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RESEARCH

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User communities: from nice-to-have to must-have

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Abstract

With Industry 5.0 already on the horizon, firms need to adapt their strategies to better cater to an increasingly demanding and sustainability-conscious customer base. At the same time, the role of customers has shifted from being mere passive buyers to active users, who not only demand personalized products and services to suit their needs and preferences, but also actively engage other users and stakeholders, thereby grounding the Quadruple Helix model. The objective of this paper is to assess the role of user communities in fostering firms' innovation in all types of innovation. Econometric estimations identified the user community as a driver of innovation propensity. Additionally, the relevance of these communities across all types of innovation (mainly for product and process innovation) was proven. Robustness analysis confirmed the results obtained in different dimensions and established a connection to human capital. This finding revealed that absorptive capacity serves not only as a facilitator of innovation, but also as a moderator. The empirical contributions point towards the urgency of policy actions that consistently involve these agents as vehicles of responsible innovation, which can fine-tune the innovation paths towards an eco-friendlier innovation ecosystem. Further testing the connection between human capital and the user community is required, as the establishment of efficient communication channels promoting the knowledge flows inside the firm will leverage innovation outputs in the different innovation types.

Keywords: User communities, Open innovation, Industry 5.0, Quadruple Helix model, CIS, Logit models

Introduction

Over the last 20 years, Open Innovation has been an increasingly explored topic, discussed by academics and attracting the attention of innovation managers, practitioners, and policymakers (Bigliardi et al., 2020). In the second wave of the conceptual proposal, Chesbrough and Bogers (2014, p. 12) defined Open Innovation as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model". This definition takes the innovation processes beyond the limits of an organization, incorporating external players inside the value chain and, more recently, heterodox agents such as customers and users (Venez et al., 2022).

The "increasingly demanding and rapidly changing customer needs" withstand the also increasing need for firms to listen to and capture the customers' preferences and necessities (Mohamed, 2018, p. 257). As such, firms implement Open Innovation processes and other strategies to better capture diverse external knowledge, making them more agile, flexible, and efficient for their target markets (Carayannis & Campbell, 2009; Cepeda & Arias-Pérez, 2019). The reliance upon the external community is further leveraged by the expansion of information and communications technology (enabling easy, fast, and efficient communication between virtually anyone) and the increasing openness of enterprises by sharing their challenges with external parties (Bogers et al., 2018).

In what relates to the ecosystem, alternative frameworks are being layered, successively encompassing additional agents with alternative roles in knowledge production and diffusion. As such, from the traditional Academic and Governmental players, users and the environment were called to leverage the innovative process speeding up its pace as well as its embedded responsibility. In this vein, the Quadruple Helix model emerges as a theoretical framework emphasizing the role of civil society (Carayannis & Campbell, 2012). This framework is in complete harmony with the concept of Open Innovation, as the actions and decisions taken by each actor are exposed to feedback from others, creating interaction and accountability.

An essential set of recent academic studies (Carayannis & Campbell, 2021; Saha & Nagle, 2019; Venesz et al., 2022; Yun & Liu, 2019) highlights the role of the "civil society" in Open Innovation practices, with a big focus on the transition from "passive buyers" into active co-creators and co-developers of goods and services, but also as promotors of responsible developments in the innovation processes. However, there is a lack of empirical studies quantifying the role of user communities in fostering innovation. Furthermore, there is a clear gap in the type of innovations these communities can impact (product process, marketing, or organizational innovations). Thus, this article aims to investigate the role of user communities in fostering each innovation type, as well as the innovation intensity among Portuguese firms. The main research question is: "What is the role of user communities in fostering different types of innovations?" This analysis will allow a better understanding of how co-creation processes occur, the impact of user communities on a firm's innovation strategies, and, lastly, transpose these results into relevant information for firms who want to engage in these processes and design policy recommendations.

This user-centric approach is also compatible with the emerging paradigm of Industry 5.0. As we move from Industry 4.0–5.0, new challenges and necessities get the pride of place, such as sustainability, human-centricity, and resilience (Carayannis & Morawska-Jancelewicz, 2022; Xu et al., 2021). Firms that adapt their strategies considering these vectors (as opposed to only profitability) gain a competitive advantage by catering to and getting the trust of an ever-growing environmentally conscious customer base (Nahavandi, 2019; Wang, 2019). But how can firms successfully implement sustainability-oriented strategies and still capture profits? As technologies evolve, the workforce will be released from repetitive tasks, and the role of humans in manufacturing will evolve to rely more heavily on critical thinking and creativity (Javaid & Haleem, 2020). Through the new paradigm of Industry 5.0, machines and human workers will work together, as machines will learn human intention and use it during their work

(Nahavandi, 2019). This will be crucial for mass personalization, as it will provide the tools to massively manufacture products tailored to the customers' requirements regarding sustainability (Javaid & Haleem, 2020). Being sustainable is no longer an option but imperative (Xu et al., 2021). Increasingly demanding consumers push the sustainability agenda and demand transparency from firms, which will shape and deeply influence their decisions (Carayannis et al., 2021).

This implies a complete transformation of the Industry, transitioning into a circular economy by implementing processes and practices capable of using resources efficiently and reducing the environmental impact of the products and services (Grabowska et al., 2022). It is already possible to observe significant changes being put into place by various types of stakeholders (Gur, 2020), such as public entities/government bodies—the European Commission has already implemented several strategies to promote Industry 5.0 (Xu et al., 2021); research institutes/universities—Industry 5.0 is a subject undergoing intense study by academics with over 230 publications[1] since 2016; consumers/users—contribute to this transformation through their demand of sustainability-conscious and personalized products/services (Carayannis & Morawska-Jancelewicz, 2022). Therefore, firms must transform and adapt to this paradigm to successfully keep up with this demand and maintain their competitiveness (Wasono et al., 2019). A holistic innovation policy perspective will be crucial for this transformation (Fagerberg, 2018; Gur, 2020).

The achievement of these purposes will rely very heavily on knowledge from the users to adapt the firms' products and services according to their preferences and behaviors (Aquilani et al., 2020). The implementation of "data infusion, massive customized manufacturing processes and smart automation in the production process", which will incorporate said knowledge, will pave the way for Industry 5.0 (Maddikunta et al., 2022, p. 10). Furthermore, this implies a significant transition in policy models to a holistic approach that integrates the users to successfully develop human-centered innovations (Carayannis et al., 2021).

"Users are increasingly acknowledged as important actors fostering those fundamental socio-technical innovations needed to achieve a sustainable society" (Meelen et al., 2019, p.1). Given the characteristics of Industry 5.0—a human-centered paradigm focused on solving societal issues—user communities are essential for developing responsible innovations (Wang et al., 2020), which will shift toward a sustainable economy and environment (Sindhwani et al., 2022).

Despite the vast existing literature on co-creation and user communities, the quantification of the importance of these players in each innovation type is still overlooked. It also lacks the measurement and quantification of the economic effects of user communities on firms, as pointed out by Shah and Nagle (2019). Most studies on the interaction of firms and users through co-creation processes focus exclusively on product innovation (i.e., the introduction of new or improved goods or services to the market) (Markovic & Bagherzadeh, 2018), neglecting other types of innovation.

With this gap in mind, the article's primary goal will be to quantify the impact of user communities on the firms' innovation processes (measured through the engagement in

[1] The search was conducted on Scopus on publications related to "Industry 5.0".

co-creation processes with user communities). The impact measured will be in terms of innovation output (quantity and type—product, process, organizational, or marketing innovations). The results will shed light on the expected impacts on innovation related to the co-creation processes conducted by firms. These outcomes will provide valuable insights for firms to adjust their innovation strategy, namely, their interaction with user communities, according to the type of innovation they pursue. In this vein, the goal is to put into test the importance of engagement with user communities in innovation outputs, providing valuable material to firms—who can use this evidence to better tailor their innovation strategy according to the expected outcomes—as well as enabling to draw policy recommendations that can foster the approach between these agents in the helix.

Literature review

In this section, relevant insights about the key concepts, Open Innovation, and user communities, will be explored and discussed. First, the Open Innovation concept will be addressed, as well as the Quadruple Helix model, creating the theoretical foundations of the study. Then, several perspectives on user communities will be addressed, such as their nature, motivations, relevance, and how they interact with firms. The aspects developed in this section are crucial to fully understanding and explaining the significance of the engagement between firms and user communities.

Open innovation

Open innovation is a framework encompassing inward and outward flows of information circulating outside the boundaries of organizations (Bogers et al., 2018; Chesbrough, 2003). This framework emerged due to environmental factors such as the democratization of knowledge, significant development of Information and Communication Technologies, greater openness by large enterprises, and increasingly demanding consumers (Bogers et al., 2018; Mohamed, 2018).

In the initial stages of development, Open Innovation was only concerned with the relationships among actors of the value chains. However, the concept continuously evolved and broadened the scope of the firms' innovation processes, either by including additional actors—governments, research institutes/universities, other firms, consumers/users—or by being more geographically dispersed, making these processes evermore complex, holistic, and sophisticated (Binz & Truffer, 2017; Carayannis & Campbell, 2009; Chesbrough, 2003, 2019; Chesbrough & Bogers, 2014; Etzkowitz, 1989; Leydesdorff, 2011; McGahan et al., 2020; Vrande et al., 2010; West et al., 2014; Yun & Liu, 2019).

As the focus is on the fourth helix framework, we will now draw attention to the impact of the inclusion of user communities in innovation processes. User communities were mentioned in the innovation context[2] in 2005; the research examined the role of these communities as innovation diffusers of Open Source Software in firms, disrupting the software market led by Microsoft's Windows (Sieber et al., 2005). In this case study,

[2] The search was conducted on Scopus using the keywords "User community" and "Innovation".

the user community effects were indicated as the main reason for adopting this software in firms, revealing the capacity of influence of these communities.

Moreover, one of the most relevant articles on this subject dates back to 2006 and studies the attributes and motivations of users that actively contribute to firm-hosted user communities. It was conducted on the music industry and concluded that the users who actively engage in these communities are "hobbyists", lead users and motivated by firm recognition (Jeppesen & Frederiksen, 2006). It concluded that the benefits of relying upon these communities depend on the organization's product and area, indicating that areas more prone to hobbyists (such as consumer goods) are also more prone to benefit from the insights of such communities.

Recently, Ek and Sörhammar (2022) assessed the User Community Sensing (UCS) capability in the video game industry. The study found a positive correlation between product innovation and UCS, through the knowledge obtained by the communities (Ek & Sörhammar, 2022). However, no evidence was found regarding the increase in the speed of product development.

It is also worth mentioning that these communities are relevant across all sectors (Shah & Nagle, 2019). The knowledge and information retrieved from them can be used by different industries (that would not be the obvious target audience). To successfully transition into the Industry 5.0 paradigm, the transformation has to occur across the whole economy (Aquilani et al., 2020). The user community will allow speeding up the pace of innovation while preventing some hindering factors to the process (Costa & Matias, 2020).

Quadruple Helix model

The inclusion of additional actors in the innovation system is compatible with the Quadruple Helix model, in which "government, academia, industry, and civil society are seen as key actors promoting a democratic approach to innovation through which strategy development and decision-making are exposed to feedback from key stakeholders, resulting in socially accountable policies and practices" (Carayannis & Campbell, 2010; p. 1). Additionally, this model is characterized by both top-down government policies—similarly to the Triple helix model—and bottom-up activities, capable of affecting innovation, such as co-creation processes with civil society (Etzkowitz, 1989; Yun & Liu, 2019).

As illustrated by the Quadruple Helix model, there are many sources of knowledge from different stakeholders—academia/universities, industry, government/public institutes, and society (Carayannis & Campbell, 2009; Carayannis et al., 2018). As innovation processes benefit from several types of knowledge and expertise, firms have an excellent incentive to fully engage with all the stakeholders (Cavallini et al., 2016; Prause & Thurner, 2014). Focusing on the fourth helix, its relevance, and importance as a source of external knowledge are well recognized (Costa et al., 2021); however, its conceptualizations are not consensual among scholars (González-Martinez et al., 2021). For the remainder of the paper, most conceptualizations of the fourth helix revolve around "citizens" (Carayannis & Campbell, 2012), "wider community" (Kolehmainen et al., 2015), or "users" (Compagnucci et al., 2021; Roman et al., 2020),

Quintuple Helix model

The Quintuple Helix model introduces the environment helix (Carayannis & Campbell, 2010) to the previously mentioned Quadruple Helix (Carayannis & Campbell, 2009, 2012, 2014; Hasche et al., 2019). The fifth helix incorporates the wider environment, including concerns with sustainability and ecology, thus, becoming a driver for eco-innovations and knowledge creation (Carayannis et al., 2017; Durán-Romero et al., 2020). In addition, the environment helix increases the complexity of the model as it entails a complete interdisciplinary and transdisciplinary understanding of the environment (Carayannis & Campbell, 2010; Carayannis et al., 2017).

As such, we consider the fifth helix to be of a higher level, which cannot be isolated from the others as it characterizes its surrounding environment (Mineiro et al., 2021). Given this, it seems not to be possible to directly compare the environment with the other helices and even to accurately quantify or measure its impact on innovation. The environment is much closer to an embedding variable than a simple helix. Subsequently, for the present analysis and discussion, we shall disregard it and consider the Quadruple Helix model as the representation of the innovation ecosystem (Cai & Etzkowitz, 2020; Cai & Lattu, 2021).

To Sindhwani et al., (2022, p. 1), "the Industry 5.0 (I5.0) revolution is a call to bring forth the ideas of sustainability into practice, integrate human values with technology, and is considered a step forward for achieving sustainable development goals". Thus, understanding the value of the engagement between user communities and firms is a requirement to effectively transition into the new emerging paradigm (Aquilani et al., 2020).

User communities

"Users are the consumers of an enterprise's products who voluntarily participate in innovation tasks and submit solutions or ideas out of their interests or love of the products" (Liu et al., 2018, p. 6). User communities are groups made up of users with a common interest in an artifact (product or service), that work together (voluntarily), exchanging and developing knowledge that translate their own capabilities, preferences, recommendations, and needs (Shah & Nagle, 2019). These communities provide a common space (often virtual) for users with mutual interests to share their opinions, and experiences and interact with each other for the general purpose of knowledge development and exchange (Antorini & Muñiz, 2013; Füller et al., 2006). They play a determinant role not only making advancements in certain innovations, but also deterring other paths of innovation and promoting alternative diffusion methods and continuous improvements. The insights from this community are also of extreme value in small incremental innovations as well as product improvements from original versions, updates, and re-styles.

The communities are composed of various kinds of users, from amateurs to lead users and enthusiasts (Schütz et al., 2019; Shah & Nagle, 2019). For the knowledge to be more significant, valuable, and accurate for firms, user communities should have two characteristics:

- Large dimension: user communities need a large number of users to accurately represent the firm's target client (Oertzen et al., 2020). If the communities have a reduced number of users, the knowledge carried will not be as impactful, as it may not correctly translate the preferences, needs, or feedback of the larger pool of consumers (Füller et al., 2006; Pan, 2020; Rayna & Striukova, 2015; Surowiecki, 2004).
- Diversity: to get the most out of the communities, the users should have different profiles (age, gender, education, user degree) to potentialize their creativity and to assure the presence of complementary skills, able to generate high-quality innovations and knowledge (Füller et al., 2006; Oertzen et al., 2020; Pan, 2020; Prause & Thurner, 2014; Rayna & Striukova, 2015; Schütz et al., 2019).

Why are these communities interesting for firms?

In general, firms can create a competitive advantage through two distinct strategies: low-cost or differentiation. User communities can be beneficial for both strategies (Antorini & Muñiz, 2013; Chatterji & Fabrizio, 2013), however, as this work is focusing on the development of innovations, we will only focus on the differentiation strategy.

User communities are a valuable source of knowledge for future innovations, as they can provide insights on features and improvements of their preference, which would then translate to commercial success (Etzkowitz, 2014; Lee et al., 2022; Prause & Thurner, 2014), either by providing feedback on existing products/services, by using them in unusual ways/contexts, not originally planned by the firms, or by introducing new or improved products created by the users themselves (user innovation) (von Hippel, 2017). Additionally, by involving the users in the innovation processes, firms can reduce costs and mitigate the risk of market rejection (Yang & Li, 2019). However, this knowledge is scattered and dispersed among all users (Chen et al., 2020; Hayek, 1945). To obtain correct and significant information, this knowledge has to be aggregated, which can be challenging given the substantial number of potential users. Concerning this, the development of ICT opened a world of possibilities, with the creation of online communities, which can be more easily managed by firms (Mahr & Lievens, 2012).

The notion of responsible innovation is not recent (Blok & Lemmens, 2015; Hartley et al., 2019; Pansera & Owen, 2018; Stilgoe et al., 2013), being extensively explored both on the subject of social technology studies and social corporate responsibility (Gallego-Álvarez et al., 2011). Business actions of a corporation actively contribute to answering societal challenges. Given that most innovation and research is conducted (and funded) by companies and industries, it is no surprise most innovation processes only focus on profitability, not factoring in possible negative impacts on the society and environment (Gurzawska, 2021).

However, both policymakers and society are now more watchful of these practices (Gur, 2020), bringing both top-down (regulation and restricting funding opportunities) (Genus & Stirling, 2018; Voegtllin & Scherer, 2015) and bottom-up (demand) incentives for companies to pursue responsible innovation practices (Schlaile et al., 2017). Moreover, the aforementioned practices have to be aligned with society values and with innovation outputs (Gurzawska, 2021). As such, user communities are key stakeholders in responsible innovation (Compagnucci et al., 2021).

As previously mentioned, this notion is intimately related to the one of Corporate Social Responsibility (CSR) (Costa & Fonseca, 2022). CSR can be defined as the responsibility of firms for their actions' impact on society. With this goal, the firms' processes should take into consideration their implications on various domains of the society—such as human rights and environmental issues—and work in close collaboration with other stakeholders to better comprehend these impacts as well as put in place prevention or mitigation measures (European Commission, 2011). In order for firms and corporations to implement and strategize effective CSR practices, once more, it is a fulcrum to include the societies' needs and wants, namely, in terms of sustainability and environmental concerns, and the natural vehicle for this to happen is the user community.

But why is it beneficial for firms to implement and follow CSR practices? Even though these practices may result in added costs for firms (for instance, through getting sustainable suppliers or Fairtrade raw materials), these firms can gain the trust of the consumers, especially those more environmentally conscious (Księżak, 2017; Sprinkle & Maines, 2010). On the other hand, focusing on profitability alone without considering sustainability can cost the loyalty of consumers in the long run (Mačaitytė & Virbašiūtė, 2018).

What is user-led innovation?

According to von Hippel (2017, p. 1452), "user innovator is a single firm or individual that creates an innovation in order to use it". Several examples can be found in the literature, with the most prominent ones being related to medical devices and sporting goods (Grabher & Ibert, 2018). As such, these users create/develop/modify products or processes, capable of better fulfilling their needs than existing ones (or available to them) (von Hippel, 2017).

Eric von Hippel developed extensive literature on this subject, answering questions such as *Why do users want custom products?* or *Why do users share their innovations freely?* and developing the *Lead User Theory*. Focusing on the former, he argues that users' needs are very heterogeneous, and, because of this, mass-produced products will not be able to answer the needs of many users (von Hippel, 2017). As for producers, it is more efficient to produce a *one size fits all* product, as such, the users whose needs are not met by said product will be compelled to create/modify a fitting product themselves. But why do these users share their innovations freely, instead of profiting from them? It is extremely difficult for these users to successfully protect their innovations from imitation (Chesbrough et al., 2014; von Hippel, 2016). In this sense, the question for the users is not *Should I protect my innovation?* but *Should I share my innovation voluntarily or should I wait for imitation to happen either way?* Given that, more often than not, user innovators that share freely their innovations receive *private benefits* among communities—such as reputation, recognition, or social status (these benefits will be further developed in a later section), users feel more compelled to share their innovations freely (von Hippel, 2016). The *Lead User Theory* theorizes that most of the user innovations are developed by lead users (von Hippel, 2016). Lead users are characterized as being at the forefront of market trends, and highly interested in the product/service; given this, they are early adopters and test out the product/service before the majority of customers.

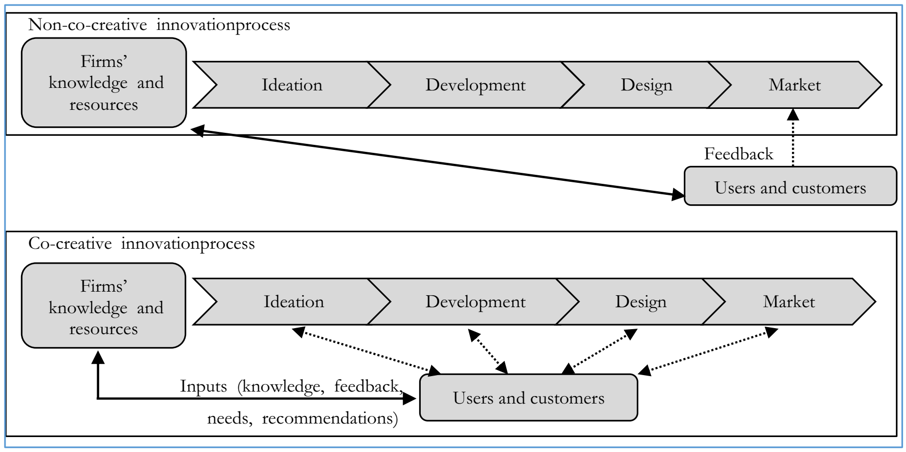

Fig. 1 A comparison of the non-co-creative and the co-creative innovation process

These users also anticipate receiving significant benefits from getting a product able to answer their needs, leading them to innovating themselves, in order to get it (Escobar et al., 2021; von Hippel, 2016).

How do firms engage with user communities?

To successfully engage user communities in the firm's innovation processes, these have to evolve from linear processes (that have the consumers as the endpoint) and truly integrate the users along the process, creating space for interaction and exchange of ideas and feedback from the users (Prause & Thurner, 2014; Roman & Fellnhofer, 2022). To do this, the firm's innovation processes need to be a cooperative process, where the communities actively participate in the production, development, design, and/or marketing of the products/services (Guo et al., 2017; Romero & Molina, 2011; Yun & Liu, 2019).

In this matter, the concept of co-creation emerges (Füller et al., 2009). Co-creation processes can be defined as activities and interactions in which the customers actively contribute to the design and development of new products or services involving the engagement of organizations (Durugbo & Pawar, 2014; Ramaswamy & Ozcan, 2014; Romero & Molina, 2011). In these interactions, the customer is no longer a mere buyer but a user able to provide valuable knowledge, which is then incorporated by firms and organizations in their innovation processes (Grabher & Ibert, 2018; Ramaswamy & Ozcan, 2014; Roman & Fellnhofer, 2022; Yun & Liu, 2019). As a reward, the users get co-developed products/services with added value for them, as they were developed with their needs in mind (Romero & Molina, 2011). In this context, users and firms simultaneously are the key co-creation actors and beneficiaries (Liu et al., 2018). Figure 1 shows the distinction between the non-co-creative and co-creative innovation processes.

In the non-co-creative innovation process, the users and customers assume the role of validators by providing feedback and opinions on the finalized product/service, taking a passive role outside the firm's borders (Grabher & Ibert, 2018; Roman & Fellnhofer, 2022). This process does not involve the user or customer directly in the product/service development, nor does it consider their needs and ideas, as the communication between the firm and the customer only happens at the last stage of the product/service development (Durugbo & Pawar, 2014). Alternatively, in the co-*creative innovation process,* the users and customers are actively involved in the innovation process, exchanging knowledge and inputs throughout the entire journey (Zhang et al., 2020). The product/service is jointly developed in a process that occurs beyond the organizational limits of the firm. Co-creation processes emerge as a way of implementing Open Innovation strategies by distributing the innovation process through different actors (Abbate et al., 2019; Roman & Fellnhofer, 2022; Roman & Nyberg, 2017).

What is in it for the users?

So far in this section, the focus has been on the underlying reasons for the firm's interaction and engagement with users and other external actors. However, no explanation has been provided on why these communities want to co-create with firms. As these factors draw on the nature of user communities and their existence, a further understanding can benefit firms currently implementing Open Innovation strategies.

According to Zare et al. (2018), the determinants of interest in co-creation from the consumer side are first divided into two categories: individual related drivers and product related drivers. Focusing on the former, the following conclusions were drawn:

- Learning motivations: users want to engage in co-creation processes to learn about products and technologies, and exchange information with peers and firms. Acquiring added information and gaining new skills are considered benefits of this approach.
- Social motivations: creating relationships within the community and firm, insertion into new networks, and feeling of belonging motivate participation in co-creation activities.
- Personal motivations: fame/reputation and authority create incentives to participate in these processes, with some firms even promoting initiatives capable of further igniting this factor (status level, rewarding systems, prizes, etc.).
- Hedonic motivations: pure fun and enjoyment can also motivate users. Participation in these activities can be seen as stimulating and entertaining for some users.
- Monetary motivations: lastly, some firms can provide financial incentives for the users to participate in co-creation activities (money prizes, products/services). However, this practice can wrongfully attract users without sufficient knowledge of the products/services.

Besides these motivations, some inhibitors of the process are worth mentioning, such as the time and energy required to take part in the co-creation processes (if too demanding, it can restrict the number of users interested and willing to participate) (Zare et al., 2018); and the risk of discredit which occurs when the users are afraid of losing IPR, being used by the firms, or being ridiculed by their ideas. As such, the firms must guarantee the co-creation processes are attractive and secure to the users willing to participate (Antorini & Muñiz, 2013; Rayna & Striukova, 2015; Zhang et al., 2018), involving all groups of clients appraised accordingly to their idiosyncrasies.

Additionally, some user profiles are more desirable than others to engage in co-creation activities (Oertzen et al., 2020; Schütz et al., 2019; Wang et al., 2020), such as

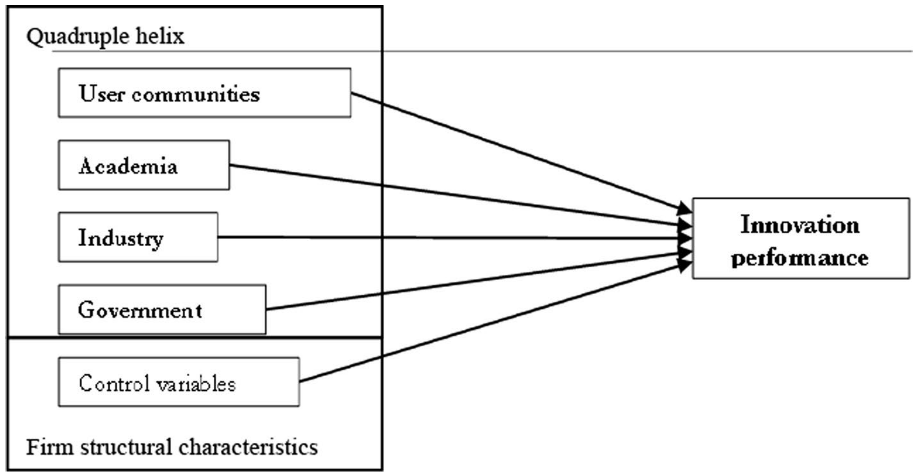

Fig. 2 Conceptual model

Innovation leaders—suggest ideas for new products/services, avant-garde, and very active in the communities—Product Comparers—demanding users, constantly compare the products with those of rival companies, highlighting weak and strong features on both sides—and lastly, Product Critics—mainly intervene to point out problems and disappointments, very concerned with quality improvement (Wang et al., 2020). However, it is still vital to ensure these accurately represent the target client (Oertzen et al., 2020) by including Ordinary users in these activities (Abbate et al., 2019; Magnusson, 2009).

How co-creation activities are conducted also affects the users' willingness to participate and co-create with a firm (Ardichvili, 2008; Verleye, 2015). In addition, firms' characteristics, such as previous co-creation experience, product knowledge, and the industry of the product/service that is being co-developed, are influential factors for the willingness to participate in co-creation activities (Zare et al., 2018). Therefore, firms may have to adapt to benefit from co-creation processes (Cambra-Fierro et al., 2018; Wang et al., 2020).

Materials and methods

Once more, the main goal of this study is to understand the impact of the engagement between firms and user communities on innovation outputs (for the different innovation types—product, process, marketing, or organizational). The conceptual model that serves as the basis of the study is displayed in Fig. 2. The main hypotheses to be assessed through econometric estimations are the following:

H1: Firms' engagement with user communities' increases innovation propensity in general.
H1.1: Firms' engagement with user communities' increases product innovation propensity.
H1.2: Firms' engagement with user communities' increases process innovation propensity.
H1.3: Firms' engagement with user communities' increases marketing innovation propensity.

Table 1 Determinants of firms' innovation performance

Determinants	Literature reviewed
Interaction with user communities	Prause and Thurner (2014); Schütz et al. (2019); Wang et al. (2020); Costa et al. (2021)
Interaction with academia	Guzzini and Iacobucci (2017); Kobarg et al. (2017); Wang et al. (2020); Atta-Owusu et al. (2021)
Interaction with industry	Stejskal et al. (2018); Damioli et al. (2019); Wang et al. (2020); Basit (2021)
Interaction with government	Afzal et al. (2018); Wang et al., 2020; Afcha and Lucena (2022)
Human capital intensity	Basit (2021); Costa et al. (2021); Odei et al., (2021); Afcha and Lucena (2022)
International trade	Shu and Steinwender (2019); Geng and Kali (2021); Odei et al. (2021); Kampik and Dachs (2011)
Size	Kampik and Dachs (2011); Hashi and Stojčić (2013); Basit (2021); Costa et al. (2021)
Technological regime	Doran and Jordan (2016); Kampik and Dachs (2011); Basit (2021); Costa et al. (2021)

H1.4: Firms' engagement with user communities increases organizational innovation propensity.

The conceptual model is primarily grounded in extant theory. Table 1 compiles the identified determinants of firms' innovation performance. The first four rows are related to previous evidence about the role of each of the helices in innovative performance, and the last four relate to firms' structural characteristics, which must be considered in the model given their importance in innovation performance.

The study uses a quantitative methodology to test the proposed hypotheses. This methodology complies with the existing stream of innovation studies that follow a deductive logic, formulating hypotheses based on existing literature that is then assessed using secondary data (Faems, 2020). Using quantitative research methods allows to generalize the validated hypothesis to other similar situations and enables other academics to replicate the study. Additionally, this method provides objectivity, clarity, and precision, given the neutrality of the researcher and the reduced degree of subjectivity of the data (Basias & Pollalis, 2019).

The data used for analysis were collected from Portuguese firms (referring to the period between 2016 and 2018) by *Direção-Geral de Estatísticas da Educação e Ciência* and *Instituto Nacional de Estatística* in 2020, as part of the Community Innovation Survey (CIS) conducted in 2018. The sample comprises 15,876 firms; however, the analysis only considers 13,701 firms (86%) to level out non-existent answers. The sample was arranged based on simple random sampling while simultaneously fulfilling specific criteria to assure the quality of the results and an accurate representation of the population. The evidence was retrieved from the Portuguese CIS of 2018 microdata (DGEEC, 2020).

Dependent variable(s)

To measure the innovation performance of firms, five dummy variables were considered: innovation in general, product innovation, process innovation, organizational innovation, and marketing innovation, with the variable innovation being a proxy derived from the remaining ones, allowing a more comprehensive analysis, as the variable encompasses every innovation type. The measurement of innovation output included in the

CIS 2018 follows the Oslo Manual recommendations (OECD, 2005; Andersson et al., 2021). These variables are commonly used in innovation studies using CIS data, namely by Tavassoli and Karlsson (2015), Costa et al. (2018), Crescenzi and Gagliardi (2018), and Costa and Matias (2020).

Explanatory variables

As explanatory variables, the interaction between firms and the four actors of the Quadruple Helix (Carayannis & Campbell, 2012) was considered.

The key variable was the interaction with user communities, which was measured through the engagement in co-creation processes led by firms together with the users (Prause & Thurner, 2014; Schütz et al., 2019). This variable takes the value of 1 if the firm has engaged in co-creation processes with user communities and 0 in all other cases. Using this engagement as a proxy for the interaction between firms and user communities is not new in studies using CIS data (e.g., see Costa et al., 2021).

Concerning the Academia helix, the cooperation related to innovation with Universities or Public research institutes was measured, being 1 if the firm answered positively and 0 in all other cases. This variable is commonly used in innovation studies using the CIS databases, such as Guzzini and Iacobucci (2017), Kobarg et al. (2017), and Atta-Owusu et al. (2021).

Regarding the interaction with other firms (Industry helix), the variable followed the same logic as the previous one. These firms can be either national, foreign, clients, suppliers, competitors, or even from the same group as the firm concerned, taking the value of 1 if the firm cooperated with any external firm, and 0 if otherwise. Similarly, the use of this variable is not new in studies that rely on the CIS database (e.g., see Stejskal et al., 2018; Damioli et al., 2019; Basit, 2021).

The interaction with the Government was quantified by means of receiving financial support from public entities (either local, regional, central, or at a European level), taking the value of 1 in this case, and 0 in all others. This proxy indicator is not new to innovation studies, such as seen in Kampik and Dachs (2011), Afzal et al. (2018), and Afcha and Lucena (2022).

Control variables

For statistical control, a set of control variables capable of influencing the firms' innovation performance were considered.

Human capital intensity

This multinomial variable measures the percentage of human capital, following the CIS scale indicated in Table 2. We expect this variable to positively impact innovation performance (Afzal et al., 2018; Colapinto & Porlezza, 2011; Farace & Mazzotta, 2015; Gur, 2020; Papa et al., 2018). The role of human capital in innovation performance is generally accepted by academics and commonly used as a control variable in studies using CIS data (Basit, 2021; Costa et al., 2021; Odei et al., 2021). Moreover, this variable is commonly measured through the percentage of personnel with at least undergraduate education (Afcha & Lucena, 2022).

Table 2 Variable description

Variable	Description	Measurement
INNOV(1)	Having performed at least one type of innovation	Binary
PROD_I(2)	Having performed product innovation	Binary
PROC_I(3)	Having performed process innovation	Binary
ORG_I(4)	Having performed organizational innovation	Binary
MARK_I(5)	Having performed marketing innovation	Binary
INTER_IND(6)	Interaction with Industry	Binary
INTER_ACAD(7)	Interaction with Academia	Binary
INTER_GOV(8)*	Interaction with government	Binary
INTER_COMM(9)	Interaction with user community	Binary
H_CAP(10)	Human capital intensity	Scale (1 = "0%"; 2 = "≥ 1% to < 5%"; 3 = "≥ 5% to < 10%"; 4 = "≥ 10% to < 25%"; 5 = "≥ 25% to < 50%"; 6 = "≥ 50% to < 75%"; 7 = "≥ 75%")
EXP(11)	Exporting company	Binary
SIZE(12)	Nr. of employees	Scale (1 = small; 2 = medium; 3 = large)
TECH(13)	Technological regime, according to Costa et al. (2021)	Scale (1 = supplier dominated; 2 = scale intensive; 3 = specialized supplier; 4 = science-based)

*Measured by being a beneficiary of public funding

International trade

This dummy variable takes the value of 1 for exporting firms and 0 for non-exporting firms. International trade can have ambiguous effects on innovation performance, specifically, expanding the market size can create a positive effect, but the increased market competition can create some constraints for less productive firms (Shu & Stinwender, 2019; Geng & Kali, 2021). This control variable is commonly used in innovation studies, such as Kampik and Dachs (2011), and Odei et al. (2021).

Size

This variable is based on the CIS original scale, small (1), medium (2), and large (3) according to the European Innovation Scoreboard scale (European Commission, 2020). Larger firms tend to have better access to funding, and, consequently, can have larger investments in innovation processes but not necessarily produce more innovations (Hashi & Stojčić, 2013). This variable is largely used in similar studies, as seen in Kampik and Dachs (2011), Basit (2021), and Costa et al. (2021).

Technological regime

In this variable, some basic mathematical transformations were performed to group the various sectors according to their technical regime (from 1 to 4), instead of using the CAE classification (Costa et al., 2021). The use of this variable is broadly accepted in innovation studies to control sector-specific effects on innovation performance (Doran & Jordan, 2016). This is even more relevant concerning CIS-based studies, as shown by Kampik and Dachs (2011), and Basit (2021). Table 2 describes the variables used for the descriptive statistics and econometric estimations.

Table 3 Number of firms by sector, entire sample vs. interacting with user communities

Sector	All		Interaction with user community	
	N	%*	*N*	%#
Manufacturing	4216	30.77	1078	25.57
Wholesale and retail trade; repair of motor vehicles and motorcycles	2355	17.19	181	7.69
Construction	1441	10.52	202	14.02
Administrative and support service activities	863	6.30	134	15.53
Consultancy, scientific and technical activities	863	6.3	188	21.78
Accommodation and food service activities	682	4.98	72	10.56
Transportation and storage	630	4.60	56	8.89
Information and communication activities	499	3.64	159	31.86
Human health and social work activities	430	3.14	33	7.67
Agriculture, farming of animals, hunting and forestry	376	2.74	27	7.18
Water collection, treatment, and distribution; sewerage, waste management and remediation activities	271	1.98	18	6.64
Financial and insurance activities	261	1.90	40	15.33
Real estate activities	229	1.67	16	6.99
Arts, entertainment, sports, and recreation activities	164	1.20	20	12.20
Other service activities	144	1.05	18	12.50
Education	138	1.01	16	11.59
Mining and quarrying	98	0.72	11	11.22
Electricity, gas, steam, cold and hot water, and cold air	41	0.30	4	9.76
Total	13,701	100	2273	16.59$

*In the total number of respondents

In the total number of respondents that interact with User Communities

$ Percentage in the total number of respondents

Exploratory analysis

As displayed in Table 3, the sample is diverse in terms of sector and industry. Likewise, the percentage of firms interacting with user communities also has a high degree of variability. It is important to highlight the large percentage of firms conducting Information and communication, Manufacturing, and Consultancy, scientific and technical activities (31.86%, 25.57%, and 21.78%, respectively) that engage with user communities. By contrast, water collection, treatment, and distribution, sewerage, waste management and remediation activities, and real estate activities firms display residual values of engagement with user communities. This variability seems to indicate that the firms' sector is a determining factor. Almost 17% of all inquired firms indicated to collaborate with user communities, revealing the prevalence of the fourth helix in the Portuguese innovation ecosystem.

From Table 4, we can establish a positive connection between the interaction with user communities and innovation performance, given the overall improvement across the four innovation indicators. This is particularly significant for product and process innovations and less relevant in marketing innovation. It is also worth noting that the propensity to interact with user communities seems to be slightly higher in firms with highly skilled human capital and significantly higher in firms with a presence in international markets. The typical Portuguese firm engaging with user communities

Table 4 Innovation performance and structural characteristics of firms by interaction with the user community

Interaction with user community	*N*	Product innovation		Process innovation		Organizational innovation		Marketing innovation		Science-based firms		Highly skilled human capital		Exporting firm	
		N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Yes	2273	1388	61.06	1116	49.10	1045	45.97	787	34.62	187	8.23	293	12.89	1735	76.33
No	11,428	2305	20.17	1758	15.38	2121	18.56	1460	12.78	575	5.03	904	7.91	5927	51.86
Total	13,701	3693	–	2874	–	3166	–	2247	–	762	–	1197	–	7662	–

Table 5 Collaboration with external partners for innovation development

Interaction with user community	N	No collaboration, only the firm		The firm in collaboration with other firms or organizations		The firm adapts or modifies processes developed by other firms or organizations		With other organizations	
		N	%	N	%	N	%	N	%
Yes	2273	787	34.62	187	8.23	293	12.89	1735	76.33
No	11,428	1460	12.78	575	5.03	904	7.91	5927	51.86
Total	13,701	2247	–	762	–	1197	–	7662	–

creates product and process innovations, exports products/services, is not science-based, and has low human capital intensity. This fact further underlines the importance of user communities in organizations in which the availability of skilled workers is lower, which may work as an external enhancer of the innovation propensity. Notwithstanding, firms with very high intensity of skilled workers also establish connections with the user communities.

In Table 5, we can observe an interesting phenomenon. Firms that do not have partners for innovation development are the ones that most interact with user communities (54.25%). This apparent paradox can be explained by a substitution assumption (instead of complementary) between the interaction with user communities (consumers) and other firms/organizations (value chain). Firms with partners for innovation development seem to neglect user communities, as they have other external sources of input. This can be further explained by the difficulty of understanding a different type of partner; communication between firms can be easier than with users, as they have different objectives and perspectives.

Table 6 displays the characteristics of firms that interact with each innovation ecosystem actor. From this data, we can highlight the strong influence of the interaction with other firms (Industry) on innovation performance, and the modest influence of the interaction with Governments. The latter result can be explained given that most public incentives/subsidies relate only to product or process innovation, hence, the minimal impact of this helix on marketing innovation. In addition, the interaction between science-based firms and Academia is surprisingly low, given the knowledge intensity of these firms and the established benefits of this connection. Lastly, it is important to note that most firms interacting with one of the actors are firms present in international markets, highlighting the importance of these interactions for their competitiveness.

Table 7 shows the contrast between small, medium, and large firms. There is a clear significant improvement in innovation performance in larger firms, namely regarding product innovation, with almost 50% of large firms developing this type of innovation comparatively with 22% of small firms. On the other hand, the proportion of science-based firms, highly skilled human capital, exporting firms, and interaction with user communities do not vary substantially according to the size of the firm, although the indicators have a slightly better performance on large firms.

Table 6 Innovation performance and characteristics by helix interaction

Interaction with	***N***	**Product innovation**		**Process innovation**		**Organizational innovation**		**Marketing innovation**		**Science-based firms**		**Highly skilled human capital**		**Exporting firm**	
		N	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**
User community	2273	1388	61.06	1116	49.10	1045	45.97	787	34.62	187	8.23	293	12.89	1735	76.33
Government	2417	1167	48.28	959	39.68	922	38.15	705	29.17	173	7.16	280	11.58	1698	70.25
Academia	652	493	75.61	418	64.11	391	59.97	292	44.79	103	15.8	145	22.24	510	78.22
Industry	1156	878	75.95	715	61.85	696	60.21	536	46.37	158	13.67	236	20.42	873	75.52

Table 7 Innovation performance and characteristics by helix interaction

Firm size	*N*	Product innovation		Process innovation		Organizational innovation		Marketing innovation		Science-based firms		Highly skilled human capital		Exporting firm		Interaction with user community	
		N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Small	9451	2127	22.51	1633	17.28	1845	19.52	1293	13.68	500	5.29	821	8.69	4870	51.53	1456	15.41
Medium	3509	1212	34.54	985	28.07	1039	29.61	750	21.37	192	5.47	307	8.75	2324	66.23	656	18.69
Large	741	354	47.77	256	34.55	282	38.06	204	27.53	70	9.45	69	9.31	468	63.16	161	21.73
Total	13,701	3693	–	2874	–	3166	–	2247	–	762	–	1197	–	7662	–	2273	–

Table 8 Innovation performance and structural characteristics by technological regime

Technological regime	*N*	Product innovation		Process innovation		Organizational innovation		Marketing innovation		Highly skilled human capital		Exporting firm		Interaction with user community	
		N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Supplier dominated	7933	1987	25.05	1500	18.91	1726	21.76	1307	16.48	310	3.91	4408	55.57	1088	13.71
Scale intensive	2699	734	27.02	576	21.34	574	21.27	372	13.78	161	5.97	1539	57.02	556	20.60
Specialized supplier	2307	641	27.79	542	23.49	584	25.31	371	16.08	459	19.9	1305	56.57	442	19.16
Science-based	762	331	43.44	256	33.6	282	37.01	197	25.95	267	35.04	410	53.81	187	24.54
Total	13,701	3693	–	2874	–	3166	–	2247	–	762	–	1197	–	7662	–

Lastly, in Table 8, we can see the differences in the several indicators according to the technological regime of firms. Science-based firms have significantly better innovation performance on all types of innovations—with almost half of the firms developing product innovations, while the remaining firms do not have a high disparity among the four innovation indicators. Concerning the human capital indicator, non-surprisingly, the science-based firms have a significant value (35.04%), contrasting with the supplier-dominated and scale-intensive firms with 3.91% and 5.97%, respectively.

Descriptive statistics

Table 9 reports the descriptive statistics and zero-order correlations of the abovementioned variables. Innovative firms account for 27% of the sample; Product innovation is the most prominent type of innovation, followed by organizational innovation (23%), process innovation (21%), and, lastly, marketing innovation (16%). The sampled firms show low levels of interaction with the industry and academia (only 8 and 5%, respectively), and slightly higher indicators for the interaction with government and user communities (18 and 17%, respectively). In addition, more than half of the firms are present in international markets (56%).

The correlation is significant for most of the pairings with moderate intensity. The Variance Inflation Factor also guarantees the inexistence of multicollinearity. Also, the added value of interacting with user communities becomes clear (see details in Table 13), with the first subgroup surpassing the second in every innovation performance variable, especially in product (61% vs. 20%) and process innovation (49% vs. 15%). In addition, firms that interact with user communities also interact more with the industry, academia, and government than those that do not. In terms of size, both human capital intensity and technological regime subgroups show similar results, with slightly higher indicators in the first subgroup. It is also important to highlight that three in every four firms that interact with user communities have a presence in international markets, contrasting with half of the other subgroup. Regarding the correlations between variables, except for the high correlation among innovation performance variables [given INNOV(1) was created by merging the other four] and the high correlation between interaction with Academia and Industry, all other coefficients are below 0.372.

Econometric analysis

Estimations and results

Through the following estimations, we aim to measure the impact of the interaction between firms and user communities on the different innovation outcomes. We chose to perform binary logistic regressions to properly assess the impact, given the characteristics of the dependent variables. The significance of the variables was assessed through likelihood ratio tests (Table 12). Table 11 provides the results of the logit regressions.

The coefficients for the variable INTER_COMM(9) are consistent and positive across all types of innovation, particularly in terms of product and process innovation, with statistical significance (p-value < 0.01). These results confirm that the interaction between firms and user communities' benefits firms, fostering their innovation performance.

Similarly, interacting with other firms, measured by the variable INTER_IND(6), also shows consistent and positive effects on innovation outcomes, namely on

Table 9 Summary statistics and correlation table

Variables	Min	Max	Mean	SD	VIF	1	2	3	4	5	6	7	8	9	10	11	12
INNOV(1)	0	1	0.27	0.443	–	1											
PROD_I(2)	0	1	0.27	0.444	–	0.782**	1										
PROC_I(3)	0	1	0.21	0.407	–	0.806**	0.630**	1									
ORG_I(4)	0	1	0.23	0.422	–	0.779**	0.564**	0.599**	1								
MARK_I(5)	0	1	0.16	0.370	–	0.710**	0.529**	0.539**	0.597**	1							
INTERIND(6)	0	1	0.08	0.278	1.679	0.337**	0.335**	0.305**	0.267**	0.246**	1						
INTERAD(7)	0	1	0.05	0.213	1.652	0.250**	0.245**	0.237**	0.195**	0.171**	0.609**	1					
INTERGOV(8)	0	1	0.18	0.381	1.130	0.217**	0.223**	0.213**	0.165**	0.160**	0.257**	0.287**	1				
INTERCOMM(9)	0	1	0.17	0.372	1.096	0.310**	0.343**	0.308**	0.242**	0.219**	0.230**	0.171**	0.146**	1			
H_CAP(10)	1	7	3.39	1.859	1.238	0.199**	0.205**	0.149**	0.177**	0.169**	0.204**	0.179**	0.133**	0.107**	1		
EXP(11)	0	1	0.56	0.496	1.066	0.194**	0.205**	0.175**	0.139**	0.152**	0.120**	0.100**	0.134**	0.183**	0.109**	1	
SIZE(12)	1	3	1.36	0.583	1.072	0.160**	0.162**	0.138**	0.134**	0.115**	0.191**	0.177**	0.122**	0.050**	0.156**	0.118**	1
TECH(13)	1	4	1.70	0.938	1.175	0.076**	0.074**	0.079**	0.068**	0.027**	0.117**	0.110**	0.019*	0.085**	0.372**	0.002	0.016

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 10 Logit models for the different types of innovation

Variables	Model 1				
	INNOV(1)	**PROD_I(2)**	**PROC_I(3)**	**ORG_I(4)**	**MARK_I(5)**
	Exp(B)	**Exp(B)**	**Exp(B)**	**Exp(B)**	**Exp(B)**
INTER_COMM(9)	3.669*** (0.053)	4.496*** (0.054)	3.682*** (0.054)	2.654*** (0.053)	2.479*** (0.057)
INTER_IND(6)	4.859*** (0.091)	4.845*** (0.093)	3.356*** (0.087)	3.064*** (0.084)	2.870*** (0.087)
INTER_ACAD(7)	1.311** (0.125)	1.186 (0.126)	1.288** (0.116)	1.056 (0.112)	-0.888 (0.113)
INTER_GOV(8)	1.797*** (0.055)	1.860*** (0.055)	1.894*** (0.056)	1.500*** (0.055)	1.545*** (0.060)
H_CAP(10)	1.163*** (0.013)	1.178*** (0.013)	1.083*** (0.014)	1.161*** (0.013)	1.217*** (0.015)
EXP(11)	1.761*** (0.046)	1.845*** (0.047)	1.721*** (0.050)	1.417*** (0.046)	1.733*** (0.054)
SIZE(12)	1.361*** (0.036)	1.377*** (0.037)	1.316*** (0.038)	1.303*** (0.036)	1.238*** (0.040)
TECH(13)	− 0.969 (0.025)	− 0.953* (0.025)	1.043 (0.026)	− 0.975 (0.025)	− 0.847*** (0.028)
Constant	− 0.060*** (0.078)	− 0.054*** (0.079)	− 0.050*** (0.083)	− 0.068*** (0.077)	− 0.043*** (0.089)
− 2 Log likelihood	13,156.551	12,909.444	11,854.279	13,161.061	10,804.392

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

product innovation. This interaction has a more significant effect on general, product, organizational, and marketing innovation, compared to the interaction with user communities.

Concerning the interaction between firms and universities or research institutes, measured by the variable INTER_ACAD(7), the results are somewhat inconsistent (not statistically significant for product and organizational innovation and with a negative impact on marketing innovation). This demonstrates the fragility of this cooperation and the lack of fruitful interactions between firms and academia (Table 10).

Finally, the interaction with government, measured by the variable INTER_GOV(8), shows consistent positive effects across all types of innovation, with higher relevance for process and product innovation. These results indicate that public funding of innovation significantly impacts firms' innovation performance.

Regarding the control variables, human capital intensity, exporting firm, and size show similar results with consistent and positive effects across all types of innovations. The intensity of human capital has a larger significant impact on organizational innovation, whereas the firm's presence in international markets has a slightly lower impact on this type of innovation. The size variable also demonstrates positive and consistent results across all types of innovation (also showing a slightly lower effect on organizational innovation), indicating that larger firms have a higher propensity to innovate.

Remarkably, the variable TECH(13) indicates the firms' technological regime has a negative effect on general, product, organizational, and marketing innovation. In addition, this variable is not statistically significant for general, process, and organizational

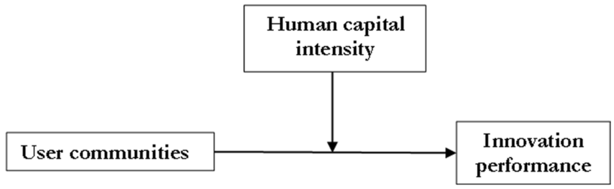

Fig. 3 Moderation effect

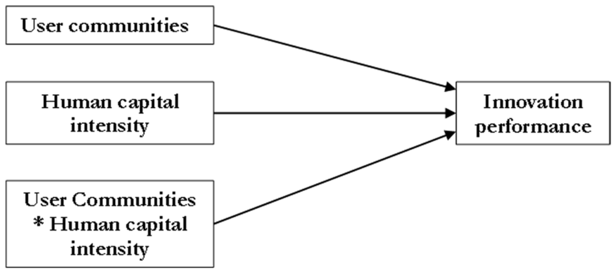

Fig. 4 Moderation effect empirically tested

innovation, which suggests that the firms' sector is not a decisive factor in their innovation performance.

Overall, these results reveal that the Portuguese innovation system is characterized by the Quadruple Helix model, further reinforcing the value of implementing Open Innovation practices. However, the interactions with these actors do not uniformly foster all types of innovation. The interaction with user communities is positive and consistent across all types of innovation, with an increased effect on product and process innovation.

Moderation effects

A moderator is a variable capable of influencing the relationship between an independent variable and a dependent variable by means of direction and/or intensity. According to Baron and Kenny (1986), the moderator should simultaneously function as an independent variable, and this way, there will be three causal paths affecting the dependent variable: the independent variable—as a predictor, the other independent variable—as a moderator, and the interaction between the two.

The moderation effect of Human Capital intensity can be illustrated in Figs. 3 and 4. Human Capital intensity moderates the relationship between a firm interacting with user communities and their innovative performance.

The acquisition of external knowledge and successful integration with the internal one is key for innovative firms (Chesbrough, 2003), which is highly dependent on the firm's absorptive capacity (West & Gogers, 2013). Absorptive capacity can also drastically affect external collaborations (West & Gogers, 2013). On the one hand, it may stimulate these collaborations; on the other hand, it may reduce the need for collaborations.

As shown in Model 2 from Table 11, the sign of the coefficient of the interaction term is negative, indicating that human capital intensity and interaction with user communities are somehow substitute characteristics. This means that the marginal effects on

Table 11 Robustness check summary

Variables	Model 2		Model 3		Model 4	Model 5	Model 6	Model 7	Model 8
	INNOV(1)	PROD_I(2)	INNOV(1)	PROD_I(2)	INNOV(1)	INNOV(1)	INNOV(1)	INNOV(1)	INNOV(1)
INTER_COMM(9)	5.126*** (0.119)	6.852*** (0.119)	4.674*** (0.101)	5.393*** (0.101)	–	3.670*** (0.053)	3.584*** (0.054)	3.172*** (0.054)	3.647*** (0.053)
INTER_IND(6)	4.860*** (0.091)	4.844*** (0.092)	4.865*** (0.091)	4.848*** (0.093)	4.651*** (0.092)	4.852*** (0.091)	4.343*** (0.092)	4.423*** (0.091)	4.579*** (0.092)
INTER_ACAD(7)	1.342** (0.124)	1.193 (0.125)	1.307** (0.125)	1.184* (0.126)	1.291** (0.125)	1.305** (0.125)	1.299** (0.126)	1.254** (0.124)	1.241** (0.125)
INTER_GOV(8)	1.795*** (0.055)	1.858*** (0.055)	1.801*** (0.055)	1.862*** (0.055)	1.741*** (0.055)	1.799*** (0.055)	1.562*** (0.056)	1.566*** (0.055)	–
H_CAP(10)	1.185*** (0.014)	1.206*** (0.014)	1.163*** (0.013)	1.178*** (0.013)	1.120*** (0.013)	1.163*** (0.013)	1.123*** (0.013)	1.098*** (0.013)	1.159*** (0.013)
EXP(11)	1.760*** (0.046)	1.844*** (0.47)	1.870*** (0.051)	1.933** (0.052)	1.756*** (0.047)	1.761*** (0.046)	1.591*** (0.047)	1.594*** (0.047)	1.698*** (0.046)
SIZE(12)	1.360*** (0.036)	1.376*** (0.037)	1.362*** (0.036)	1.377*** (0.037)	1.311*** (0.037)	1.362*** (0.036)	1.052 (0.195)	1.293*** (0.037)	1.299*** (0.037)
TECH(13)	− 0.972 (0.025)	− 0.956* (0.025)	− 0.970 (0.025)	− 0.953* (0.025)	− 0.967 (0.025)	− 0.970 (0.025)	− 0.974*** (0.300)	− 0.992 (0.025)	− 0.964 (0.025)
INTER_COMM(9)* H_CAP(10)	− 0.914*** (0.029)	− 0.892*** (0.029)	–	–	–	–	–	–	–
INTER_COMM(9)* EXP(11)	–	–	− 0.717*** (0.119)	− 0.778** (0.119)	–	–	–	–	–
INTER_COMM2	–	–	–	–	3.837*** (0.045)	–	–	–	–
BARRIERS	–	–	–	–	–	1.018 (0.051)	–	–	–
INVEST	–	–	–	–	–	–	1.563*** (0.023)	–	–
CHANNELS	–	–	–	–	–	–	–	4.730*** (0.073)	–
INTER_GOV2	–	–	–	–	–	–	–	–	2.031*** (0.049)
Constant	− 0.056*** (0.081)	− 0.049*** (0.083)	− 0.057*** (0.079)	− 0.052*** (0.081)	− 0.050*** (0.080)	− 0.059*** (0.087)	− 0.050*** (0.080)	− 0.024*** (0.097)	− 0.061*** (0.078)
− 2 Log likelihood	13,146.713	12,893.923	13,148.731	12,904.997	12,818.166	13,155.337	12,765.226	12,569.439	13,065.764

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

innovation performance of highly skilled employees should be more relevant to firms that interact with user communities. However, this conclusion contradicts the findings of a study by Dahlin et al. (2019), in which they found that absorptive capacity had positive indirect effects on innovation through co-creation, both in Sweden and Norway.

This result can be explained by the substitution effect between having the absorptive capacity and having the need for external sources of knowledge, meaning that firms with greater absorptive capacity do not engage with user communities, as they do not find their knowledge beneficial. In addition, the not invented here (NIH) syndrome can further foster this effect, as human resources can resist external knowledge and ideas (Zhao et al., 2015).

Robustness check

To further validate the results presented in the previous section, we conducted a robustness check through the seven models showcased in Table 11.

In Model 3, we applied the same logic as before, but now with the variable EXP(11). In this case, the term interaction also has a negative coefficient, indicating that these characteristics are substitutes for each other. For both models, the regression included general innovation and product innovation as dependent variables. Given the consistent results for the remaining models, we only display the regression results for general innovation.

In Model 4, we broaden the variable of interaction with user communities to also include mass customization, and personalization processes (Rayna & Striukova, 2015). This change did not significantly impact the estimations compared to Model 1, further validating the results obtained.

For Model 5, we included the variable BARRIERS, which is a dummy variable that indicates whether a firm had encountered any difficulty that negatively impacted the decision to start or implement innovation activities. The coefficient of this variable is not statistically significant; however, it is worth noting that, paradoxically, this value is positive. This counter-intuitive result is consistent with other studies using CIS data (Basit, 2021).

We added INVEST in Model 6, a multinomial variable that ranges from 0 to 3 according to the firms' investment (absolute values). With the addition of this value, the coefficients did not present relevant changes, but the variable SIZE(12) became statistically non-significant. This indicates that the dimension of a firm and its investment are substitutes, i.e., an SME with adequate funding and investment can be as innovative as a large company.

In Model 7, we included CHANNELS, a dummy variable that measures whether the firm used any channel as a source of knowledge (including scientific journals, crowdsourcing, open-source software, or reverse engineering). This variable is statistically significant and has a high coefficient (4.730).

Finally, in Model 8, we broaden the variable that measures the interaction with the Government helix to also include receiving tax credits and subsidies. This did not make substantial differences in the remaining variables and increased the coefficient of this variable (2.031).

In sum, it is important to highlight the consistency of the User Community, Industry, and Government interaction across all models, further supporting the value of these helixes for firms' innovation and reinforcing the results obtained in the previous models.

Conclusions

Theoretical and empirical findings

With the emergence of Industry 5.0 and the rising awareness regarding societal issues among the Quadruple Helix model actors, firms have an increased incentive to engage with user communities to successfully keep up with this transformation and accustom the society's needs and wants. With this in mind, interacting with user communities and receiving their valuable knowledge and feedback as innovation inputs becomes even more relevant, allowing the firms to design and create human-centered products and services. Furthermore, it is already possible to see the emergence of this paradigm in several actors of the innovation ecosystem, which further encourages firms to adapt their innovation processes and gather new knowledge sources.

Regarding the firm structural characteristics, the results mostly align with the expectation, as larger firms are more prone to engage in innovative activities; firms operating in international markets also have an increased probability of engaging in innovation activities. Additionally, the existence of absorptive capacity through a skilled labor-force raises the propensity to innovate.

This research was conducted to determine whether the engagement between user communities and firms positively impacted their propensity to innovate. To further explore this result, this hypothesis was assessed for several types of innovation. Upon the empirical research conducted, we can establish that the engagement between user communities and firms does foster their innovation performance (across all types of innovation, with increased impact on product and process innovation). The robustness analysis further confirmed this result.

Empirical evidence reinforces the existence of significant differences in what relates to the importance of the user community in promoting the different innovation types. Our results indicate that the interaction with this player has the most significant effect in the case of Product Innovation. This, in turn, deserves further analysis, given that Product Innovation is the most resource-consuming strategy in innovation and the one with the most expected results. Engaging with the user community seems to be an excellent option to leverage product innovation while maintaining an efficient cost structure.

Also, the results show the relevance of the remaining actors of the Quadruple Helix model and reinforce the benefits of these interactions regarding innovation outcomes. Specifically, the interaction inside the value chain is evidenced as one of the most important players inside the ecosystem. As such, policy actions should support the existence of persistent links with other players acting in the same sector. However, the results evidence the fragility and lower effects of interacting with Academia, indicating that these collaborations need to be improved to capitalize on them entirely. In addition, the positive and consistent results of the interactions with the Government prove the effectiveness of the conventional policy instruments; the significance and magnitude of the effects in all types of innovations prove that future policy actions must encompass a broader definition of innovation and not only product innovation. The complementarities among the helices demonstrate the need to further promote these connections as a way to foster firms' innovation performance.

According to previous literature, the availability of a skilled labor-force is determinant in enhancing innovative activities, mainly regarding technological innovation (product or process). The present results prove the existence of some complementarity between the connection to the user community and the presence of a skilled labor-force, which goes along with similar findings for a multi-country (Rodríguez-López, 2021) and a Norwegian analysis (Ågotnes & Midtgård, 2022).

Furthermore, when analyzing the moderation effect of human capital in the impact of interacting with user communities, the results may seem, at first glance, hard to explain. Still, the negative effect of the moderation may be due to some overlap between these two sources of knowledge in innovative strategies. This result needs to be further appraised, as it may evidence some substitution effect between the internal capacity and the information aired by user communities. Accepting the user community as a partial substitute for human capital may allow firms to draw a smarter innovation strategy, given that the first does not claim financial rewards. Moreover, human capital may not be interacting in the best way with the external information flows, which accelerate and reduce the costs of the innovation processes.

Transversally, the empirical results presented in the main models and the robustness tests prove the meaningful role of user communities in firms' innovation, as well as the presence of the Quadruple Helix model in the Portuguese innovation system. With the emerging paradigm of Industry 5.0, we predict this role will be increasingly meaningful and become a pivotal factor for firms' competitiveness.

Limitations and future research

This analysis used the CIS database with 13,701 Portuguese firms. As such, the results may only be valid for the Portuguese innovation system. As a future research avenue, this study could be replicated with CIS databases from other countries. Moreover, the financial data from the database presented several restrictions with few valid observations; for this reason, financial factors were disregarded. Nevertheless, incorporating financial factors could bring information of interest to academics, practitioners, and policymakers.

Given the importance of the environment or the context in which the innovation is developed, future analysis should consider aspects such as the territorial dimension of these processes as well as the geographical and non-geographical dimension of proximity, given the fast transition to a virtual ecosystem.

Future research must investigate the relationship between internal innovation competencies by exploiting internal talent and the connection with the user community. It seems that firms can no longer neglect the external community of users in their innovation process, as it is a reliable and intelligent spring of relevant knowledge free from any additional cost.

It could be a valuable option to further study the impact of engaging with user communities through the perspective of radical or incremental innovations to comprehend the nature of the innovations further. Furthermore, conducting a dynamic analysis can also be a viable option to better the impact of these interactions over time.

In terms of future research, we can also highlight studying the moderation effect of human capital on the relationship between a firm interacting with user communities and their innovative performance. As the independent effects of both user communities and human capital present the expected sign, the unexpected results arise in the combined effect deserving future analysis. On the one hand, this fact may be due to some overlapping flows, or even some mismatches in the communication between the external communities and the skilled employees; on the other hand, the external information flows may be underrated by the internal collaborators due to a not invented here syndrome, which leads to a waste of costless and relevant information. As such, tuning user community contributions with the absorptive capacity of skilled collaborators will transform the forces from substitutes to complements.

Policy recommendations

Given the results, we can establish a positive relationship between the interaction with user communities and firms' innovation performance. Thus, promoting and enhancing these interactions should be a priority for innovation policymakers. Firms must be aware of the need to interact with user communities and how to enable them effectively. In addition, financial incentives can also be effective in promoting this engagement.

Public policy can also have a decisive role in supporting firms as they adapt their processes and strategies for Industry 5.0. Implementing responsible innovation and CSR practices can lead to increased costs, and the benefits may not be immediate. Consequently, it is important that firms have access to funding or incentives. Furthermore, from our analysis, we can conclude that public innovation funding generates a positive and consistent effect on firms' innovation outputs, reinforcing the importance of this instrument.

The empirical findings proved that the interaction with the quadruple helix is key to enhancing innovative activities. In this vein, policy actions need to signal the desirability of this cohesive networking as an intelligent way to promote vibrant, innovative ecosystems. Policy actions need to enhance the collaborations among the helices and promote a multidimensional ecosystem, in which each player has a unique rapport with a complementary perspective. Promoting knowledge and technological proximity between collaborators with both academics and users maybe the next framework to be implemented, requiring some plasticity from the first to move into the different layers from which information for innovation arises.

Overall, the connection to Academia needs to be shaped to generate mutual benefits and the approximation of the players must be in the agenda of policymakers. It is crystal clear that policymakers need to consider the spillovers emerging from the expertise and surveillance of the users and create a mechanism that reinforces the obligation to embrace their contributions. This approximation with additional helices in the ecosystem will even potentially reshape the governance, generating involvement, citizen responsibility, and responsible and resilient communities, which provide opportunities for all and grant sustainability to the production process through intelligent and responsible innovation strategies.

Appendix

See Tables 12, 13.

Table 12 Model log-likelihood

Variable	Model log-likelihood	Change in − 2 log-likelihood	df	Sig. of the change
INTER_COMM(9)	− 6871.477	586.402	1	< 0.001
INTER_IND(6)	− 6738.769	320.988	1	< 0.001
INTER_ACAD(7)	− 6580.632	4.713	1	0.030
INTER_GOV(8)	− 6634.096	111.642	1	< 0.001
H_CAP(10)	− 6647.546	138.541	1	< 0.001
EXP(11)	− 6655.091	153.631	1	< 0.001
SIZE(12)	− 6613.682	70.812	1	< 0.001
TECH(13)	− 6579.075	1.599	1	0.206

Table 13 Added value of interacting with user communities

Variables	Interaction with user community				No interaction with user community			
	Min	Max	Mean	SD	Min	Max	Mean	SD
INNOV(1)	0	1	0.58	0.494	0	1	0.21	0.405
PROD_I(2)	0	1	0.61	0.488	0	1	0.20	0.401
PROC_I(3)	0	1	0.49	0.500	0	1	0.15	0.361
ORG_I(4)	0	1	0.46	0.498	0	1	0.19	0.389
MARK_I(5)	0	1	0.35	0.476	0	1	0.13	0.334
INTER_IND(6)	0	1	0.23	0.419	0	1	0.06	0.230
INTER_ACAD(7)	0	1	0.13	0.336	0	1	0.03	0.174
INTER_GOV(8)	0	1	0.30	0.459	0	1	0.15	0.359
INTER_COMM(9)	0	1	1.00	0.000	0	1	0.00	0.000
H_CAP(10)	1	7	3.84	1.829	1	7	3.30	1.852
EXP(11)	0	1	0.76	0.425	0	1	0.52	0.500
SIZE(12)	1	3	1.43	0.622	1	3	1.35	0.574
TECH(13)	1	4	1.88	0.994	1	4	1.66	0.923

Abbreviations

CIS Community Innovation Survey
CSR Corporate Social Responsibility
NIH Not invented here
UCS User Community Sensing

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JC and IA conceptualized, collected the data and drafted the research article. JR and NM revised all parts of the manuscript throughout the drafting process. All authors read and approved the final manuscript.

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