The Interplay of Competency Diversity and Resilience in High-tech Companies

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Received: May 19, 2025 Accepted: June 18, 2025 Online Published: June 21, 2025

doi:10.5430/ijba.v16n2p108 URL: https://doi.org/10.5430/ijba.v16n2p108

Abstract

This study explores how competence diversity influences the resilience of small and medium-sized enterprises (SMEs) in high-technology industries, including mechatronics, aerospace, and automotive. Based on the theories of dynamic capabilities (Liu, Y., & Wang, J., 2024) and distributed innovation, the study demonstrates that companies with broader, interdisciplinary, and cross-sectoral competencies can better cope with external shocks, recover more rapidly, and respond effectively to changing industrial challenges. The findings indicate a growing need to move beyond linear innovation models, which conceptualise innovation as a unidirectional, internally driven process and adopt distributed competence-based approaches. At the centre of this research is the concept of cross-fertilisation, defined as a practice-driven form of cross-sectoral collaboration that enables the integration of different areas of knowledge to solve complex problems. This rethinking is particularly important for SMEs working in environments with high levels of technological uncertainty, where responsiveness, adaptability and innovation capacity are essential for competitiveness.

The study highlights persistent gaps in comprehending how enterprises can effectively manage diverse competence sets and regulate collaborative innovation processes. Moreover, the authors raise new issues about the trade-offs between competence extensions and the structural conditions necessary to ensure sustainable interdisciplinary cooperation. The results of this study highlight practical issues for improving sustainability and innovation performance in industrial sectors.

Keywords: industrial resilience, dynamic capability, competency diversity, clustering, aerospace

1. Introduction

Competencies play a crucial role in opportunities, innovations and internationalisation of business processes. A business can compete in the domestic and international markets by expanding its sales markets and cooperating with other companies (Capobianco-Uriarte et al., 2019). Therefore, in our paper, we analyse SMEs' dynamic capability and the resilience of high-tech industries. In our previous study (Peirone et al., 2024), we examined the hypothesis that the decisive factors of SME competitiveness are the company's dynamic capability and competencies. We proposed analysing a company's competencies through further audits using its capability matrix. We suggest considering a capability matrix as a strategic tool, grounded in the theories of resource-based and dynamic capabilities. It maps a company's core competencies represented by the company's products and services, resulting from innovation development, supply chain management and digitalisation. We also indicate the capability matrix as a tool to assess the company's competitiveness and resilience. It is particularly relevant for high-tech enterprises, as it allows for the identification of strengths, weaknesses, and potential for diversification. The study by Peirone et al (2024) shows its effectiveness in identifying companies that support growth through innovation and cross-sector competencies within agglomeration economies. A systematic audit of competences allows companies to anticipate vulnerabilities, adapt to crises and align strategic development with market dynamics.

In the current research, we analyse to what extent a company's success depends on the number of its competencies, the variables of dynamic capability, and the resilience of industries. We are interested in studying how competency diversity within high-tech companies affects their ability to adapt to market fluctuations.

Papers often identify various competencies contributing to organisational resilience (Linnenluecke, 2017; Hillmann & Guenther, 2021; Zhou et al., 2023; García-Valenzuela et al., 2023). However, insufficient attention is paid to how these competencies interact and create synergies in high-tech firms, thereby enhancing the resilience of industry developments. While the role of adaptability and dynamic environments is often recognised, the mechanisms by which competency diversity enhances resilience in rapidly changing high-tech markets need further elaboration. A review of the existing literature (Conz & Magnani, 2020; Duchek, 2020; Zhmoreou et al., 2022; Ma et al., 2023) demonstrates that theoretical research on organisational resilience of high-tech SMEs has a well-grounded theoretical foundation. However, it shows potential for further research, particularly in exploring the integration and synergy of different theoretical perspectives. Furthermore, the limited focus on causality is a valuable area for future research to enhance our comprehension of the mechanisms that define the resilience of small and medium enterprises. Our findings demonstrate that companies with a broad and well-integrated competencies base recover faster from the impact of exogenous shocks, sustain higher rates of post-crisis growth, and are better equipped to capitalise on emerging opportunities. It is important to note that the benefits of competency diversity are enhanced when digital technologies facilitate real-time knowledge recombination and organisational culture encourages disciplined experimentation. These results extend existing theory in at least two dimensions: they reveal the synergistic mechanisms by which heterogeneous capabilities are combined to achieve adaptive performance, and they highlight that resilience is not merely a protective attribute, but a dynamic advantage that enables active reconfiguration.

Building on the critical literature assessment, our study offers a more comprehensive understanding of industrial resilience and contributes to existing research in the field of strategic management of SMEs, with a focus on cross-sectoral collaboration and enhancing industrial resilience.

Our results demonstrate that companies with a broad interdisciplinary competence base can resist systemic disruptions, accelerate recovery and respond adaptively to emerging challenges. Therefore, this paper adopts an approach that will help compare the impact of industry resilience on companies' performance.

Our sample of SMEs is based in the Piemonte region of Northern Italy, which is strategically important for the country's high-tech manufacturing backbone. Piemonte is long acknowledged as one of the most developed and industrialised regions in the country, with a concentration of companies in the automotive, aerospace and mechatronics sectors — three industries that together represent key components of Italy's manufacturing economy and innovation potential (ICE, 2023; Invest in Italy, 2023).

The region's industrial strength is historically based in the automotive industry. In 2023, Italy's automotive sector generated a turnover of €113.3 billion, representing approximately 5.8 per cent of national GDP and 9 per cent of total manufacturing revenue. The sector comprised 5,451 companies and employed approximately 273,000 individuals, accounting for 7.1 per cent of the national manufacturing workforce (ANFIA, 2024). At the same time, Piemonte is home to a network of companies involved in aerospace activities, including global players such as Avio Aero and Leonardo, as well as over 300 small and medium-sized enterprises (SMEs) engaged in the production of civil and military aerospace systems (Trade.gov, 2023).

In addition, the mechatronics sector in Piemonte relies on a strong engineering talent pool and a tradition of precision manufacturing, making it a leader in industrial automation and robotics. (Invest in Italy, 2023).

The reason for choosing Piemontese companies on analytical grounds is that this region demonstrates strong sectoral specialisation, high integration with research institutions, and active participation in global value chains.

These factors create a suitable environment for capacity development and innovation dynamics at the company level. The region thus provides an empirically interesting background for studying how SMEs in high-tech sectors build and adapt competences in response to changing technological and market conditions. It also enables an in-depth analysis of capacity configurations within a mature regional innovation ecosystem (Camagni & Capello, 2013), making the results relevant to both regional development policies and international debates on SME competitiveness and sustainability.

Considering this regional context, it is essential to examine the sectoral dynamics of the economy within broader global developments in the studied high-tech industries, where rapid growth, technological convergence, and increased competition continue to alter the industry's trajectories.

According to the Space Foundation (Aerospace and Defence Industry Outlook, 2025), the global space economy grew to US$ 570 billion in 2023, a 7.4 per cent year-over-year increase (in line with a predicted five-year compound annual growth rate of 7.3 per cent), driven primarily by the commercial sector. In particular, the positioning, navigation, and timing subsector accounted for about 47 per cent (US$209 billion) of the commercial total of US$445 billion in 2025. This market is expected to grow by 155 per cent by 2035 and may be the prime focus in the year ahead

(Deloitte, 2024).

Mechatronics plays a vital role in the development of automation in various industries, which aligns with global trends of increasing efficiency and technological integration. The mechatronics market is expected to grow from USD 13.70 billion in 2024 to USD 34.60 billion by 2029 at a Compound annual growth rate (CAGR) of 20.4 per cent (Markets and Markets, 2024). At the same time, the automotive predictive technology market is expected to grow from USD 74.86 billion in 2024 to USD 111.07 billion by 2029 at a CAGR of 8.21 per cent (Mordor Intelligence, 2024).

Based on the potential of the industries mentioned above, we would like to focus on them in more detail. To establish the reliability of our findings, we conducted the study in several phases. In the first stage, we explored the theoretical aspects of industrial resilience and dynamic capabilities, laying a foundation for our empirical study. In the second stage, we conducted an empirical study using cluster analysis to examine the impact of industries on dynamic capabilities. The results of this study can help small and medium-sized enterprises (SMEs) enhance their competitiveness and financial performance. Based on the study results, we identified a list of actions that companies can take to improve their competitiveness in the market and encourage further development.

2. Theoretical Framework

The rapid development of technology and increasing competition are forcing companies to focus on improving their solid performance to gain a competitive advantage. They adapt to these changes and develop their capabilities to satisfy customer needs (A. Taweel & A. Hawary, 2021).

With globalisation and market expansion, there are significantly increased competitive pressures in all sectors, SMEs face especially complex challenges due to their limited resources. Among the conditions for maintaining competitiveness, SMEs should implement multidimensional strategies, with special attention given to agility and innovation. The systematic development of organisational competencies is crucial for gaining a competitive advantage and resilience in the global market (García-Valenzuela et al., 2023).

Identifying and managing companies' competencies becomes especially important in integration processes and the development of international strategies within the framework of dynamic capabilities theory (Teece, 2007). Dynamic capabilities theory emphasises the potential for companies to integrate, build, and reconfigure internal and external competencies in response to a rapidly changing environment (García-Valenzuela et al., 2023). Studies by Weerawardena et al. (2007), Jantunen et al. (2005), Prange and Verdier (2011), and Wilden et al. (2013) provide empirical findings of a positive correlation between effective capability reconfiguration and improved international performance. These findings emphasise the critical role of dynamic capabilities in building resilience and strategically positioning companies in international markets.

Establishing industrial resilience in this context requires SMEs to manage the challenges of globalisation and leverage their unique capabilities to respond to specific industrial needs and international market dynamics. This highlights the significance of a deep understanding of how competences intersect with dynamic capabilities to ensure sustainable growth and resilience in an increasingly competitive global market environment.

Lee et al. (2023) define resilience as the ability of a socioeconomic system to recover from unexpected shocks. Xiao, Boschma, and Andersson (2018) argue that resilience is defined as the ability of countries or regions to withstand shocks and recover from them. Boschma (2015) highlights that industrial resilience is a key element of long-term economic development and creates the potential to maintain high rates of market entry during a crisis or to develop high rates of market entry in response to a crisis (Xiao, Boschma, and Andersson, 2018). There are various definitions of resilience in Table 1.

Table 1. Literature review of the definition of “industrial resilience”

Definition	References
Industrial resilience refers to the ability of industrial systems to withstand disruptions, absorb shocks, and recover rapidly to maintain their functionality.	Bruneau et al. (2003). Holling (1973), Walker et al. (2004)
The capacity of industries to adapt to adverse conditions and evolve by leveraging learning, innovation, and resource reallocation.	Folke et al. (2002). Martin & Sunley (2015)
The ability of a system to maintain operations during	Pant et al. (2014). Righi et al. (2015), Bruneau et al.

disruptions by reorganising resources and structures effectively.	(2003)
Industrial resilience refers to the capacity of industries to prevent, mitigate, and recover from disruptions caused by external shocks.	Francis & Bekera (2014), Perrow (1984), Steenge & Bočkarjova (2007)
The dynamic capability of an industrial network to recover its essential functions and minimise economic losses during crises.	Sheffi (2005), Simmie & Martin (2010), Ouyang & Dueñas-Osorio (2012)
Resilience in industry is defined as the systemic ability to sustain critical outputs and adapt strategies in the face of prolonged stress.	Linkov et al. (2013), Ganin et al. (2020), Woods (2015)
Industrial resilience emphasises the role of redundancy, flexibility, and collaboration to maintain competitive performance under uncertainty.	Gunderson & Holling (2002), Hamel & Välikangas (2003)

Despite the differences in the wording and focus of the use of the notion “resilience” in Table 1, all definitions have in common several basic conceptual elements, such as the ability to resist change to recover rapidly and effectively with a return to previous productivity; adaptation and evolution; and the ability to be flexible and focused on achieving the company's goals.

In addition, according to the review of definitions, we would like to highlight the differences in the interpretations. Some authors narrowly define resilience as returning to function; not all definitions emphasise whether resilience is short-term or long-term. Also, worth noting that definitions implicitly draw from different schools: systems theory, dynamic capability (Sheffi, 2005; Simmie & Martin, 2010), Ouyang & Dueñas-Osorio (2012), risk management (Francis & Bekera, 2014; Perrow, 1984), Steenge & Bočkarjova (2007) or collaboration (Gunderson & Holling, 2002; Hamel & Välikangas, 2003).

From a theoretical perspective, we suggest that existing definitions be refined, taking into account the holistic theoretical model, the ambiguity in system boundaries, and the potential trade-offs and costs associated with resilience. Thus, we consider industrial resilience as industries' multidimensional and dynamic ability to anticipate, absorb, adapt and transform in response to disruptions while maintaining essential functions and providing long-term competitiveness. It operates across time phases (preparation, response, recovery, renewal), spans system levels (firm, network, region) and relies on structural flexibility, learning mechanisms, institutional support and collaborative capacity.

In current research, there is a notable trend toward more distributed and competence-based approaches, reflecting the increasing complexity and agility of knowledge creation in high-tech economies, as opposed to traditional linear models of innovation. Traditional linear models of innovation conceptualise technological progress as a sequential process, typically moving from basic research to applied research, development, production and market diffusion. Despite the foundational role of traditional linear models, among their disadvantages, we can determine a unidirectional process, thereby ignoring the importance of feedback mechanisms, user involvement, and the systemic and interactive nature of contemporary innovation dynamics (Godin, 2006). Linear models, such as the “technology push” and “market leap” paradigms, represent innovation as a sequential process, typically proceeding from basic research to development, production and diffusion (Godin, 2006)

In contrast, distributed models of innovation emphasise the decentralised, networked character of innovation activities, where multiple actors, such as companies, universities, suppliers, customers, and regulatory bodies, collaborate and exchange knowledge across institutional boundaries (Lundvall, 1992; Chesbrough, 2003). These approaches acknowledge that innovation often emerges from inter-organisational learning, feedback loops, and collective problem-solving, particularly within regional innovation systems and sectoral clusters.

In addition to this view, competence-based theories emphasise the internal capabilities of the enterprise as the most important drivers of innovation. This framework considers innovation a co-evolutionary process between technological and organisational capabilities (Dosi et al., 2000; Teece et al., 2007). To increase their competitiveness, companies develop new technologies and adapt their organisational structures, routine processes, and human capital to implement these innovations effectively. The interaction between external knowledge flows and internal learning mechanisms is central to sustainable competitiveness. This transformation of theoretical models emphasises the capability matrix as a tool that enables monitoring how companies integrate distributed knowledge and strengthen their core competencies. A capability matrix is particularly valuable in dynamic industries, such as aerospace and mechatronics, where innovation is systemic, multifaceted, and dependent on the company's ability to be agile.

When studying the resilience of SMEs, it is essential to consider the industry-specific aspects, which will inform the development strategy tailored to the company's evolving external environment. Since the companies in our sample belong to high-tech industries such as aerospace, mechatronics, and automotive, it is crucial to determine which criteria can help assess industry resilience and better understand how companies can use their competencies to adapt to changes in the external environment.

The aerospace industry's resilience can be characterised by innovation and flexibility, namely the ability to adapt to new technologies, the introduction of artificial intelligence, advanced materials, and systems for aircraft development, diversification of supply chains, flexibility in production processes, and the investment attractiveness of the industry.

The significant demand for space products has increased investor interest and led to the emergence of state support programmes. In response, aerospace companies invest in flexible manufacturing technologies such as 3d printing, digital twins and automation. This enables rapid reconfiguration of production in response to changes in demand, technical requirements and regulations (PricewaterhouseCoopers, 2017). Flexible manufacturing processes allow companies to reduce time-to-market for new products by 20-30 per cent, providing a competitive advantage and greater resilience (Weckenborg et al., 2024). High-tech industries remain attractive for investors, and the stable demand (military and civilian needs) and growth potential attract long-term investment, favouring financial sustainability. According to KPMG (2021), more than 60 per cent of venture companies view the aerospace sector as a fast-growing area for long-term investments, indicating its high investment attractiveness (Katuu, S., 2018). The resilience of the aerospace industry can be characterised by market volatility and demand shocks, as our sample is regionally dependent.

The aerospace sector faces cyclical demand fluctuations influenced by global economic trends, geopolitical tensions, and disruptions associated with pandemics. Brown et al. (2021) also note that risks to the aerospace industry arise from reduced investment in aviation and defence during economic downturns. As the Institute of Electrical and Electronics Engineers (2016) highlights, the aerospace industry is characterised by technological obsolescence, as the rapid development of aerospace technologies, including electric and hybrid propulsion, forces regional players to innovate (Olszewska et al., 2019). Otherwise, they risk losing competitiveness.

The disruption in the supply chain is equally important to the industry's sustainability. Dependence on international suppliers of critical materials (composites, electronic components) makes the aerospace sector vulnerable to global supply chain disruptions (Smith et al., 2022).

Mechatronics' resilience is driven by adaptability, technological integration, and advanced data management. These variables collectively enhance manufacturing efficiency and enable the system to withstand disruptions effectively (Liagkou et al., 2021; Gehlot & Rana, 2024).

The automotive industry faces vulnerabilities due to its reliance on globalised supply chains. Dependencies on international suppliers for raw materials, such as lithium and semiconductors, highlight risks exacerbated by geopolitical tensions and pandemic-induced disruptions. Among the key factors which characterise the resilience of mechatronics are supply chain diversification, digital integration, geopolitical risk management, regulatory adaptability, and technological advancement (Fraga-Lamas & Fernandez-Carames, 2019; Britsche & Fekete, 2024).

3. Method

Our sample comprises 200 small and medium-sized Italian companies, represented in the aerospace, mechatronics, and automotive industries. The selection of companies was based on multiple criteria, including compliance with the SME definition outlined in the EU Recommendation 2003/361/EC of 6 May 2003, evidence of internationalisation, and engagement in innovative activities. The sampled SMEs are located in the Piemonte region. Data collection was conducted through structured interviews, providing insight into each firm's core competencies, which are key determinants of their competitiveness and positioning within their relevant sectors.

We conducted interviews with company representatives between 2022 and 2023 to gather detailed information about their competencies. In view of the rapid development of high-tech industries, we accept that the competences identified may be incomplete. We intend to address these potential limitations and include new competencies in future research. For the empirical study, we used clustering analysis based on the k-means clustering algorithm, which is the most commonly used (Alasali, T., & Ortakci, Y., 2024) and regression analyses. The hypotheses in the proposed model were tested with the software Jamovi. For this purpose, we used a sample of 200 companies at a 95 per cent confidence interval.

Clustering, as a generic tool for finding groups or clusters in multivariate data, has found wide application in biology, psychology and economics. One of the main difficulties for cluster analysis is that the correct number of clusters for different types of datasets is seldom known in practice (Alasali et al.). The procedure follows a simple approach to classify a data set into several clusters. The main idea is to define k centroids, one for each cluster (Kodinariya, 2013; Logamani, K., & Punitha, S., 2014). The purpose of clustering is to ensure that entities within the same cluster are similar to each other while entities in different clusters are significantly different.

When the original data includes a list of companies and groups of competencies and the presence of these competencies, expressed as ones (1) and zeros (0), cluster analysis can be used to group companies based on their competencies. In this context, a one (1) indicates that a company has a specific competence, and a zero (0) indicates that it does not.

In the first step of the study, each company is represented as a vector whose elements correspond to the presence or absence of specific competencies. This is binary data where each competency is either present (1) or absent (0). Similarity measures such as Jaccard's or Hamming's coefficient are often used for binary data. These measures help determine how close companies are to each other regarding their competencies.

As we have already mentioned, for clustering, we chose k-means (although for binary data, k-means may not be ideal without data transformation) and a density-based method, such as DBSCAN (Kriegel et al., 2011) (Figure 1).

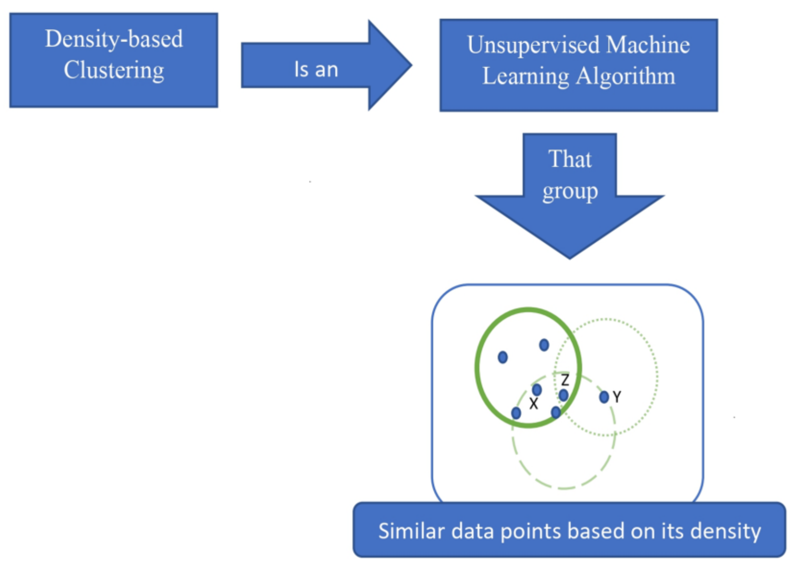

Figure 1. Density-based method (Kriegel et al., 2011)

The k-means cluster analysis divided the companies into four clusters by competencies. The table displays the "Sum of squares" (1) for each cluster, the sum of squares between clusters, and the "total" sum of squares

$$WCSS_k = \sum_{i \in C_k} (x_i - \mu_k)^2 \quad (1)$$

where: $WCSS_k$ is the within-cluster sum of squares for cluster k (Thongnim, P. et al, 2025); xi represents each data point i in cluster k; μ_k is the centroid of cluster k. The "sum of squares" within each cluster (for clusters 1, 2, 3 and 4) measures the dispersion within each cluster, namely, how well the companies within each cluster are distributed across their competencies.

Lower values indicate that companies within each cluster are more similar, implying less variation within the cluster regarding competencies.

We suggest the following hypothesis: Companies with more interdisciplinary competencies have an advantage in creating innovations and responding faster to industry challenges, which increases their resilience

4. Results

Rethinking global outreach through the lens of a capability-driven dynamic model enables us to identify various dynamic skills that facilitate either exploitative or rapid entry into international markets, as identified by Prange and Verdier (2011). Up to this point, they have delineated four distinct dynamic capabilities — foundational, enhancement, value-augmentation, and transformative capabilities — and associated them with the dual processes of global exploration and exploitation.

For aerospace, mechatronics, and automotive companies, a specific set of competencies is crucial to maintaining competitiveness, ensuring quality assurance, and driving innovation. We identify several groups of components that can be beneficial for all three sectors: Aircraft Systems, Space Systems, Design, Manufacturing, Mechatronics products, Mechatronics services, Automotive products, Components, Subsystems, and Systems, as well as Production Management. This set of competencies was derived from the survey responses provided by company representatives.

The availability of the above-mentioned competencies allows companies to diversify their production and risks by expanding the range of products and services they offer in the market. Therefore, the applied clustering algorithm grouped the companies into clusters based on the selected competency groups. Thus, companies with similar competencies joined the cluster (Table 2).

Table 2. Clustering vectors using the K-means Clustering

Sum of squares Table

	Value
Cluster 1	650
Cluster 2	491
Cluster 3	791
Cluster 4	418
Between clusters	3228
Total	5578

Source: Model Calculations

According to Table 2, Cluster 1 has a sum-of-squares value of 650, indicating a certain degree of dispersion within this cluster. The sum of squares of Cluster 2 demonstrates that companies in Cluster 2 are more similar to each other in terms of competencies than companies in other clusters. Cluster 3 demonstrates the highest sum of squares value (791), indicating the highest variance within the cluster.

Dispersion measures how much the data points differ from the central value (mean or median), and a high degree of dispersion indicates that data points are spread out over a wide range of values (Roy & Chakravarty, 2021). Conversely, a low degree of dispersion suggests that the data points are closely bunched together, implying that the entities within the cluster are very similar to each other with respect to the clustered variables. Companies in this cluster have a diverse set of competencies. Cluster 4 is characterised by sufficient cohesion of companies, but not as cohesive as in Cluster 2.

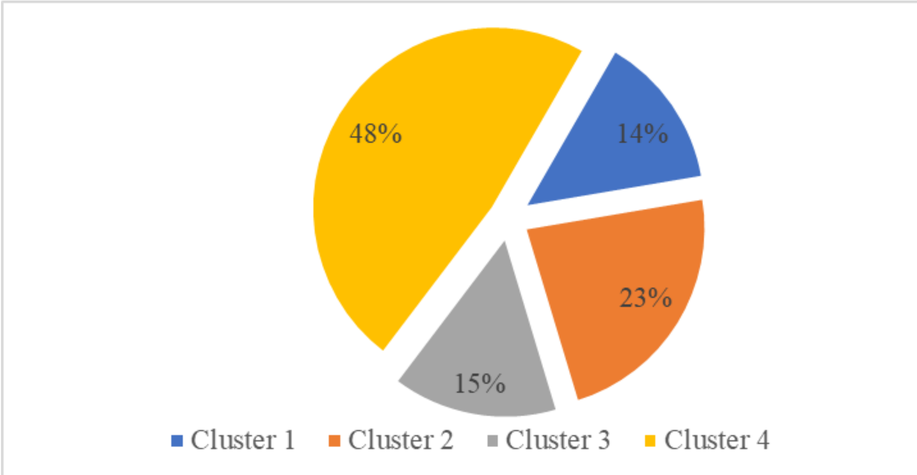

Figure 2. Clustering of companies by competence groups

Source: Model Calculations

The clustering results from Figure 2 demonstrate that most of the sample companies (96) were in Cluster 4, 46 companies in Cluster 2, 30 in Cluster 3, and 28 in Cluster 1.

In the clustering process, we determined the centroids (2) of the clusters from a k-means clustering analysis (Table 3).

$$\mu_k = \frac{1}{n_k} \sum_{\{i \in C_k\}} x_i \qquad (2)$$

where: μ_k is the centroid of cluster k; n_k is the number of data points in cluster k; x_i represents each data point *i* in cluster k (Castro, J. et al. 2017). Each centroid value represents the mean score of the competencies for the companies within that cluster.

Table 3. Centroids of clusters

	Aircraft System	Space System	Design	Manufac turing	Products in mechatro nics	Service in mechatro-nics	Products in automotive	Components Subsystems & Systems	Manufacturing & Production Management
1	1.241	0.310	0.379	1.000	0.310	0.793	4.517	5.828	5.828
2	0.533	0.533	0.733	0.267	0.311	0.689	5.289	1.111	1.111
3	0.177	0.302	0.333	0.135	0.625	0.458	0.208	0.333	0.333
4	2.778	2.037	1.333	4.889	0.407	0.556	0.296	0.370	0.370

Source: Model Calculations

Cluster 1 includes companies with a high and moderate number of competencies. A high number of competencies include high scores in “Automotive Products”, “Component Subsystems and Systems”, and “Production and Process Management”, indicating that these companies specialise in automotive products and pay much attention to production and release systems.

A moderate to low number of competencies characterise this Cluster in that moderate scores in “Aviation Systems” and “Service in Mechatronics” indicate some capabilities in these areas, but are not as pronounced as in the automotive and manufacturing competencies.

In Cluster 2, some companies are relatively balanced in terms of the number of competencies. However, there are moderate indicators in the areas of “Space System”, “Design”, “Products in Mechatronics”, and “Service in Mechatronics”. These companies can be considered universal, possessing a range of competencies but not leading in one area.

The scores for “Production and Manufacturing Process Management” and “Component Subsystems and Systems” are relatively low compared to Cluster 1, indicating less focus or capabilities in these competencies of the represented companies.

The highest score for Cluster 3 is in Mechatronics Products, which indicates the sample's specialisation in this area. Also in this cluster are companies with the lowest scores for most competencies, suggesting that these companies may be small or niche companies with a specific focus or less developed competencies in these industrial sectors.

Cluster 4 is notable for its high competence indicators in all areas, especially in the areas of “Manufacturing”, “Aviation Systems”, and “Space Systems”. The companies in this cluster are industry leaders with a broad and highly developed set of competencies. The extremely high scores in the “Manufacturing” domain indicate that these companies may specialise in manufacturing processes, indicating a competitive advantage in manufacturing capabilities.

Therefore, we conducted a regression analysis to analyse how the number of competencies in aerospace, automotive and mechatronics correlates.

Aircraft Systems have a correlation with Space Systems ($r = 0.423$, $p < .001$), Design ($r = 0.222$, $p < .002$), Components Subsystems and systems and Manufacturing and production Management ($r = 0.138$, $p < .054$).

Space system has a moderate positive correlation with Design ($r = 0.480$, $p < .001$). The correlation between Design and Manufacturing ($r = 0.267$, $p < .001$) shows a moderate to strong positive correlation of competencies that is statistically significant. At the same time, Design has a negative, weak correlation with Products in Mechatronics ($r = -0.173$, $p < .015$) and a positive direct correlation with Service in Mechatronics ($r = 0.162$, $p < .023$).

Products in Mechatronics characterise the indirect correlation between Products in automotive ($r = -0.158$, $p < .027$) and, finally, the group of competencies “Products in automotive” demonstrates a positive, strong and statistically significant correlation with Components and Production management ($r = 0.477$, $p < .001$).

During the analysis, we obtained the following result. The transformative character of the innovation needed for the innovative development of industry underpins a broad conceptualisation based on cross-fertilisation. Under cross-fertilisation, we understand a modern form of partnership interaction between companies from different industries, integrating interdisciplinary research and development results to solve complex problems, primarily through a practical orientation.

For SMEs operating in a highly technologically dynamic environment, cross-sectoral and interdisciplinary interactions are becoming not only a challenge but also a strategic resource for building adaptive, integrative and regenerative competencies in the context of modern industrial transformation.

5. Discussion

Based on the clustering of SMEs’ competencies using the K-means algorithm, we can formulate the following suggestions:

For companies that are in the first cluster, it is reasonable to enhance aviation and space systems to create a more balanced company profile and undertake actions aimed at keeping leadership in production. These activities will help companies focus on their strengths in production and management, further improving quality and efficiency.

Based on the study's results, companies in the second cluster were recommended to develop aviation and space systems competencies to diversify their business and invest resources in developing production competencies and production management.

Companies in Cluster 3 demonstrate a low level of competencies in all areas. The most developed competencies are in mechatronic products and services. The study's findings indicate that companies should prioritise the development of general competencies. In addition, companies are encouraged to focus their resources on strengthening and expanding capabilities in mechatronic products and services, which were identified as relatively well-developed among the companies in the sample.

To ensure the competitive advantage and sustainable development of companies in the fourth cluster, which is characterised by extremely high competencies in aviation systems, space systems, design, and manufacturing. Expand competences in automotive and mechatronics for a more balanced company profile and consider investments in innovative production.

The results of the cluster analysis provide insight into the resilience and interdependence of the aerospace, mechatronics and automotive sectors. Each sector demonstrates its own individual strengths and challenges within its network of competencies, providing opportunities for cross-sector cooperation to enhance sustainability and innovation.

The concepts of the number of competences in companies and industry sustainability are closely linked, as the set of competences in companies determines the industry's ability to adapt to change, recover from crises, and remain competitive in the long term.

We can look at industry sustainability in terms of sectoral resilience and cross-sectoral capabilities. Sectoral resilience encourages us to consider and study each sector separately, taking into account the unique features of the industry that could be the subject of future research. The aerospace sector demonstrates high specialisation in competencies such as “Aircraft Systems,” “Space Systems", “Design”, and “Manufacturing” These competencies show strong internal correlation, reflecting a holistic innovation ecosystem. However, limited diversification and weak links to competences in mechatronics and the automotive sector indicate vulnerability to disruptive processes beyond the industry. Strengthening collaborations with mechatronics to integrate advanced robotics and the Internet of Things technologies into manufacturing processes could address this gap (Smith et al., 2022).

The Mechatronics sector, characterised by the competencies “Mechatronics Products” and “Mechatronics Service”, demonstrates moderate resilience due to its adaptability and cross-sectoral relevance. The strong correlation with automotive competences such as “Automotive Manufacturing” emphasises its role as a linking competence. However, its restricted integration with aerospace competencies limits its potential for broader application. Strategic partnerships with the aerospace industry to develop autonomous systems and intelligent components can boost sustainability.

The automotive sector is characterised by high interdependence between core competencies, including “Automotive Products”, “Component Subsystems and Systems” and “Manufacturing and Production Management”. While such integration contributes to improving operational efficiency, dependence on traditional manufacturing methods and reduced diversification into related industries create challenges for resiliency.

At the same time, industry resilience provides an opportunity for companies to consider cross-sector collaboration. Our analysis identifies several opportunities for synergy between sectors. Mechatronics emerges as a key enabler of cross-sector resilience, particularly in facilitating technological integration. For instance, the aerospace sector can leverage mechatronics expertise in robotics to automate manufacturing processes, and the automotive sector could integrate mechatronic systems for electric and autonomous vehicles (Zhang et al., 2023). Furthermore, collaborative R&D across sectors can foster the development of lightweight materials, hybrid propulsion systems, and digital twin ecosystems, thereby accelerating innovation and reducing costs. In addition, collaborative sustainability initiatives, such as recycling advanced materials and adopting circular economy practices, offer promising paths to confront environmental and regulatory challenges collectively (Garcia et al., 2021).

The findings reveal clear opportunities for collaboration across various sectors to enhance resilience and adaptability. Mechatronics is a critical force in providing common competencies that benefit both the aerospace and automotive sectors. The autonomous robotics and modular manufacturing systems developed in mechatronics would boost efficiency in all industries. Furthermore, the aerospace and automotive industries could collaborate on joint R&D initiatives for lightweight materials, hybrid propulsion systems, and energy-efficient designs. We should establish shared digital platforms, such as digital twins, and promote standardised technologies across sectors. This will facilitate seamless integration and accelerate innovation. Joint resilience initiatives, including circular economy practices and the recycling of advanced materials, are crucial to strengthening resilience while addressing global environmental challenges (Garcia et al., 2023).

According to the clustering analysis, in order to increase their resilience and innovation potential, aerospace companies could diversify their competencies. Companies represented in mechatronics can expand cross-sector applications, and automotive companies can boost the implementation of new technologies through collaboration and digital transformation.

Furthermore, the analyses show a paradigm shift from traditional linear innovation models to distributed and competence-based frameworks in which innovation is increasingly understood as a co-evolutionary process involving multiple actors and competence areas.

However, while these findings contribute to theoretical and practical understanding, they also reveal a number of unresolved issues and emerging questions. First, while competence diversification is valuable, it remains theoretically and empirically unclear how firms with limited resources can effectively develop, integrate and sustain a broad set of capabilities without inefficiency or strategic risk. This raises the need for more detailed models of competence organising that consider scale, sector and absorptive capacity.

Second, the idea of "cross fertilisation" as a transformative, practice-oriented way of interdisciplinary and cross-sectoral collaboration poses important issues regarding its governance, institutional preconditions and long-term implications for effectiveness. The lack of conceptual clarity hinders companies' ability to leverage their full potential.

Third, the shift from linear to distributed and competence-based models of innovation, while conceptually compelling, raises new coordination dilemmas. In particular, how firms harmonise learning processes, collaborative technological development and strategic goals in fluid and diverse innovation networks remains under-researched.

Finally, a crucial empirical question remains: When does the expansion of a firm's competence base cease to produce marginal benefits and begin to generate complexity costs or opportunities? Determining the thresholds of productive competence diversity will be crucial for informing future policies and managerial interventions aimed at building resilience through cross-sectoral innovation.

Acknowledgments

We would like to express our gratitude to the Piemonte Agency for Internationalisation, Investments and Export for providing access to the database of Italian enterprises and for their assistance in arranging interviews with company representatives.

Authors' contributions

Prof. Nezghoda and Prof. Peirone were responsible for study design, revision and data collection. Prof. Peirone was responsible for paragraphs 1 and 2. Prof. Nezghoda for paragraphs 3 and 4. Both professors wrote the conclusion paragraph. All authors read and approved the final manuscript.

Funding

This research received no external funding.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of Sciedu Press.

The journal and publisher adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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