can bring opportunities outside of their current situation (Kahle et al. 2020). Hence, the following hypothesis is retained:

H5: The change dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

Finally, the sixth dimension is 'capability', which addresses the knowledge-based capabilities to promote technological skills in ecosystems. Capability includes knowledge-based aspects, such as local data processing, sensing, and embedded IoT systems (Porter and Heppelmann 2015). According to our sixth hypothesis, we can assume that the capability dimension of the IE is the core of each ecosystem due to the need for collecting, monitoring, controlling, and optimizing data through smart products (Kahle et al. 2020; Ruiz-Alba et al. 2021; Zhang et al. 2022). Hence, the following hypothesis is retained:

H6: The capability dimension of the innovation ecosystem accelerates high levels of smart products in SMEs.

3 Methodology

3.1 Study area

This paper focused on the selection of 21 European countries due to their original archive of innovation and smart products. In this regard, we should mention the innovation statistics and indicators archived by the Organization for Economic Cooperation and Development (OECD). However, this archive only covers European countries, as the confirmed members registered during an affirmed time frame. The research cases were selected from 21 European countries based on the registered and accessed data in the OECD database (Table 2). We focused our study on these 21 countries because the availability of data on variables related to both IE and SP indicators was restricted to the mentioned countries through the OECD database. In this regard, we merely obtain the list of countries with continuous membership and information in the OECD (2021).

Furthermore, the reason for selecting three time intervals (2015, 2017, and 2019) relates to the restricted intervals of the OECD innovation indicator database, which was prepared only for 2013 (the old version), 2015, 2017, 2019, and 2021 (the incomplete initial version). The total population of the selected countries is estimated to equal 518.8 M in 2021, contributing 68% of the total population of the EU region (World Bank 2021). As a main indicator, these 21 European countries have an average innovative business density of 5.8 registrations per 1,000 people, while the EU region and the world have lower values of 3.7 and 1.4, respectively (World Bank 2021). This fact reveals the intense situation of the study areas in the innovation ecosystem.

3.2 Data collection

This study complements country-level analyses by offering a quantitative method, i.e., panel data analysis and hierarchical clustering analysis (HCA), using a statistical database of SMEs (business innovation statistics of OECD) for three time intervals (2015, 2017, and 2019) to examine the effects of a six-dimensional model of the inno-

Table 2 The summarized profile of 21 selected European countries (2021)

Country Name	Population (million)	Country Name	Population (million)
Austria	8.88	Netherlands	17.33
Belgium	11.48	Norway	5.35
Czech	10.67	Poland	37.97
Denmark	5.82	Portugal	10.27
Estonia	1.33	Slovakia	5.45
Finland	5.52	Slovenia	2.09
France	67.06	Spain	47.08
Germany	83.13	Sweden	10.29
Greece	10.72	Switzerland	8.71
Hungary	9.77	United Kingdom	66.83
Italy	60.3		

vation ecosystem (IE) in the smart product (SP). The given panel data analysis was adopted by Dora (2019) and Jafari-Sadeghi et al. (2021) to analyse the lack of circularity and sustainability in the SMEs of each country-level study area. Concerning the research method, the very recent use of panel data analysis to evaluate the circularity rate of European countries is observed in the work of Kostakis and Tsagarakis (2022), revealing the successful role of the method in the circular economy.

Furthermore, an HCA is known for its ability to divide 21 European countries into homogeneous and distinct groups, creating members with similar characteristics (see Shukla et al. 2000). This method is the most valuable data mining task for discovering groups and identifying interesting patterns in the underlying data, including case studies or variables (Halkidi et al. 2001).

According to the definition of firm size and scale in the OECD (2021) and Eurostat (2022) databases, an SME is a firm that includes between 10 and 250 employees. Additionally, the required variables for the SMEs in each country-level study area are overlaid between the relevant and available global databases and the literature review. Using the corresponding questions in the literature review (see Kahle et al. 2020), we selected 20 indicators (from [1] to [20]) based on international databases to correspond to the six constructive dimensions of the IE (context, construct, configuration, cooperation, change, and capability) in addition to a variable of [21] ICT (information and communication technology) development index (unitless) for indicating the SP subject. The data were obtained from business innovation statistics and indicators of the OECD (2021) via the following link: https://www.oecd.org/innovation/inno/inno-stats.htm, and national development indicators of the World Bank (2021) via the following link: https://databank.worldbank.org/home.aspx (Table 3).

In the SP category, data are generated from the virtualization of products and service-related assets and the usage of products, which can be collected based on information and digital technology data (Dalenogare et al. 2022). In this regard, ICT development is significant and directly linked to company growth data, representing its smart indicator. Additionally, the essential definitions of each indicator are shown in Table 4. However, the World Bank database has no complete data for 2021. Hence, we must select time intervals for three years, 2015, 2017, and 2019, using complete data tables from both databases.

3.3 Data analysis

A model was produced based on two main subjects, innovation components and smart products, as shown in Fig. 1. In this regard, 20 indicators [1–20] were assumed to be independent variables corresponding to the six constructive dimensions of IE, and a dependent variable, SP, was used to indicate the information and communication technology in the study area. In the next step, the relationships between the six dimensions of the IE model and the SP are investigated using static panel data analysis within three time intervals (2015, 2017, and 2019) to validate the model. Statistical analysis of panel data synthesis in Stata software (ver. 14) revealed significant associations between IE and SP among the selected European countries when the correlation values were meaningful. We obtained four controlling variables, GDP growth (%), GNI growth (%), ICT service exports (%), and high-technology exports

Table 3 Selected 21 indicators to correspond to the dimensions, components, and modules of the innovation ecosystems for smart products after business innovation statistics and indicators of the OECD (2021) and national development indicators of the World Bank (2021)

Dimension	Component	Module	Corresponded indicator title [Code]
Context	Mission	Commercialization	Product innovative active firms [1]
	Barriers	Adoption	Barriers affecting trade in digitally enabled services [2]
		Cooperation	Taxes on income, profits, and capital gains [3]
		Financial	Cost of business startup procedures [4]
		Infrastructure	Less infrastructure and connectivity [5]
	Drivers	Economic	Firms receiving public financial support for innovation [6]
		Technological	Share of turnover from new, improved products [7]
		Market	Innovative firms operating in international markets [8]
Construct	Actors	Government and universities	Firms cooperating on innovation activities with governments and institutions [9]
		Business associations and suppliers	Firms cooperating on innovation activities with suppliers [10]
		Customers and clients	Firms cooperating on innovation activities with clients [11]
	Resources	Technological centres	High technology [12]
Configuration	External relationships	Research and development	R&D active product and process innovative firms [13]
	Innovation partnership	Industrial collaboration	Product and process innovative firms [14]
Cooperation	Governance	Leadership coordinator	Labour force with advanced education [15]
	Absorptive capacity	Integration external SMEs	Firms engaged in international collaboration [16]
Change	Changes in the status quo	Structural	New businesses registered [17]
	Culture openness	Performance	High employment in innovative firms [18]
Capability	Knowledge	Knowledge dissemination	Firms that applied for patents [19]
	Technological	Technological skills	Firms that registered a design [20]
Smart products			ICT development index [21]

(%), from panel data analysis of data from the World Bank (2021). In the last step, to correlate the IE and SP variables, the Pearson test in the Statistical Package for Social Science (SPSS) software was used to examine six research hypotheses (from H1 to H6). For this purpose, the correlation values between the six dimensions of the IE (independent variable) and the SP indicator (dependent variable) in the study areas are estimated.

Table 4 The essence definition of each indicator

Indicator code	Definition
[01]	Product innovative active firms as a percentage of total firms with SME size
[02]	Barriers affecting trade in digitally enabled services indexed from 0 to 1
[03]	Taxes on income, profits, and capital gains (% of revenue)
[04]	Cost of business startup procedures (% of GNI per capita)
[05]	Less infrastructure and connectivity in digital innovative activities indexed from 0 to 1
[06]	Firms receiving public financial support for innovation, as a percentage of product and process innovation-active firms
[07]	Share of turnover from new or significantly improved products
[08]	Innovative firms operating in international markets as a percentage of total firms with SMEs size
[09]	Firms cooperating on innovation activities with higher education or government institutions, as a percentage of product and/or process innovation-active firms
[10]	Firms cooperating on innovation activities with suppliers, as a percentage of product and/or process innovation-active firms
[11]	Firms cooperating on innovation activities with clients (private and/or public sector), as a percentage of product and/or process innovation-active firms
[12]	High technology (% of manufactures)
[13]	R&D active product and/or process innovative firms, as a percentage of product and/or process innovation-active firms
[14]	Product and/or process innovative firms as a percentage of total firms with SMEs size
[15]	Labour force with advanced education (% of the total working-age population with advanced education)
[16]	Firms engaged in international collaboration, as a percentage of product and/or process innovation-active firms
[17]	New businesses registered (indexed from 0 to 1)
[18]	Employment in innovative firms (product/process or organizational/marketing) as a percentage of total employment
[19]	Firms that applied for patents as a percentage of total firms
[20]	Firms that registered a design as a percentage of total firms
[21]	A composite index reflecting different levels of ICT development (unitless)

4 Results and discussion

4.1 Reanalysis of the variables

The obtained raw data for 21 variables were considered in this section. First, the values of 20 indicators for the innovation ecosystem [from 1 to 20], derived from SME information and summarized into six dimensions of IE, and the values of a variable of smart products [21] were extracted through three time intervals. Second, all values were converted to standardized digits. The mean standardized values of the six dimensions of the IE model and SP for 21 selected countries and three time periods (2015, 2017, and 2019) are listed in Tables 5 and 6, and 7. The tables can explain the simple ranking of countries based on the initial status of IE.

For instance, the last table revealed that Germany has the highest values of the capability and change dimensions of the IE in their SMEs (0.99-1.00), the United Kingdom has the highest values of the cooperation and constructs dimensions, and the Netherlands represents the top values of both context and configuration dimen-

Table 5 Mean standardized values of six dimensions of the innovation ecosystems and smart products in 2015

Country	Innovation ecosystem						Smart products
	Context	Construct	Configuration	Cooperation	Change	Capability	
Austria	0.93	0.79	0.77	0.90	0.89	0.94	0.87
Belgium	0.99	0.87	0.82	0.91	0.86	0.17	0.85
Czech	0.70	0.71	0.71	0.83	0.67	0.21	0.76
Denmark	0.69	0.84	0.66	0.89	0.69	0.17	0.99
Estonia	0.65	0.84	0.70	0.97	0.77	0.25	0.86
Finland	0.78	0.88	0.86	0.84	0.89	0.17	0.98
France	0.87	0.70	0.74	0.80	0.79	0.61	0.89
Germany	0.86	0.49	0.87	0.69	0.89	1.00	0.88
Greece	0.69	0.89	0.79	0.86	0.81	0.22	0.76
Hungary	0.80	0.75	0.44	0.81	0.44	0.19	0.72
Italy	0.94	0.24	0.80	0.69	0.78	0.47	0.78
Netherlands	1.00	0.74	0.81	0.84	0.83	0.17	0.95
Norway	0.56	0.67	0.56	0.87	0.92	0.73	0.96
Poland	0.61	0.47	0.25	0.81	0.38	0.24	0.75
Portugal	0.81	0.35	0.89	0.80	0.91	0.38	0.75
Slovakia	0.70	0.73	0.48	0.92	0.47	0.20	0.72
Slovenia	0.74	1.00	0.69	1.00	0.60	0.17	0.80
Spain	0.64	0.42	0.55	0.77	0.56	0.29	0.82
Sweden	0.69	0.82	0.81	0.91	0.77	0.81	1.00
Switzerland	0.75	0.78	0.77	0.89	1.00	0.75	0.92
United Kingdom	0.62	0.70	1.00	0.94	0.82	0.17	0.95

sions among the selected countries in 2019. Based on the six dimensions of the IE model, the countries' arrangement changed overall within three time intervals. From the point of view of smart products, the United Kingdom, Germany, Sweden, Switzerland, and the Netherlands had frontier ranks in the SP, with values above 0.95 in 2019. However, the mean values of the SP represent the various trends for the countries between 2015 and 2019.

4.2 Application of panel data analysis

The relationships between the SP (dependent variable) and each dimension of the IE model (independent variable) were examined by fixed-effect and random-effect analyses. The Hausman test was rectified automatically with Stata software to avoid the potential for endogeneity (Khatami et al. 2022). The correlation matrix and descriptive statistics of the variables in the panel data analysis and the regression coefficients between IE dimensions and SP (within 2015–2019) are shown in Tables 8 and 9. Based on the results, three dimensions of the IE model, i.e., configuration, change, and capability, significantly correlate with the SP indicator. Therefore, three H3, H5, and H6 hypotheses were confirmed due to P values <0.1. In this regard, creating components of these three dimensions, including (i) the external and internal economic partnerships of the institutions and companies, (ii) cultural changes in functional status, and (iii) the knowledge-based capabilities of the technological skills in each

Table 6 Mean standardized values of six dimensions of the innovation ecosystems and smart products in 2017

Country	Innovation ecosystem						Smart products
	Context	Construct	Configuration	Cooperation	Change	Capability	
Austria	0.78	0.60	0.73	0.69	0.89	0.94	0.87
Belgium	1.00	0.71	0.93	0.69	0.86	0.17	0.88
Czech	0.68	0.44	0.70	0.59	0.67	0.21	0.76
Denmark	0.68	0.59	0.55	0.64	0.69	0.17	0.96
Estonia	0.67	0.63	0.74	1.00	0.77	0.25	0.82
Finland	0.72	0.66	1.00	0.63	0.89	0.17	0.85
France	0.82	0.51	0.83	0.59	0.79	0.61	0.90
Germany	0.81	0.32	0.73	0.51	0.89	1.00	0.97
Greece	0.70	0.53	0.66	0.58	0.81	0.22	0.79
Hungary	0.72	0.50	0.53	0.58	0.44	0.19	0.76
Italy	0.87	0.21	0.61	0.51	0.78	0.47	0.81
Netherlands	0.95	0.63	0.98	0.63	0.83	0.17	0.97
Norway	0.71	0.69	0.94	0.69	0.92	0.73	0.92
Poland	0.59	0.32	0.43	0.59	0.38	0.24	0.76
Portugal	0.80	0.24	0.69	0.58	0.91	0.38	0.81
Slovakia	0.64	0.60	0.55	0.70	0.47	0.20	0.74
Slovenia	0.73	0.60	0.85	0.70	0.60	0.17	0.84
Spain	0.66	0.34	0.55	0.58	0.56	0.29	0.83
Sweden	0.59	0.41	0.75	0.58	0.77	0.81	1.00
Switzerland	0.77	0.36	0.78	0.61	1.00	0.75	1.00
United Kingdom	0.71	1.00	0.83	0.77	0.82	0.17	0.97

ecosystem, are meaningful characteristics of SP promotion among the selected countries. In contrast, the three hypotheses of H1, H2, and H4 are not supported due to their P values > 0.1. Hence, the context, construct, and cooperation dimensions of the IE model do not play a meaningful role in the SP. The results above revealed that the quantitative examination of the six-dimensional model of IE proposed by Kahle et al. (2020) is not entirely valid for SP in European countries, and we are obliged to focus on the chosen variables and dimensions, i.e., configuration, change, and capability.

4.3 Correlation tests

In this section, the correlation coefficients between the dependent variable (SP indicator) and independent variables (IE dimensions) were calculated to support the results of the panel data analysis. Based on Table 10, the correlation tests between the IE dimensions and the SP indicator can be used to examine the six hypotheses as a result of the research model (Fig. 2). Similar to the panel data analysis, the correlation tests confirmed significant and positive correlations (R = 0.45 to 0.50, Sig. < 0.1) between the three dimensions of the IE model, i.e., configuration, change, capability and SP, on average, within 2015–2019. These results support three hypotheses for H3, H5, and H6. In contrast, nonsignificant correlations (R < -0.40, Sig. > 0.1) were observed between three dimensions of the IE model, i.e., context, construct, cooperation, and

Table 7 Mean standardized values of six dimensions of the innovation ecosystems and smart products in 2019

Country	Innovation ecosystem						Smart products
	Context	Construct	Configuration	Cooperation	Change	Capability	
Austria	0.78	0.53	0.71	0.89	0.92	0.54	0.89
Belgium	1.00	0.39	0.86	0.69	0.94	0.11	0.91
Czech	0.73	0.32	0.72	0.72	0.70	0.24	0.80
Denmark	0.68	0.47	0.59	0.82	0.85	0.33	0.94
Estonia	0.80	0.60	0.62	0.98	1.00	0.16	0.85
Finland	0.80	0.52	1.00	0.80	0.87	0.11	0.85
France	0.84	0.51	0.80	0.76	0.76	0.58	0.95
Germany	0.82	0.26	0.70	0.67	0.99	1.00	1.00
Greece	0.76	0.66	0.73	0.84	0.88	0.25	0.83
Hungary	0.67	0.38	0.44	0.74	0.42	0.14	0.82
Italy	0.95	0.14	0.70	0.66	0.87	0.53	0.83
Netherlands	0.95	0.38	0.92	0.77	0.98	0.32	0.98
Norway	0.74	0.41	0.89	0.82	0.56	0.49	0.89
Poland	0.59	0.33	0.37	0.76	0.41	0.10	0.77
Portugal	0.86	0.21	0.73	0.77	0.63	0.33	0.84
Slovakia	0.66	0.42	0.49	0.86	0.45	0.12	0.76
Slovenia	0.73	0.55	0.78	0.94	0.98	0.11	0.86
Spain	0.67	0.27	0.52	0.74	0.47	0.17	0.84
Sweden	0.67	0.47	0.82	0.88	0.92	0.57	0.96
Switzerland	0.75	0.32	0.73	0.81	0.77	0.44	1.00
United Kingdom	0.67	1.00	0.81	1.00	0.68	0.11	1.00

Table 8 Correlation matrix and descriptive statistics

Var.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	1.00										
(2)	0.21	1.00									
(3)	0.22	-0.10	1.00								
(4)	0.51	0.51	0.28	1.00							
(5)	0.07	-0.24	0.71	0.13	1.00						
(6)	0.45	0.44	0.14	0.66	0.08	1.00					
(7)	0.43	0.17	-0.29	0.18	-0.28	0.41	1.00				
(8)	-0.25	-0.31	0.00	-0.34	0.27	-0.37	-0.42	1.00			
(9)	-0.20	-0.24	-0.02	-0.27	0.21	-0.33	-0.29	0.86	1.00		
(10)	-0.19	0.06	-0.01	-0.05	-0.01	0.14	-0.06	0.20	0.17	1.00	
(11)	0.35	0.02	0.33	0.26	0.12	0.18	0.24	-0.18	-0.17	0.23	1.00
Mean	7.7	22.2	17.6	44.6	48.8	28.4	2.5	2.4	2.6	36.0	14.7
Std. Dev.	0.8	3.3	6.2	10.3	6.2	6.8	1.8	1.2	1.4	18.9	6.2
Min	6.1	15.6	5.8	14.5	39.3	14.5	0.9	-0.2	-0.6	7.4	5.8
Max	9.2	30.1	40.8	65.3	77.0	38.7	9.0	5.5	6.5	68.1	28.1

(1) Smart product, (2) Context, (3) Construct, (4) Configuration, (5) Cooperation, (6) Change, (7) Capability, (8) GDP, (9) GNI, (10) ICT, (11) High tech

Table 9 Results of the panel data analysis

Variables	Smart production	
	Fixed	Random
Context	0.0076	0.0197
	(0.0515)□	(0.0373)□
Construct	0.0178	0.0339
	(0.0198)□	(0.0196)□
Configuration	0.0122	0.0119
	(0.0129)*	(0.0117)□
Cooperation	-0.0162	-0.0202
	(0.0195)□	(0.0195)□
Change	0.0096	0.0157
	(0.0167)*	(0.0162)□
Capability	0.2376	0.2038
	(0.1038)*	(0.0725)*
GDP	0.3020	0.2041
	(0.1040)*	(0.1128)*
GNI	-0.0073	-0.0021
	(0.0713)□	(0.0821)□
ICT	-0.0176	-0.0161
	(0.0038)*	(0.0039)*
High tech	-0.0443	0.0061
	(0.0268)□	(0.0201)□
R^2	0.0000	0.4106
F Test	0.0000	0.0000
P-Value	0.0013	
Hausman Test	(Fixed)	
Observations	63	63
Groups	21	21

Coefficients (Std. Errors) * $p<0.1$, □ $p>0.1$

SP, indicating the rejection of the three hypotheses of H1, H2, and H4, for a second time.

On the other hand, the constant correlation between the mean IE and SP values revealed a significant correlation at a confidence level of 90% ($R=0.55$, Sig. < 0.1), revealing the direct role of the IE effects in smart products during 2015–2019. This fact can be plotted as a relationship chart between the IE and SP mean standardized values for the 21 selected countries in Fig. 3. This figure shows that some countries, i.e., the United Kingdom and the Netherlands, which have high mean IE values, could support SMEs' powerful smart products at the national level. In contrast, some other countries, such as Poland and Hungary, which have low mean IE values, could not support their weak SP status.

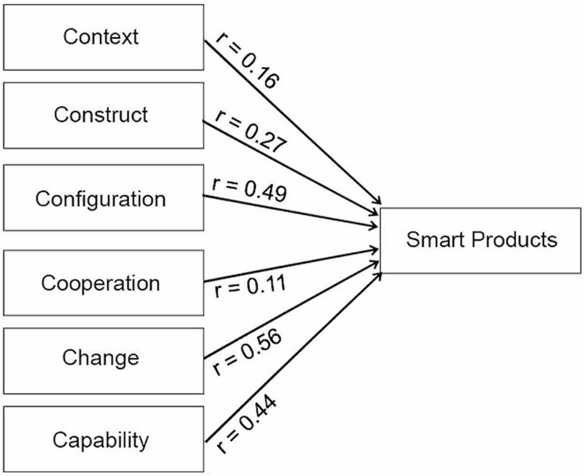
4.4 Hierarchical clustering

HCA was carried out using Ward's method to understand the different and distinct groups and classes of the European countries. The mean standardized values of the IE and SP were used to obtain a proximity matrix based on the squared Euclidean

Table 10 Correlation test between innovation ecosystem and smart products within given countries ($N=21$)

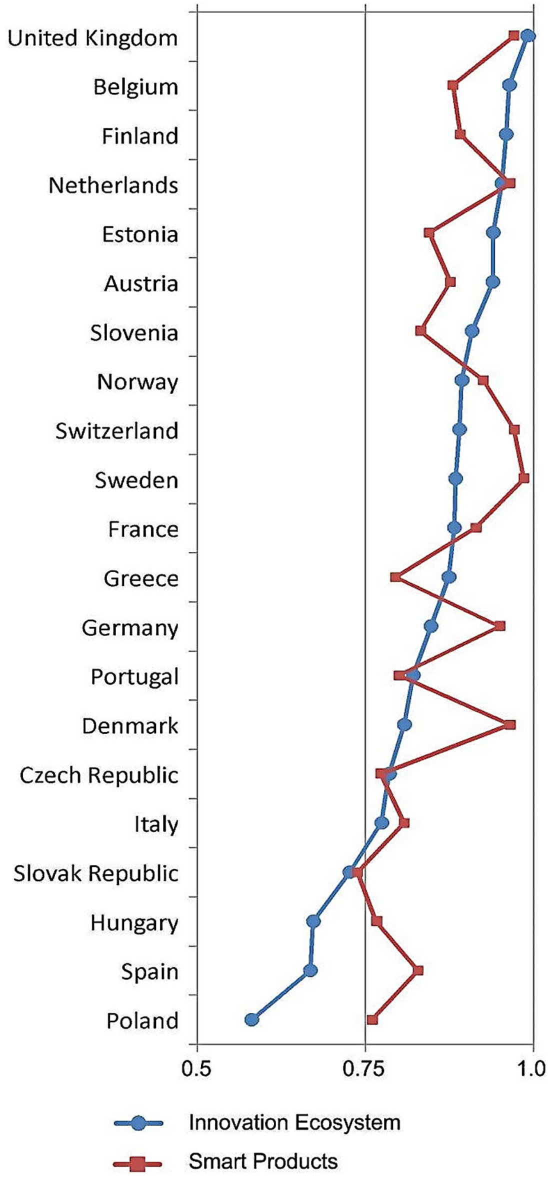
Dimensions of Innovation Ecosystem (IE)	Test	Smart Products (SP)			
		2015	2017	2019	Mean
Context	R	-0.02	0.25	0.25	0.16
	Sig.	0.93	0.28	0.27	0.49
	N	21	21	21	21
Construct	R	0.32	0.23	0.26	0.27
	Sig.	0.15	0.31	0.26	0.24
	N	21	21	21	21
Configuration	R	0.45	0.51	0.52	0.50
	Sig.	0.04	0.02	0.02	0.03
	N	21	21	21	21
Cooperation	R	0.22	-0.01	0.11	0.11
	Sig.	0.34	0.95	0.63	0.64
	N	21	21	21	21
Change	R	0.57	0.62	0.50	0.56
	Sig.	0.01	0.00	0.02	0.01
	N	21	21	21	21
Capability	R	0.31	0.48	0.53	0.45
	Sig.	0.18	0.03	0.01	0.07
	N	21	21	21	21
Mean IE	R	0.57	0.50	0.58	0.55
	Sig.	0.01	0.02	0.01	0.01
	N	21	21	21	21

Fig. 2 Research results



distance (Table 11) and hierarchical clustering of the countries (Fig. 4). The HCA is known for its ability to divide the dataset into homogeneous and distinct groups and cases by identifying patterns in the underlying data. The HCA method is usually based on a distance matrix with the Euclidean distance measure (Khatami et al. 2021).

Fig. 3 The relation chart between mean standardized values of IE (Innovation Ecosystem) and SP (Smart Products) among 21 selected countries



Furthermore, the HCA and its dendrogram could be assumed to classify countries into homogeneous and distinct groups and members with similar characteristics (Shukla et al. 2000). The dendrogram in Fig. 4 classifies the case studies of 21 countries into three clusters: high, medium, and low promotion of IE for the SP. Eight countries are identified as having a high level of IE promotion for the SP: the United Kingdom, Netherlands, Sweden, Switzerland, Germany, Denmark, France, and Norway. On the other hand, seven countries are identified as having a low level of IE

Table 11 Proximity matrix for the 21 countries (case studies) based on the squared Euclidean distance in the HCA

Country	Austria	Belgium	Czech	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Italy	Netherlands	Norway	Poland	Portugal	Slovak	Slovenia	Spain	Sweden	Switzerland	UK
Austria	0.00																				
Belgium	0.00	0.00																			
Czech Republic	0.04	0.04	0.00																		
Denmark	0.03	0.03	0.04	0.00																	
Estonia	0.00	0.00	0.03	0.03	0.00																
Finland	0.00	0.00	0.04	0.03	0.00	0.00															
France	0.00	0.01	0.03	0.01	0.01	0.01	0.00														
Germany	0.01	0.02	0.04	0.00	0.02	0.02	0.00	0.00													
Greece	0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.02	0.00												
Hungary	0.09	0.10	0.01	0.06	0.08	0.10	0.06	0.07	0.04	0.00											
Italy	0.03	0.04	0.00	0.03	0.03	0.04	0.02	0.03	0.01	0.01	0.00										
Netherlands	0.01	0.01	0.07	0.02	0.01	0.01	0.01	0.01	0.04	0.12	0.06	0.00									
Norway	0.01	0.01	0.04	0.01	0.01	0.01	0.00	0.00	0.02	0.07	0.03	0.01	0.00								
Poland	0.14	0.16	0.04	0.10	0.14	0.16	0.11	0.11	0.09	0.01	0.04	0.18	0.13	0.00							
Portugal	0.02	0.03	0.00	0.03	0.02	0.03	0.02	0.02	0.00	0.02	0.00	0.05	0.02	0.06	0.00						
Slovak Republic	0.06	0.07	0.01	0.06	0.06	0.08	0.05	0.06	0.02	0.00	0.01	0.10	0.06	0.02	0.01	0.00					
Slovenia	0.00	0.01	0.02	0.03	0.00	0.01	0.01	0.02	0.00	0.06	0.02	0.02	0.01	0.11	0.01	0.04	0.00				
Spain	0.08	0.09	0.02	0.04	0.07	0.09	0.05	0.05	0.04	0.00	0.01	0.10	0.06	0.01	0.02	0.01	0.06	0.00			
Sweden	0.02	0.02	0.06	0.01	0.02	0.02	0.01	0.00	0.04	0.09	0.04	0.01	0.00	0.14	0.04	0.09	0.03	0.07	0.00		
Switzerland	0.01	0.01	0.05	0.01	0.02	0.01	0.00	0.00	0.03	0.09	0.04	0.00	0.00	0.14	0.03	0.08	0.02	0.07	0.00	0.00	
UK	0.01	0.01	0.08	0.03	0.02	0.01	0.02	0.02	0.04	0.14	0.07	0.00	0.01	0.21	0.06	0.12	0.03	0.12	0.01	0.01	0.00

promotion for SP, namely, the Czech Republic, Slovakia, Poland, Portugal, Hungary, Italy, and Spain. The remaining countries are categorized as medium-level countries.

5 Discussion

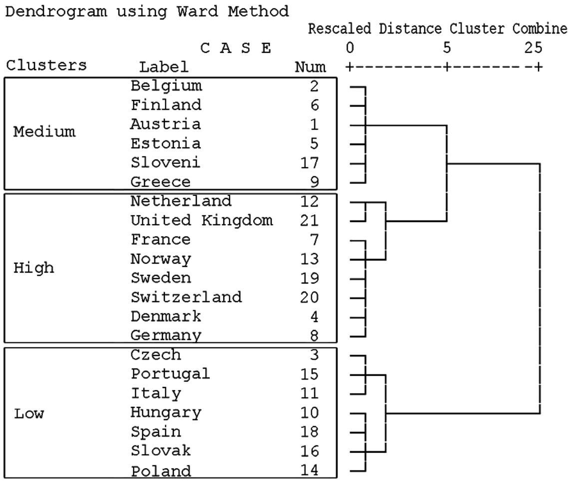
The quantitative methodology of the research showed that three dimensions of the IE model, i.e., configuration, change, and capability, have enough effects to accelerate high SP in SMEs in European countries (2015–2019). On this basis, not all six dimensions of the IE model (after Kahle et al. 2020) could be supported by quantitative approaches at the European country level. Our empirical research supported the positive effects of three IE dimensions (configuration, change, and capability) on SP status. This supporting the studies of Rong et al. (2015) and Porter and Heppelmann (2014) while our study has expanded more cases (21 countries) and offers new insights and potential that may have yet to be detectable with fewer cases in comparison to the two mentioned studies.

This means that creating components of these three dimensions, including institutions and companies' external and internal economic partnerships, cultural changes in functional status, and knowledge-based technological skills in each ecosystem, are meaningful characteristics of SP promotion among the selected countries. Regarding the significant and insignificant correlations between some dimensions of the IE model and SP, we can claim that indirect innovation functions (such as firms cooperating on innovation activities with clients or suppliers among the construct dimension of IE) are critical data for direct innovation functions (such as product and process innovative firms among the configuration dimension of IE).

The IE can configure the SP platform of companies where they can share knowledge-based capabilities (Rong et al. 2015). According to the managerial relevance of innovation ecosystems, research results can be followed by a variety of topics, including cultural change in digital transformation (Chanias et al. 2019), SME capability development (Li et al. 2018), and the configuring of internal and external capabilities (Westerman 2016). As Shaw and Allen (2018) mentioned, the process of cultural change and capability occurs in response to technological change in ecosystems. In support of our findings, Porter and Heppelmann (2014) emphasized that technological changes enable SP. In addition, Zhang et al. (2022) highlighted the technological-driven paradigm to create shared values in the SP among SME stakeholders, supporting the knowledge-based capabilities of the technological skills in each ecosystem. In this regard, research findings support technologically driven provisions in the literature by developing a common standard for IE and SP (Matt et al. 2021; Benitez et al. 2020, 2021). In comparison to our finding Matt et al. (2021) showed that innovative research activities in each SME should be complemented with an ecosystem of training and networking, involved the various dimension of SP, e.g., Industry 4.0 adoption.

Our results also revealed that the high level of knowledge-based IE in European countries could support the powerful smart products of SMEs. From the viewpoint of the knowledge-based capabilities of ecosystems, our results support the findings of Bouncken et al. (2021), who provided knowledge-based and innovation-based

Fig. 4 Hierarchical clustering dendrogram of the countries based on IE promotion for the SP in the European countries



empirical approaches. In this regard, we can verify that IE corresponds with functional capabilities and customer engagement in new production processes and smart product development through European countries (see Klimas and Czakon 2022b). Hence, the results confirm that developing ecosystems' technological capabilities require a knowledge-based economy for advanced products to flourish (Ruiz-Alba et al. 2021). In addition, new knowledge-based SPs need to cover the promotion of new partnerships in each IE (Lubik and Garnsey 2016; Gomes et al. 2021).

Finally, our findings showed that some countries, i.e., the United Kingdom and the Netherlands, which have high mean IE values, could support their powerful smart products for SMEs nationally. According to research by Amitrano et al. (2018), these two countries contributed to the top main research and developments in conceptualizing innovation ecosystems. As mentioned by the official report of the ITU (2018), the mentioned countries are leading in ICT and smart coverage among European countries. These findings confirmed that overall high IE values could accelerate high SP values in Europe.

6 Discussion and conclusion

6.1 Conclusion

This research attempted to represent a systematic manner of quantitative methods to evaluate the effects of the dimensions of the IE model in the SP. For this purpose, the six dimensions of the IE model were quantified based on SME information at the country level. The research focused on 21 European countries with considerable innovation levels of SMEs among the world countries. The quantitative methods of panel data analysis and Pearson correlation tests between variables of the IE and SP were considered to examine six research hypotheses following six dimensions of the IE model.

Based on the panel data analysis, three hypotheses, namely, H3 (configuration dimension of the IE accelerates the high SP), H5 (a change in the dimension of the IE accelerates the high SP), and H6 (the capability dimension of the IE accelerates the high SP) were confirmed due to their P values < 0.1. Similarly, the Pearson correlation tests confirmed the significant and positive correlations ($R = 0.45$ to 0.50, Sig. < 0.1) between the three dimensions of the IE model, i.e., configuration, change, capability and SP, on average within 2015–2019, supporting the three hypotheses above. Conversely, neither the panel data analysis nor the Pearson correlation tests supported the acceleration of three dimensions of IE (i.e., context, construct, and cooperation) in SP development, rejecting three hypotheses of H1, H2, and H4.

The HCA classified the case studies of 21 countries into three clusters: high, medium, and low promotion of IE for the SP. This finding showed that some countries, i.e., the United Kingdom and the Netherlands, with high mean IE values, could support their powerful smart products of SMEs at the national level. In contrast, some other countries, such as Poland and Hungary, which have low mean IE values, could not support their weak SP status.

6.2 Theoretical implications

The theoretical contributions of this paper could help the innovation ecosystem's theoretical background and practical dimensions in smart product promotion. From a theoretical point of view, Kahle et al. (2020) highlighted the role of the six dimensions of an IE model on SP at the firm micro level. Hence, we contribute by using macrolevel databases to increase insights into how to quantitatively scale and validate the six dimensions of the IE model through the development level of SP. Although recent attention has been given to IE approaches (e.g., Gawer and Cusumano 2014; Valkokari et al. 2017; Yin et al. 2020; Visscher et al. 2021), this paper attempts to develop an empirical approach using quantitative data in the country, which is beneficial for understanding the associated IE variables.

Moreover, the current research findings respond to several calls. First, the research call has developed the IE framework for SPs with the provision of technological resources. Other scholars (e.g., Yin et al. 2020) have focused on analysing different literature on the sustainability of IE as a promising approach for improving SP in SMEs. Third, the research call (e.g., Yan et al. 2021; Bandera and Thomas 2019; Burmaoglu and Saritas 2019) examines the different roles of IE in various disciplines and perspectives to promote SME development. Our results can complement these calls by validating and analysing a six-dimensional model of IE and its correlation with SP among the SMEs of 21 European countries. Ultimately, the results obtained regarding differences between the multiattitude variables in the conceptualization of IE and SP could also, along with some research calls such as Amitrano et al. (2018) and Dalenogare et al. (2022), respectively.

6.3 Managerial implications

We can describe the managerial implications regarding the knowledge-based capabilities of the technological skills in each ecosystem utilized by managers and stakeholders in SMEs, such as simulations of applications in smart notebooks, smartphones, etc. As Lubik and Garnsey (2016) and Gomes et al. (2021) mentioned, new science-based materials and smart products could be affected by the promotion of new partnerships in each innovation ecosystem. Based on the results, SME managers should consider institutions' and companies' external and internal economic alliances and cultural changes in functional status to increase their SP level. In this respect, SME stakeholders should look at the entire ecosystem to upgrade the cultural changes in functional status as a pillar for future receptions of innovative technologies. In addition, SME managers should promote the knowledge-based capabilities of technological skills to accelerate their abilities.

6.4 Limitations and future research

This research's main limitation was the availability of research datasets within restricted periods. As mentioned in the data collection, the specified intervals of the databases obliged this study to select time intervals for three years: 2015, 2017, and 2019. Hence, this issue influenced the selection of countries and their SME-based variables. Future studies should be repeated using extensive data collected from countries, multiple time scales, and different variables based on SMEs or other entrepreneurial ecosystems. Our study did not focus on the detailed typification of smart products (such as AI technology). In this regard, another limitation of the research was the exclusive recognition of smart products based on the values of IT, ICT, and artificial intelligence (AI) due to the limitations of global datasets. Hence, future research could examine more IT, ICT, and AI development values for quantifying SP characteristics at the country level. On the other hand, the research revealed that not all six dimensions of the IE model (after Kahle et al. 2020) could be supported by quantitative approaches at the European country level. It seems that further research needs to examine this model among Asian, African, or American countries to obtain robust propositions of the IE model.

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Data availability Our manuscript has no associated data.

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