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Assessing the Open Innovation Outcome in Living Labs

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Abstract

This study introduces a model to assess the innovation outcome in living labs, which is a particular type of open innovation network. We propose that the outcome of open innovation activities in living labs can be assessed using a multiple linear regression model that builds on a set of empirically identified variables. Based on data from 26 living labs across four countries, we present a set of variables that can determine the conditions for co-creation in living labs and apply them in a multiple linear regression model to assess the innovation outcome of the living labs. The four pivotal variables include strategic intention, passion, knowledge and skills, and resources. All four variables have an equally positive effect on the innovation outcome. We also propose a maximum and an optimal number of participants to maintain passion in open innovation. While the paper advances scholarly research on open innovation by identifying and applying variables that impact the outcomes of innovation activities in living labs, practitioners can also apply the model to enhance innovation endeavours and targeted outcomes in living labs.

Keywords: assessment method; living labs; open innovation; strategic intention; passion; knowledge.

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1 Introduction

Open innovation is increasingly popular across numerous academic disciplines and industrial fields (Lambrechts et al., 2017; Nestle et al., 2019; West & Bogers, 2014). It builds on the principle of acquiring knowledge, resources, and technologies from outside the company's boundaries (Chesbrough, 2003; Lopez-Vega et al., 2016). Hence, open innovation is characterized as a process of innovation dispersal, in which knowledge circulates across organizational boundaries in a deliberate manner, defined as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries" (Chesbrough & Bogers, 2014, p. 17). Scholarly work on open innovation has primarily focused on the dynamics of innovation between firms (cf. West et al., 2014), but recent studies increasingly suggest shifting the focus to include a plurality of stakeholders in open innovation (e.g., Urbinati et al., 2021; Fisher et al., 2024) and

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multi-stakeholder innovation networks with diverse external partners (e.g., Reypens et al., 2019; Ozdemir et al., 2023).

We define open innovation networks in accordance with Leminen et al. (2020) as partnerships in research and development (R&D) that allow knowledge sharing and creation to exceed the limits of the organization. A living lab is a relatively new and rapidly growing form of open innovation networks (Greve et al., 2020). Living labs comprise diverse stakeholders, including companies, public organizations (e.g., agencies, universities, research institutes), users, citizens, and potentially any others beyond the organizational boundaries of firms (Ballon et al., 2018). In essence, living labs offer a real-life context (physical or virtual) in which stakeholders participate to jointly design, construct, test, and demonstrate innovations such as novel products, services, systems, and solutions (Leminen et al., 2012).

In living labs, stakeholders such as firms can gain novel ideas, and access to previously inaccessible resources, knowledge, skills, and technologies. The diversity of engaged stakeholders enables ideation, co-development, testing, and validation of the value and functionality of novel solutions, products, and services (Engels et al., 2019; Furr et al., 2016; Voytenko et al., 2016). However, while engaging in open innovation, such as living labs, is a significant strategic decision for many stakeholders, the predictability of possible, or even probable outcomes is challenging. Previous literature highlights numerous benefits of engaging in open innovation (cf. Spithoven et al., 2013), which are largely similar to those suggested in living lab literature. While the living lab literature generally highlights advantages for various stakeholders involved in living lab activities, it often neglects to address how these networks are beneficial or what specific outcomes can be expected from such collaboration. Furthermore, there are no existing models to quantify or quasi-quantify open innovation activities and connect them to specific types of outcomes. Only a few studies have addressed this area, e.g., Nyström et al. (2014), Leminen et al. (2016), Leminen et al. (2020), and Paskaleva & Cooper (2021).

However, to study and assess the outcomes of open innovation, it is of essence to first identify the factors driving the outcomes. We argue that it is insufficient to merely identify variables affecting open innovation outcomes; the logic and interplay must also be addressed. To this end, we developed a mathematical model to represent the dynamics of open innovation activities in living labs. As stated in the Oxford learner dictionary, a mathematical model is "a simple description of a system, used for explaining how something works or for calculating what might happen". Mathematical models are thus instruments to mediate and facilitate dialogue between stakeholders and are also considered independent from theories and the empirical context they elucidate (Morgan & Morrisson, 1999).

This study focuses on assessing the relationships between foundational variables in open innovation activity and the innovation outcomes in living labs. In so doing, we address the fundamental question of how open innovation outcomes can be assessed in living labs. Our overall objective is to identify and apply innovation-related variables to compose a mathematical model which can assess the probable innovation outcome when diverse stakeholders co-create and engage in living labs. We refer to co-creation and innovation activities as innovation endeavours. An innovation outcome is affected by circumstances and the specific context of the innovation practices in living labs (Leminen et al., 2020). Therefore, building on prior studies of performance indicators in open innovation, we explored data on innovation outcomes in 26 living labs to identify key variables for the model. Our subsequent research objectives are as follows:

- Identify foundational variables that affect the outcome in open innovation
- Analyse how these variables assess innovation outcome in living labs

- Present and discuss our model for assessing innovation outcome in living labs

We present multiple contributions to the open innovation literature, and specifically to research on living labs as a genre of open innovation networks. First, we identified four pivotal variables, namely strategic intention, passion, knowledge and skills, and resources. Second, we introduced a multiple linear regression model for assessing outcomes in living labs. The results indicated that all four key performance indicators have a positive effect of similar magnitude on innovation outcomes in living labs. We propose that the model can be used by researchers and practitioners as a tool to assess the probable outcome of innovation activity in living labs, thereby allowing them to evaluate whether a specific living lab is suitable for their purpose. Moreover, it can inform policymakers of network and organizational level elements and could thus impact innovation policy. Finally, the results indicate that there is a retention of passion in innovation activities, which is indicated by the number of participants according to an inverted U-shaped model. We demonstrate that there is a maximum, and an optimal, number of stakeholders for increasing passion in open innovation networks. Hence, the maximum number of stakeholders is indirectly linked via passion to the outcomes in open innovation networks.

The paper is structured as follows. Section 2 reviews the key theoretical references and explicates both the context for open innovation and the empirically identified variables that constitute the mathematical model. Section 3 details the research design, data, and methods. In section 4, we describe the dataset, the theoretical framework for the regression analysis, and summarize the findings. Section 5 discusses the results. Section 6 concludes by presenting the theoretical contributions, the managerial and policy implications, as well as future research directions.

2 Collaboration and open innovation: background and innovation variables

To explore whether innovation outcomes can be assessed, we theoretically explored the literature on (i) collaboration aimed at innovation, (ii) living labs as open innovation networks, and (iii) innovation performance in open innovation networks. The theoretical framework summarizes foundational activities and characteristics of open innovation networks, specifically living labs, along with the aspects that affect their innovation outcomes. The framework also provides the basis for a theory-centric analysis of the identified variables in line with Greve et al. (2020) and Hossain et al. (2019).

2.1 Collaborative approaches to innovation

While there is no single unified theory on open innovation, the definition provided by Chesbrough and Bogers (2014) is widely recognized. Open innovation involves a variety of approaches and methods for managing and facilitating innovation activities (Felin & Zenger, 2014). Different participating open innovation networks and operational models have been studied, including ‘open source’ (Lakhani & von Hippel, 2003; Raasch et al., 2013), ‘crowdsourcing’ (Schemmann et al., 2016), as well as the ‘innovation community’ and ‘innovation mall’ (Pisano & Verganti, 2008), and community-based open innovation networks (Jarvenpaa & Wernick, 2012). Previous literature on open innovation in a more general sense offers various classifications of corporate-centric and community-centric innovation, such as the four modes of open innovation collaboration proposed by Pisano and Verganti (2008). In addition, Bogers and West (2012) highlight a conceptual distinction: *open innovation* exemplifies either corporate-centric or community-centric innovation

(Chesbrough, 2003). In *user innovation*, or community-led innovation, open innovation is utilized in user communities for the purpose of solving their needs (von Hippel, 2007).

A major driver of open innovation is the need for shorter product lifecycles and faster revenue periods (Gaimon & Singhal, 1992; Chesbrough, 2007). Previous literature emphasizes that many new products and services seem to fail upon market launch, even if customer analyses have often been conducted (Zaltman, 2003). It is costly and difficult to interpret customer needs in a constantly evolving landscape of networks, and subsequently it is also challenging to develop products that correspond with consumer demands (Arakji & Lang, 2007). Thus, businesses make use of external sources of ideas by other means, focusing on customers who can aid them in innovation activities by creating new ideas and value (Edvardsson et al., 2010). The ultimate goal of innovation should be expansive, aiming to create a future where people can experience the highest possible quality of life (Lee & Trimi, 2018).

2.2 Living lab networks

Living labs are an increasingly popular way to organize innovation activities, address concurrent socio-economic challenges and technological opportunities. Recent living lab literature is expanding to grand social challenges (Engels et al., 2019) and high-technology areas, such as autonomous solutions (Tagliazucchi et al., 2024), digital twins (Opoku et al., (2024), the metaverse (Ma, 2023), space industry (Vidmar, 2019), and quantum computing (Leminen et al., 2023). Regardless of the many definitions of living labs (cf. European Network of Living Labs, 2024; Dell'Era & Landoni, 2014; Ballon et al., 2005; Paskaleva & Cooper, 2021), scholars share a view of the key characteristics of living labs, including real-life environments, stakeholders (or actors), activities, business models and networks, methods, tools and approaches, as well as innovation outcomes (Hossain et al., 2019).

Living labs are distinct compared to other open innovation models in three significant ways: innovation activities take place in real-world settings (Dell'Era & Landoni, 2014), collaboration is facilitated through a "public-private-people partnership" (Evans et al., 2015), and users are integral to the innovation process (Ballon et al., 2018). These characteristics make living labs especially effective and easy to implement (Hossain et al., 2019); they are characterized by a real-life context and multiple stakeholders who share a wide range of resources and knowledge for the purpose of innovation (cf. Dell'Era & Landoni, 2014;). Such real-life environments are seen as catalysts for learning and innovation between stakeholders (Leminen et al., 2020). Living labs are linked to various environments, displaying both confined and broader contexts (Hossain et al., 2019). The core idea of the living lab model is to tap into experiences and knowledge of diverse stakeholders by fostering collaboration and harnessing them to create valuable outcomes (Paskaleva & Cooper, 2021). Prior literature draws on extensive analyses of the activities of the stakeholders and explores a wide range of innovation and development activities ranging from co-creation to testing and validation (cf. Buhl et al., 2017).

The intricate network of organizations and individuals, often referred to as a public–private-people partnership, fosters engagement through a variety of activities and methods (Schuurman et al., 2013). Within living labs, the close cooperation among diverse stakeholders and their networks accelerates the innovation process (Nyström et al., 2014). Participants bring a wide range of resources and knowledge to collaborative innovation efforts (Edwards-Schachter et al., 2012. In essence, living labs are acknowledged for their open, inclusive, and collaborative methods in tackling innovation challenges in real-world environments (Hossain et al., 2019).

Over the past decade, living labs have offered numerous benefits to businesses, policymakers, users, and society at large (Leminen et al., 2012). By providing a space for co-creation, they facilitate experiments and user feedback (Hakkarainen & Hyysalo, 2016). Living labs can harness tacit knowledge to transform latent user needs into new products and services or enhance existing ones (Edwards-Schachter et al., 2012). Additionally, they offer governance and a framework for collecting user insights and identifying issues to support user entrepreneurship (Hakkarainen & Hyysalo, 2013). Living labs produce both tangible outcomes, such as designs, products, prototypes, solutions, and systems, as well as intangible outcomes, such as concepts, ideas, intellectual property rights, knowledge, and services (Buhl et al., 2017; Dell'Era & Landoni, 2014; Evans et al., 2015). These results are based on the ability of living labs to promote co-creation and share knowledge. Co-creation minimizes market risk when introducing new products, accelerates time to market, and promotes return on investment (Niitamo et al., 2012).

Conventional innovation processes start by defining the desired outcomes, followed by breaking down activities into predefined phases with allocated resources (Cooper, 1990). Progress is monitored phase by phase, correcting deviations to ensure goal achievement. This structured approach allows for efficient resource use within companies (Cooper, 2019). In contrast, living labs place significant emphasis on all actors and particularly users in the development, testing, and validation of products, services, and systems. While user involvement in innovation is not new, living labs elevate users from mere testers to equal partners in the innovation process, alongside providers, utilizers, and enablers (Leminen et al., 2016). Utilizers are organizations that instigate and encourage "living labbing" for their own ends. Enablers include public actors (e.g., towns, municipalities), financiers, and non-governmental organizations (e.g., area development organizations). Provider-driven living labs are launched by educational institutes, universities, consultants or other kinds of developer organizations. User-driven living labs aim to tackle perceived issues in users' daily lives and are usually founded by a concerned user community.

Understanding living labs requires recognizing the importance of real-world environments in innovation. These environments form the core of living labs, where products and/or services are 'collided' with real-world settings and stakeholders' experiences. This exposure to real-life conflicts and interactions is crucial for development, often revealing unforeseen issues and altering the innovation direction. Living labs promote these 'collisions' to accelerate innovation (Leminen et al., 2020). This dynamic and unpredictable nature challenges traditional, rigid innovation models, which may not accommodate unplanned changes or resource needs. The undetermined outcomes of living labs can be difficult to sell to company management, but they offer significant advantages, such as faster time-to-market and better alignment with user needs, reducing market entry risks. Additionally, living labs provide access to expertise and resources that might otherwise be unavailable to companies and organizations (Nyström et al., 2014)

Living labs tend to vary according to the aim of their innovation activities, the context, and received outcomes (Almirall & Wareham, 2011; De Vita & De Vita, 2021). Therefore, they can be differentiated based on who is directing the living lab (Leminen et al., 2012). Living labs differ regarding their aims, activities, configuration, and structures. In particular, the diversity of actors characterizes living labs, as does the network structures of the living lab. For instance, Dutilleul et al. (2010) propose that different network structures induce different purposes for living lab networks. Based on three identified archetypes of living lab network structures, Leminen et al. (2016) elaborate on how the open innovation network structures and the driving stakeholders generate different outcomes. Further, Schuurman et al. (2013) suggest that elements such as settings, stakeholders, methods, user centricity, and infrastructures delineate living lab networks.

Nevertheless, there are differing views on the role of users in new product development. While one view does not recognize a relationship between innovativeness and the roles of users (e.g., Leonard & Rayport, 1997), another suggests a clear relationship between user involvement and the success of an innovation (Coviello & Joseph, 2012). The living lab model is a distinct type of open innovation that embeds both the real-life context and may entail a smaller number of participants compared with, for example, open sourcing or crowdsourcing (Almirall et al., 2012; Bergvall-Kåreborn et al., 2009). Moreover, previous literature on living labs suggests that the innovation mechanism covering both authority and grass root activities depends on the type of living lab, i.e., whether they are coordinated by a top-down or a bottom-up logic (Leminen et al., 2016). The governance structure of top-down coordinated living labs may be more hierarchical as compared with open communities. However, similar to open communities, bottom-up coordinated living labs assume that all organizing innovation activities will be 'grass root activities.' Pisano and Verganti (2008) describe this form of open innovation as an 'elite circle', where a selected group of participants is chosen by a central actor. Such a leading actor may define a problem for innovation and choose the outcomes. This means that a living lab network can be hosted and led by a single actor such as a business organization or institution.

2.3 Innovation Performance: Open and Collaborative Perspectives

2.3.1 Open innovation performance

Previous literature only broadly analyses innovation performance within the paradigm of open innovation (see Table 1). Examples include inbound innovation (Hung & Chou, 2013; Sisodiya et al., 2013; Wang et al., 2015), outbound innovation (de Jong & Flowers, 2018; Hung & Chou, 2013) and their paired (both inbound and outbound innovation) practices for the performance of a firm (Oltra et al., 2018), the role of governmental support for innovation performance (Jugend et al., 2018), and product portfolio innovativeness, as well as the dual role of development-centric and commercialization-centric innovativeness (Rubera et al., 2016). Tsinopoulos et al. (2019) found that increasing the diversity of external knowledge restrained innovation activity and negatively affected organizational learning. The firm's openness is crucial in innovation performance and can be studied through the total number of external sources used in the firms' innovation (external search breadth) and the degree of close collaboration with these sources (external search depth) (Laursen & Salter, 2006).

Understanding a firm's openness, including the degree of external search and the breadth of cooperation in formal innovation (Tsinopoulos et al. 2019), is important as it influences the firm's ability to achieve novelty in its innovation activities. Greco et al. (2016), in their examination of firm performance, refer to external channels as coupled open innovation. Firms that employ open search strategies (search widely and deeply) are more likely to be innovative (Laursen & Salter, 2006), i.e., the outcome is affected positively by the surrounding network of actors, relationships, and sources of information.

Table 1. Overview of research on innovation performance (firm level) in open innovation

Approach to studying innovation performance	Innovation performance on a firm level
Inbound innovation	Hung & Chou 2013; Sisodiya, Johnson & Grégoire 2013; Wang, Chang & Shen 2015
Outbound innovation	Hung & Chou 2013; de Jong & Flowers 2018
Inbound, outbound and their coupled practices	Oltra, Flor & Alfaro 2018
Openness	Laursen & Salter 2006
Search breadth and/or search depth, external channels	Greco, Grimaldi & Cricelli 2016

Approach to studying innovation performance	Innovation performance on a firm level
The span and role of external stakeholders in knowledge sharing and innovation co-creation	Markovic & Bagherzadeh 2018
Openness via external search breadth, collaboration breadth	Tsinopoulos, Yana & Sousa 2019
Government support	Jugend, Jabbour, Scaliza, Rocha, Junior, Latan & Saldago 2018
Product portfolio innovativeness	Rubera, Chandrasekaran & Ordanini 2016

Open innovation activities by search breadth and/or search depth, or openness, have also been linked to product innovation (Markovic & Bagherzadeh, 2018), the diversity of employees (Bogers et al., 2018), as well as timing (Bahemia et al., 2018). Thus, innovation performance is not only examined through different approaches and conceptual constructs, but also from a perspective where openness is regarded as a mediating factor.

2.3.2 Performance in collaborative innovation networks

Collaborative innovation networks build on integrating a plurality of stakeholders in innovation endeavours to succeed in product innovation (Tsai, 2009). In concordance with the definition by Najafi-Tavani et al. (2018, 193), we characterize collaborative innovation networks as interactions between a firm and its external stakeholders, such as clients, competitors, suppliers, and research organizations, which are aimed at developing new products, services and/or solutions. Previous studies on collaborative innovation networks (see Table 2) have focused on: the interorganizational dynamics of cooperative, inter-organizational relationships (Majchrzak et al., 2015), the role of supplier collaboration for innovation performance (Luzzini et al., 2015), capabilities for product innovation (Zaefarian et al., 2017), and macro-economic aspects such as the role of patent data for innovation performance in different regions (De Noni et al., 2018). Tsai (2009) explored the firm's ability to replicate new knowledge (absorptive capacity) and its link to the performance of innovating products. Similarly, Najafi-Tavani et al. (2018) studied absorptive capacity and proposed that the external actors enhance collaboration on product and process innovation, while concurrently recognizing that studies on collaboration innovation networks show inconsistent results between innovation networks and their performance.

Table 2. Overview of research on innovation performance in collaborative innovation networks

Approach to studying innovation performance	Innovation performance on a regional level	Innovation performance on a product level	Innovation performance on a process level
Absorptive capacity	–	Najafi-Tavani et al. 2018	Najafi-Tavani et al. 2018
Absorptive capacity among different partners	–	Tsai 2009	–
Capabilities	–	Zaefarian et al. 2017	–
Supplier involvement	–	Luzzini et al. 2015	–
Patent data	De Noni et al. 2018	–	–

In summary, previous research presents contradictory results regarding innovation activity and organizational performance. Extant open innovation literature analyses innovation performance largely on a firm level. Research on outcomes in open innovation networks is limited, particularly regarding the outcomes associated with heterogeneous stakeholders in open innovation networks (Huizingh, 2011). Research on collaborative innovation networks aims to understand product and process innovation but is limited by the implication that it focuses on the collaboration between a firm and its network rather than the holistic collaboration within a network. Consequently, open innovation and collaborative innovation differ in their approaches to innovation performance and outcome. Research on open innovation networks and living labs draws on the broader network and its characteristics to understand the goals, dynamics, and prerequisites for fostering innovation within networks. It is important to adopt this holistic perspective when identifying the variables that influence innovation outcomes of open innovation networks.

2.4 Innovation outcome and variables in open innovation networks

Paskaleva and Cooper (2021) state that despite the long history of living labs, the outcomes of living labs are poorly understood. The living lab literature mentions product, service, and systems when defining *outcomes* of living labs (cf. Engels et al., 2019). Research on living labs indicates that the living lab model facilitates the emergence of unpredictable outcomes (Leminen et al., 2020) or both intended and unintended outcomes (Van Geenhuizen, 2018; De Vita & De Vita, 2021). In most of the studied cases, stakeholders predefined their objectives and shared expectations regarding collaboration; one focus of living lab activities is often on testing and validating products to meet these objectives and shared expectations (Nyström et al., 2014). In contrast, conventional R&D projects often emphasize achieving and monitoring predefined objectives.

In our coding of the empirical case data, we identified several variables that are linked to innovation outcome, namely strategic intention, passion, the number of participants, knowledge and skills, and resources (Table 3). In the following, and relying on prior studies that explicate the variables, we summarize the variables and their impacts on the outcome(s) of open innovation networks.

Table 3. Literature related to the identified variables

Variables	Sources
Outcome(s)	De Vita & De Vita, 2021; Engels et al., 2019; Nyström et al., 2014; Paskaleva, & Cooper, 2021; Van Geenhuizen, 2018
Strategic intention	Leminen et al., 2020; Mariadoss et al., 2014
Passion	Füller et al., 2008; Rindova et al. 2009
Number of participants	Furr et al., 2016; Schuurman et al., 2011; Schuurman et al., 2013; Van Geenhuizen, 2018
Knowledge and skills	Estrada et al. 2016; Evans et al., 2015; Leminen et al., 2020; Nyström et al., 2014
Resources	Edvardsson et al., 2012; Engels et al., 2019; Hossain et al., 2019; Leminen et al., 2020

Strategic intention comprises motives, reasons, desires, aims and goals of collaboration, and co-operation in living lab endeavours. The core of the collaboration includes jointly shared and agreed motives by all the stakeholders (e.g., company, public organization, research organization, or user community); however, diverse stakeholders may have their own individual desires and goals for collaboration as well (Ståhlbröst, 2012). A jointly shared strategic intention enables stakeholders to steer their own operations in the desired direction. A certain user community member may have their own individual motives, and the member may raise questions of ecological issues or sustainability or even promote a message about environmental change or criticize society. These examples illustrate the concept of an extensive community with diverse aims but a shared strategic intention. On this premise, commonly shared motives assume that diverse participants understand and value each other's collaboration in innovation. Although previous research documents strategic intent at the firm level (Mariadoss et al., 2014), studies examining shared motives, goals, desires, or aims within open innovation networks are scarce (Leminen et al., 2020).

Passion is particularly prevalent in user- and user community-driven living labs, as well as in other living labs where users play a crucial role (van Geenhuizen, 2018). Passion can be described as a force that compels individuals toward activities they are passionate about (cf. Amiot et al., 2006). Users are eager to invest their time in innovation endeavours that address the everyday problems of local communities, thereby contributing to the common good (Nyström et al., 2014). Passion is a crucial variable, but it is not sufficient on its own to achieve the goals of the entire living lab. Living lab participants seek a necessary precept for innovation endeavours. An essential question is whether living lab actors and participants support and facilitate passion for innovation endeavours in general or focus solely on the innovation endeavours of a single stakeholder. Hence, living lab stakeholders may encourage others to establish an atmosphere that incorporates passion and cultivates mutual respect. Only a small number of studies have explored the role of passion in the emergence of innovation (Füller et al., 2008; Rindova et al., 2009); hitherto research has failed to explain the role of passion as an aspect in the outcome. This study emphasizes that in living labs, passion is the essence of innovation rather than being merely a variable in the mathematical model. This implies that passionate actors are likely to be responsible for driving innovation activities forward in open innovation networks (Leminen et al., 2012).

The *number of participants* in living labs refers to the approximate number of actors involved in the innovation process. A living lab includes multiple and diverse participants (cf. Ballon et al., 2018; Schuurman et al., 2011). The complexity of actors in living labs enhances learning and networking between participants (van Geenhuizen, 2018). Living labs typically involve more users and producers than enablers and utilizers (cf. Schuurman et al., 2013). It is worth noting that increasing the number of participants may require establishing rules and guidelines for innovation activities, thereby increasing managerial efforts in living labs (van Geenhuizen, 2018). However, such rules may discourage participation and prevent the fostering of passion in the participants participating in the innovation endeavours. Unlike crowdsourcing, which is an open innovation approach suited to large-scale outreach, living labs often have a smaller number of participants, ranging from just a few to a considerable number. We propose that the number of participants has a non-monotone effect on passion in innovation activities, and thus indirectly affects the innovation outcome.

Knowledge and skills are regularly discussed in the context of living labs (Evans et al., 2015). By definition, a living lab provides knowledge and expertise that stakeholders do not typically have access to. Living lab stakeholders contribute various types of knowledge and skills to living labs, viewing them as forums for exchanging knowledge (Engels et al., 2019), enhancing their skills in innovation endeavours, and acquiring distinct knowledge and skills (cf. Evans et al., 2015). Development of skills may take place among users, who view a living lab as a vehicle to improve their living conditions as well as their neighborhoods (Nyström et al., 2014). Knowledge flows between stakeholders, and the wide sharing of knowledge and experience fosters innovation (Leminen et al., 2020). Leminen et al. (2020) proposed that stakeholders may transfer knowledge between living labs, thus enhancing learning among living labs, while Estrada et al. (2016) emphasized the importance of recombining and integrating external knowledge to enhance innovation performance. Hence, innovation outcomes are linked to the expertise and knowledge of the participants in the innovation endeavour (Leminen et al., 2016).

Previous research has identified heterogeneous *resources* in living labs (Hossain et al., 2019). These resources may range from financial resources and investments to the developed and allocated operation environments (or environments to be developed), for example a space, an item of hardware, or software. Prior studies on innovation activities highlight access to resources (Edvardsson et al., 2012) as a means of shortening time-to-market (cf. Calantone & Di Benedetto, 2000), and to "collide ideas" (Leminen et al., 2020). Skilled facilitators are employed to support innovation together with various stakeholders. Such facilitation is suggested to enhance opportunities to educate, gather, and distribute resources among participants (Engels et al., 2019). There is a diversity in available resources, and some living labs are characterized by the temporality of their activities: the aims of temporal, short-term living labs determine their funding, as well as their innovation endeavours and structures, whereas other, more long-term living labs have additional enduring structures and supporting resources (Nyström et al., 2014; Leminen et al., 2020). Researchers highlight the scarcity of available resources in living labs; for instance, financial resources and other monetary support for innovation endeavours are extremely limited in some living labs (Ondiek & Moturi, 2019). Such living labs base their innovation endeavours on grassroots activities and volunteer efforts, with the overarching goal of innovating to benefit the broader public good in society. For example, free training and education aimed at enhancing the prosperity of user communities were identified in empirical living lab studies (Leminen et al., 2016). Consequently, living labs organize and utilize their resources in unique ways (Nyström et al., 2014).

3 Method

3.1 Research setting and design

Following the notion of Yin (1989), we base our arguments for the findings, as well as their implications and transferability, on a multi-country setting. Finland, Sweden, Spain, and South Africa, the four countries chosen for the study, provide numerous examples of successfully established living labs used for collaborative innovation (European Network of Living Labs, 2024). The living lab cases were selected based on (i) open innovation activities using the living lab approach, (ii) numerous stakeholders being involved in the innovation activities, and (iii) users, user groups, or user communities being engaged for innovation in real-life environments. These criteria were also shared by the informants in the cases. Therefore, in line with Erlandson et al. (1993), we believe our findings are representative and possess adequate and relevant potential for transferability: we describe the context of the empirical setting in detail and provide a broad description of the phenomenon under study as well as the boundaries of the study.

Similarly to the multi-phased research design applied by Nyström et al. (2014), who studied actor roles in living labs, we applied a six phased research design (detailed description provided in Table 4), following a mixed-method approach (Creswell & Plano Clark, 2011), to assess the innovation outcome(s) and the related variables. Each of the 26 living labs studied provided a research case, and, following the approach of Jensen and Rogers (2001), we treated each case as a snapshot study. The cases not only unfolded the stakeholder relationships and innovation activities in living labs which is a specific type of open innovation networks, but also allowed us to cover a limited period. This limited period was necessary for us to gain an understanding of the practices in open innovation activities and their outcomes, particularly in the short term, when the relationships between them are meaningful to measure.

3.2 Data collection

We collected an international dataset of living lab cases spanning the period from 2008 to 2011, comprising a total of 26 living labs and 136 interviews with actors involved in them (see Appendix A). As suggested by Nyström et al. (2014), we focused on the principal living lab actors, as covering each network actor in large, dynamic open innovation networks such as living labs would have required an overly extensive effort. We extended our data collection beyond the driving actor in specific cases where we perceived that we did not adequately comprehend the living lab network, its activities, or innovation outcomes. In addition to the collected data, we exploited available secondary data such as associated articles, case reports and relevant web sites.

Most interviews were completed in person, and they lasted for a minimum of one hour. We also piloted some interviews over the telephone because of the informants' schedules. The interviews were transcribed verbatim. An interview guide was used to direct the data collection (Patton,1990) and it covered three main topics: (i) living labs and their actors, (ii) tasks and activities conducted by the living lab actors, and (iii) outcomes of the collaborative innovation. For confidentiality reasons, we withheld any information that could identify the living labs, or the individuals interviewed.

3.3 Data analysis process

We employed a content analysis approach (cf. Roberts, 1997; Neuendorf, 2002) to explicate each case and generate theories or constructs (cf. MacInnes, 2011; MacKenzie, 2003). In this case, the construct–i.e., the concept to be operationalized or measured–refers to innovation outcomes. With this objective in mind, our data analysis process was conducted in six stages (see Table 1). First, we conducted an overview of the empirical dataset and organized the data by case, informant position, and interview date. We analysed the data at the level of the innovation network, viewing all actors within the open innovation network as playing roles in the network's innovation activities.

Second, we mapped the activities and their associated actors to understand their roles in the outcomes. We analysed the original transcribed interviews by performing and relying on data coding. In so doing, we first coded the data separately for each living lab case, then discussed, elaborated on, and reviewed each case to reach a consensus on the identified outcomes. Further, we compared our construction of the findings with previous research on living labs as open innovation networks (Nyström et al., 2014) and body of knowledge regarding the associated types of innovation outcomes (Hossain et al., 2019).

Third, we explored the performance and outcome-related activities of the actors. The data coding elicited a set of variables linked to the outcomes of each case. We coded the pivotal variables as first order themes following Gioia et al. (2013), without using any predefined format, criteria, or requirements. In the fourth stage of the data analysis process, we compared our construction of the findings with extant research on living labs (Greve et al., 2020; Hossain et al., 2019), which induced the identification of second order themes (key theoretical themes). We also conducted a targeted coding of elements describing each identified variable and compared the coding results with theory.

Fifth, we conducted a multiple linear regression analysis (see e.g., Allison, 1999) of the constructed data set to develop a model for assisting the outcome of the innovation based on the data set from the 26 living lab cases. In the sixth and final stage, we made conclusions about innovation outcome(s) and their related variables in open innovation networks. Next, we will present and discuss our analysis of the quantified dataset including the identified variables related to innovation outcomes in open innovation networks.

Table 4. Data analysis process

Data analysis process	Activity	Result
1. First iteration of open coding	- Categorize living lab cases; - Identify stakeholders and actors according to case	Outline of each case based on the interview date and the position of the informant.
2. Second iteration of open coding	- Categorization of actor activities in each case; - Categorization of the outcomes of living lab cases	Overview of activities, stakeholders, and actors in each case (cf. Nyström et al., 2014), and outcomes (Leminen et al., 2020)
3. Third iteration of open coding	- Categorization of outcome-related activities (innovation endeavours); - Identify emerging categories of influences on innovation outcome (1st order themes)	Identification of five pivotal variables of open innovation endeavours: strategic intention, passion, number of participants, knowledge and skills, and resources.
4. Selective coding of the identified variables	- Description of variables; - Selection of key theoretical themes (2nd order themes); - Compare coding results to theory	Theory-centric analysis of the identified variables (cf. Greve et al., 2020, Hossain et al., 2019)
5. A linear regression analysis of constructed data set	- Quantification of variables in the data sets; - Construction of a mathematical model by linear regression analysis for assessing innovation outcomes	Identification of multiple linear regression model for innovation outcomes and its variables (Allison, 1999)
6. Synthetizing the findings	- Synthesis phase #1-5; - Managerial implications; - Theoretical implications	Findings and results on innovation outcome(s) and its related variables in open innovation networks

4 Description of dataset and regression analysis

We cross-checked and verified the existence of all the variables of the dataset in our cases. The researchers independently carried out the valuation of all variables in each case. The four foundational variables, i.e., strategic intention, passion, knowledge and skills, and resources were measured on an advantage scale ranging from [very significant = 5] to [insignificant = 1] to describe the various innovation endeavours in living labs by their structure (Table 5).

Table 5. Valuation of the variables

Variables	Abbreviations	Very significant	Significant	Moderate	Minor	Insignificant
Strategy	S	5	4	3	2	1
Passion	P	5	4	3	2	1
Knowledge and skills	K	5	4	3	2	1
Resources	R	5	4	3	2	1

For the number of participants [n], we adopted the approximate number of participants in the living labs. Acknowledging prior discussion of innovation types and scales of innovativeness (cf. Avlonitis et al., 2001; Garcia & Calantone, 2002; McDermott & O'Connor, 2002), we adopted a level of outcomes that ranged from [Trial not committed] to [Novelty innovation in global development] (see Table 6). A brief description of the cases can be found in Appendix A.

Table 6. Outcomes in the living lab cases

Outcome	Value	Living lab case #	Number of cases
Novelty innovation in global development	5	7	1
Novelty innovation in national development	4	2, 11, 15, 20, 21	5
Novelty innovation in regional development	3	5, 6, 8, 9, 13, 14, 16, 17, 18, 19, 23, 24, 25, 26	14
Novelty innovation in everyday life	2	4,10,12,22	4
Trial not committed	1	1,3	2

The results confirm the findings of prior living lab research, suggesting that radical innovations having significant market potential are uncommon (Case 7), and that most outcomes were incremental. Nonetheless, two of our examined cases (Cases 1, 3) indicated that the participants had vague expectations rather than being clearly focused on predefined goals. Innovation endeavours in 14 cases were classified in the category 'novelty innovation in regional development', as they were aimed at contributing to and addressing the need for development in regions or communities. We found 'novelty innovation in everyday life' in four cases (4, 10, 12, 22) and 'novelty innovation in national development' in five cases (Cases 2, 11, 15, 20, 21). Appendix A details the individual variables, their scaling, and the outcomes in the 26 examined living lab cases. These results were compared and agreed by the researchers. Table 7 provides an overview of the descriptive statistics of the variables.

Table 7. Descriptive statistics

	Count	Mean	Median	Std. dev	Min	Max
O	26	2.9615	3	0.9157	1	5
S	26	4.2308	4	0.7104	3	5
P	26	3.6154	4	0.8038	2	5
K	26	3.7308	4	0.7776	2	5
R	26	2.5385	3	0.6469	1	3
n	26	28.4615	22.5	24.0354	5	115
N	26					

4.1 Theoretical framework: assessment formula

In our coding of the empirical case data, we identified several variables that were linked to innovation outcomes, namely (i) strategic intention (S), (ii) passion (P), (iii) the number of participants (n), (iv) knowledge and skills (K), and (v) resources (R) (Table 4). We propose that the following linear equation assists the outcome of open innovation (O):

$$O(S, P, K, R) = \alpha_0 + \alpha_1 S + \alpha_2 P + \alpha_3 K + \alpha_4 R \tag{1}$$

where the slope coefficients are all positive ($\alpha_1, \alpha_2,\ \alpha_3,\ \alpha_4 > 0$), meaning that all variables ($S,\ P,\ K,\ R$) have a positive effect on the outcome of open innovation (O).

We also propose that the number of participants (n) affects passion in innovation activities (P). Thus, the number of participants has an indirect effect on the innovation outcome, via passion in innovation activities. We propose that when the number of participants increases, passion first increases and then decreases, forming an inverted U-shaped relationship between the two variables n and P, as illustrated in Figure 1.

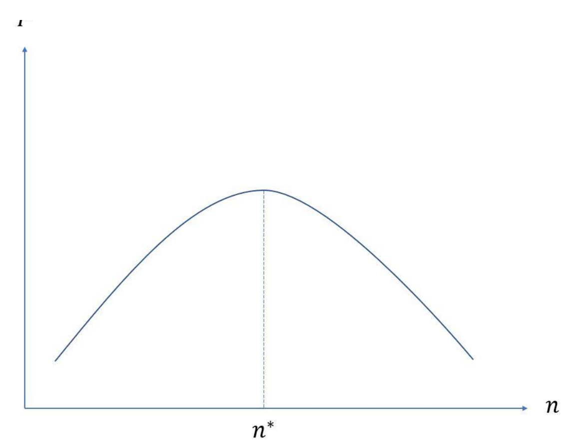

Figure 1. Relationship between the number of participants n and passion P in innovation activities

The inverted U-shape involves that there is an optimal number of participants, which we denote n^*, that maximizes passion in innovation activities P. Mathematically, n^* is determined by:

$$n^* = \arg\max_n\ P(n) \tag{2}$$

We propose that $P(n)$ can be approximated by a quadrilinear relationship:

$$P(n) = \alpha_{n,0} + \alpha_{n,1} n + \alpha_{n,2} n^2 \quad (3)$$

Maximizing P with respect to n yields the following conditions of first (FOC) and second (SOC) order:

$$\alpha_{n,1} + 2 \times \alpha_{n,2} n^* = 0 \quad \text{(FOC)}$$
$$2 \times \alpha_{n,2} < 0 \quad \text{(SOC)}$$

Since $n^* > 0$, these conditions imply that $\alpha_{n,2} < 0$ and $\alpha_{n,1} > 0$.

4.2 Regression analysis

Table 8 reports the linear correlations between each variable. The variables (S, P, K and R) correlate positively with the outcome O, and the correlation coefficients are highly significant. The number of participants (n) does not correlate linearly with any other variable (see Table 8). However, current research indicates inconsistencies (either negative or positive effects) regarding a firm's open innovation performance depending on the situation (Najafi-Tavani et al., 2018; Zhang et al., 2018). Salter et al. (2015) found a curvilinear relationship in ideation performance. Therefore, we suggest an inverted U-shaped relationship between the number of participants n and passion P, such that a higher n is associated with a higher P for low levels of n and a higher n is associated with a lower P for high levels of n, as described in section 4.1.

Table 8. Correlation table

	O	S	P	K	R	n
O	1					
S	0.506***	1				
P	0.468**	-0.119	1			
K	0.547***	0.262	-0.0443	1		
R	0.509***	0.502***	-0.124	0.379*	1	
n	0.244	-0.1	0.181	-0.0894	-0.0758	1

4.2.1 Main regression model

We propose the following multiple linear regression model to see if the variables S, P, K and R assist the innovation outcome O:

$$O_i = \alpha_0 + \alpha_1 S_i + \alpha_2 P_i + \alpha_3 K_i + \alpha_4 R_i + e_i \quad (4)$$

The constants α_1, α_2, α_3 and α_4 are the coefficients to be estimated in the multiple regression model. Each coefficient α_j measures the effect of the associated explanatory variable while holding the other explanatory variables constant. We expect the coefficients α_1, α_2, α_3 and α_4 to be positive, meaning that the explanatory variables S, P, K and R all have a positive impact on the innovation outcome O. α_0 is the intercept, and e_i is the error term, which is assumed to be normally distributed. The error term captures all the factors not included in the model that cause the innovation outcome to vary.

We report the estimation results of regression model (4) in Table 9.

Table 9. Main regression

Variable	Coefficient
S	0.4387*** (0.1548)
P	0.6357*** (0.1187)
K	0.4508*** (0.1319)
R	0.3713** (0.1774)
Intercept	−3.8174*** (0.8232)
N	26
R^2	0.7764

Standard errors in parentheses

* p < 0.10; ** p < 0.05; *** p < 0.01

All coefficients in regression (4) are positive and highly significant. $R^2 = 0.7764$ reflects that 77.64% of the variance in innovation outcome O is explained by the explanatory variables S, P, K and R. The assisted innovation outcome is equal to:

$$O_i = -3.8174 + 0.4387S_i + 0.6357P_i + 0.4508K_i + 0.3713R_i \tag{5}$$

The estimated equation (5) indicates that the impact of the explanatory variables S, P, K and R are similar in size. To formally test the equality of the coefficients, we developed the following hypotheses:

$$\mathcal{H}_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4, \quad \mathcal{H}_1 : \alpha_i \neq \alpha_j \text{ for any pair (i, j)}$$

We tested $\mathcal{H}_0$ against $\mathcal{H}_A$ and obtain the result that the F statistic with a 3 numerator and 21 denominator degrees of freedom is 1.02 (F(3,21)=1.02). The significance level of the test is 40.33% (Prob > F=0.4033). Thus, we concluded that we cannot reject the null hypothesis, i.e., that all coefficients α_i are equal (see e.g., Dougherty (2016) for an introduction to testing multiple restrictions using the F statistic).

Next, we analyzed the relationship between passion and the number of participants. Plotting P against n in Figure 1, we observed that there is an outlier in the dataset. Inspecting the descriptive statistics in Table 7, the deviation of maximum value of n from the mean is more than 3.6 times the standard deviation. As outliers may have a strong influence over the fitted slope and intercept in a regression, we excluded it from the analysis below. Thus, the number of cases in our data set is 25.

In Table 10, we report the descriptive statistics of the reduced dataset when excluding the outlier.

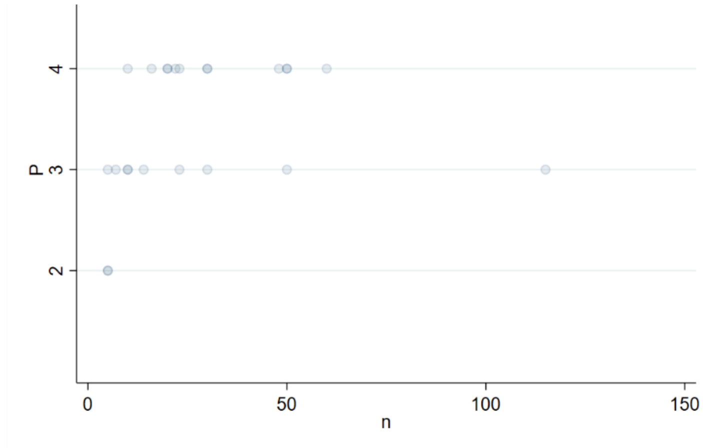

Figure 2. Plotting P against n

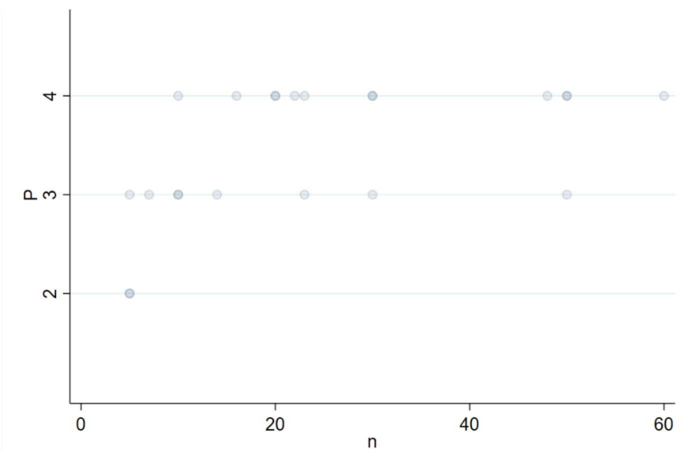

Figure 3. Excluding the outlier

Table 10. Descriptive statistics after excluding the outlier

	Count	Mean	Median	Std. dev	Min	Max
P	25	3.64	4	0.8103	2	5
n	25	25	22	16.6508	5	0
N	25					

After exclusion of the outlier, there are indications of an inverted U-shaped relationship between the number of participants n and passion P (see Figure 3). To test this relationship more formally, we propose the following quadratic regression:

$$P_i = \alpha_{n,0} + \alpha_{n,1} n_i + \alpha_{n,2} n_i^2 + u_i \tag{6}$$

The constants $\alpha_{n,1}$ and $\alpha_{n,2}$ are the coefficients to be estimated in the regression model. We expect $\alpha_{n,1}$ to be positive and $\alpha_{n,2}$ to be negative, yielding an inverted U-shaped relationship between the number of participants n and passion P (as discussed in section 4.1). $\alpha_{n,0}$ is the intercept, and u_i is the error term, which is assumed to be normally distributed. The error term captures all the factors not included in the model that cause passion P to vary.

We proceeded to estimate the regression equation (5) (see Table 11). As expected, we observed that the coefficient on n ($\alpha_{n,1}$) is positive and significant at the 1% level, while the coefficient on the squared term ($\alpha_{n,2}$) is negative and significant at the 5% level. We concluded that there is a significant quadratic (inverted-U) relationship between P and n.

Table 11. Quadratic regression

Variable	Coefficient
n	0.1105^{***} (0.0341)
n^2	-0.0015^{**} (0.0006)
Intercept	2.1971^{***} (0.4144)
N	25
R^2	0.3939

Standard errors in parentheses

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

The estimated equation is given by:

$$P_i = 2.1971 + 0.1105n_i - 0.0015n_i^2 \qquad (7)$$

Based on the regression results, we calculated the optimal number of participants that maximizes passion in innovation activities using the first order condition from the maximization problem, which we repeated as:

$$\alpha_{n,1} + 2 * \alpha_{n,2} n^* = 0 \qquad (FOC)$$

Inserting $\alpha_{n,1}$ and $\alpha_{n,2}$ from Table 10 yields $n^* \approx 37$. This means that, according to the model, the optimal number of participants in the sample in innovation activities n^* is higher than both the mean and the median number of participants in the living labs.

5 Discussion

Our study highlights a preference to placing the focal point on the open innovation network, rather than focusing on the level of the performance of a firm or a specific project. First, the findings stress that the identified four variables contribute to outcomes in open innovation networks, aiding firms in examining innovation performance in their living lab activities. Next, we estimated a multiple linear regression model for innovation outcomes in open innovation networks. The regression results indicated that all four variables positively affect the innovation outcome. Last, our study suggested a limit to the numbers of stakeholders that allow retention of their passion in innovation activities.

5.1 Foundational variables in open innovation networks

The findings stress that the identified four variables, strategic intention, passion, knowledge and skills, and resources, contribute linearly and equally to the outcomes of open innovation networks.

In other words, the four variables jointly enhance innovation outcomes in open innovation networks; the variables have an equal effect on the innovation outcomes. When the four variables are strongly and positively aligned, living labs are likely to pursue/reach innovation. Among previously identified key performance indicators, this study identified passion as a variable, which has received little attention in the extant literature on open innovation. Previously identified indicators of innovation processes are largely related to quality and process phases rather that innovation endeavours per se (Dziallas & Blind, 2019).

5.2 A multiple linear regression model for open innovation networks

Our study developed a *multiple linear regression* model for assessing outcomes in open innovation networks, specifically in the context of living labs. The study identified four pivotal variables in the regression model that reflects innovation and development activities conducted in living labs. We propose that these variables stimulate the innovation endeavours and, thus, the resulting outcomes in open innovation networks. Our model assessing open innovation outcomes in living labs can be restated as:

$$O(S,P,K,R) = \alpha_0 + \alpha_1 S + \alpha_2 P + \alpha_3 K + \alpha_4 R \quad (1)$$

where [O] refers to an outcome of open innovation endeavours in a living lab. The variables of the mathematical model are: (i) strategic intention [S], (ii) passion [P], (iii) knowledge and skills [K], and (iv) resources [R] through (v) diverse open innovation network stakeholders. Each coefficient α_j, $j \in (1,4)$ measures the effect of the associated explanatory variable while holding the other explanatory variables constant. We showed that the coefficients α_1, α_2, α_3 and α_4 were positive and of approximately equal size, meaning that the explanatory variables (S, P, K and R) all have a positive and equal impact on the innovation outcome O.

An aligned innovation decree indicates that a variable enhances the impact of other variables on the innovation outcome. This may have either a positive or negative effect, thus it can strengthen or weaken the outcome of innovation endeavours. An example of a positive alignment is when a high level of strategic intention, which goes beyond the level of the stakeholders' strategic intent, proffers help in advancing the stakeholder's knowledge and skills in open innovation networks. The cases show notable differences in available knowledge and skills. Several cases solving the challenges of users or a user community regarding everyday problems assume a rather low degree of knowledge and skills. Hence, such living labs assume a general knowledge of everyday problems. With this in mind, we also found some cases benefitting from professional knowledge and the skills of respected experts obtained from various domains and areas of expertise. Innovation endeavours seem to boost the knowledge and skills of participants and such progress assists living labs in reaching their outcomes; although the cases did not necessary show clearly presented objectives or goals.

Moreover, sharing a mutual strategic intent and passion gives impetus to pursuits beyond an individual's limits. Equivalent examples can be found in sports, where a good team spirit often has a positive effect on an individual performance, and top players may motivate others to exceed their own limits. However, our research suggests that an aligned innovation direction can also go in the opposite direction. One example of a negative effect is that living labs may reflect only a modest strategic intention due to an absence of knowledge and skills. A modest level in any of the variables may affect the other variables and lead to modest outcomes.

A reverse innovation decree implies that variables have a reverse effect and impair each other's effect in innovation endeavours. This study suggests an inversed U -shaped relationship between passion and the number of participants in open innovation networks. Thus, the number of participants is associated with higher passion when the number of participants in the open innovation is originally low. Similarly, a higher number of participants is associated with lower passion when the number of participants is originally high. Setting overly strict rules for the participating actors in open innovation may deteriorate the outcome(s). That is, a stricter model can result in diverse (and thereby weaker) results than in a loosely controlled model. A company may have a high strategic intention, expecting users to test and validate a product or a service, but such an endeavour may lessen the passion of other stakeholders. For example, users become less motivated, because the company considers them merely as objects of innovation activities rather than as co-creators of innovation (De Vita & De Vita, 2021).

Stakeholders may seek innovations with an impact. However, they seem to ignore the reverse innovation decree although it may lead to diminished innovation activities. For instance, when an organization is attempting, for example, to acquire normally inaccessible knowledge, it may be forgotten that the organization needs to open their own activities to others in the living lab. In other words, pursuing the objectives of the organization and retrieving information from others but, concurrently, not being willing to open the organization's activities to others will lead to a collective inability to utilize the potential of the open innovation network. In addition, previous research shows another reverse innovation decree, in which too many actors may lead to challenges in innovation endeavours. An overly large number of actors may lead to formal, institutionalized activities, which may decrease the motivation of actors. In fact, previous research has suggested that there is a 'threshold of openness' for the individual when pursuing ideas (Salter et al., 2015).

The reverse innovation decree concerns the reverse impact of the other variables and leads to reduced outcomes. Previous literature suggests that open innovation endeavours have either positive or negative effects on a firm's performance, depending on the situation (Najafi-Tavani et al., 2018; Zhang et al., 2018), and highlight several dynamic interorganizational patterns (Majchrzak et al., 2015). Salter et al. (2015) proposed a curvilinear relationship between the openness and performance of an individual ideation. We add to the knowledge of such patterns by suggesting the aligned innovation decree and the reverse innovation decree as new collaboration patterns in addition to the U-shaped relationships between the number of participants and passion.

5.3 Retention of passion in innovation activities

Given the inconsistency in the results of scholarly studies regarding innovation performances that have seemingly similar variables (cf. Najafi-Tavani et al., 2018), our study suggests that an inverted U-shaped relationship between the number of participants and passion may provide an explanation as to why the results for innovation performance are so inconsistent. More specifically, our study suggests that by determining the maximum point of an inverted U-shaped model there may be a maximum and optimal number of stakeholders that can realistically enhance passion in innovation activities. According to our estimations using this model, the optimal number of stakeholders is 37. However, we must interpret this number with caution due to the low number of observations in our study. Nevertheless, we suggest that exceeding the maximum number of stakeholders identified in the inverted U-shaped model may result in negative indirect effects on innovation outcomes via passion. Conversely, a low number of participants may create a situation where there are insufficient contributors to the innovation activities.

6 Concluding remarks

6.1 Theoretical contributions

Our overall objective was to identify a set of variables to construct a mathematical model that can assess the probable innovation outcome when stakeholders co-create and engage in living labs. For this purpose, we relied on a case study approach (a data set of 26 living labs) and a multiple linear regression analysis of a quantified data set to examine the variables and key performance indicators that had linear and equal effects on the outcomes. The findings were incorporated into a mathematical model based on the four key performance indicators, which have made significant contributions to the literature on both open innovation and living labs (e.g., Ballon et al., 2018; Hossain et al., 2019; Jarvenpaa & Wernick, 2012; Rodrigues & Franco, 2018).

We identified a crucial and linear relationship between strategic intention and innovation outcomes. Furthermore, the cases revealed that outcomes in open innovation networks are directly and linearly influenced by passion, which drives the efforts of stakeholders. Passion for collaborating can be compared to team spirit in sports. Additionally, the number of participating actors has a nonmonotone effect on collaborative passion in innovation endeavours. This suggests that in the innovation process, while a higher number of participants can contribute to a greater richness of ideas, perspectives, and suggestions, the opposite holds true for passion. As a result, innovation activities decline when the number of participants exceeds a threshold, corresponding to the peak of the inverted U-shaped curve.

Furthermore, the outcomes of innovation endeavours are linearly related to the enhancement of knowledge and skills among stakeholders and other actors in living labs. This notion corresponds to the living lab research that calls attention to the role of knowledge and skills in innovation and development activities (cf. Greve et al., 2020). While prior studies have mostly discussed the relationship between open innovation and performance on a project level (De Vita & De Vita, 2021; Du et al., 2018; Paskaleva, & Cooper, 2021) our study broadens this view by suggesting a linear dependency. The innovation outcomes in our study depend linearly on all four variables. Consequently, a mathematical model is proposed to assess innovation outcomes holistically at the network level of open innovation. We thus contribute to the study of open innovation networks by identifying the variables critical to the performance of collaborative networks based on their intention.

6.2 Managerial implications

Our study proposes a model that researchers and managers can use to investigate state-of-the-art activities in open innovation networks and to assess the expected outcomes. The study demonstrates a link between innovation outcome and the identified variables. The model can be applied to the assessment of open innovation endeavours and their likely outcomes in a living lab context. The essence of our model is to draw the attention of stakeholders to the diversity of innovation activities, provide a better guide, and an earlier evaluation of the potential of a given living lab to reach its intended outcomes. Moreover, it will help managers to understand how the different innovation variables influence the outcomes (aligned or reverse innovation decrees). While previous research indicated that stakeholder diversity enriches innovation endeavours (Greve et al., 2020), our study suggests that there is an optimal maximum number of participants. Exceeding this number reduces passion, which indirectly affects the outcomes.

Furthermore, to emphasize the practical relevance of our model, we recommend that managers consider the four identified variables when planning and evaluating collaborative innovation activities in open innovation networks, using them as key performance indicators to measure performance. An accurate analysis of an innovation outcome can only be achieved after identifying the key performance indicators to be monitored. The identified variables can thus contribute to identifying firm-specific and/or open innovation network specific measurement tools for improving performance that may be critical to the success of the firm. In essence, the model enables improved innovation management practices. The results indicate that the constructed mathematical model may be applied to various types of collaborative and innovation networks. By using a common assessment method, it provides a more holistic overview of a firm's open innovation activities.

6.3 Policy implications

In their pioneering work on open innovation and policy, de Jong et al. (2010) identified seven policy areas where open innovation issues should be incorporated into public decision-making processes: R&D spending, collaborative innovation, entrepreneurship, science, education, labor market, and competition policies. From a policy perspective, our study offers a potential implication fundamentally tied to collaborative innovation. Policymakers need to understand how to stimulate formal collaboration, a key element of open innovation, and especially which aspects are pivotal for the innovation collaboration to succeed. We identified passion as a key performance indicator that has persistently been under-investigated and overlooked dimension in research on open innovation research and innovation policy. Thus, we call for more research on how passion serves as a driving force and a stimulant of intrinsic motivation. Studies by Venkatesh (1999) and Frey et al. (2011) address intrinsic motivation in open innovation but do not explicitly focus on passion. Harmonious passion closely aligns with intrinsic motivation, as it involves engaging in activities driven by genuine interest and personal satisfaction. The literature could also explore how passionate individuals are more likely to experience flow and deep engagement in their activities, ultimately fostering higher levels of intrinsic motivation. Moreover, future research could explore how passion enhances well-being, performance, and persistence—key outcomes associated with intrinsic motivation. Additionally, we encourage studies that apply the mathematical model in emerging areas where living labs are currently expanding, such as the metaverse, space business, quantum computing, and autonomous solutions.

While research on innovation policy has increasingly acknowledged the important roles of interaction, collaboration, and market relationships for successful innovation (Jugend et al., 2020), policymakers and researchers have neglected the role of the organizational dimensions (cf. Pustovrh et al., 2020) and other challenges experienced at an organizational level (de Marco et al., 2020). We suggest that policymakers need to find measures for stimulating passion in open innovation. Such measures may be based on the stability of funding (e.g., a long-term perspective of 5-10 years) or the endorsement of linkages with actors. For instance, Pustovrh et al. (2020) argue that creating systematic approaches to linking groups of partners in an ecosystem is crucial for its success.

Policymakers can support open innovation by fostering connections with actors outside existing networks, such as investors, accelerators, multinational corporation (MNCs), research institutions, entrepreneurs, and the public sector. In addition, few previous studies have discussed how innovation policies can effectively increase innovation collaboration among different actors (cf. Leckel et al., 2020). Our study adds to this aspect by contributing novel open innovation practices and defining those elements that are regarded as important by firms actively involved in innovation endeavours. We also introduce the notion that there is an optimal number of innovation actors if an innovation endeavour is to retain the actors' passion; this is a factor that policymakers should take into consideration. Innovation ecosystems or platforms that are too large may not bring the expected results unless the innovating firm is very dedicated to reaching its goals. We thus call for more focus on organization and network level issues to form effective and purposeful innovation policies.

6.4 Limitations

Every study has its limitations. We acknowledge that the data was collected a decade ago. However, the fundamental principles and key characteristics identified in our study remain relevant in the current living lab literature. Additionally, we have supplemented recent literature and findings to ensure that our conclusions reflect current innovation outcomes. The fundamental concepts in living lab literature remain consistent, even as living labs have expanded into new areas. When returning to datasets collected several years ago, researchers may find that there is a need for different background information. We did not identify such a need in this paper as the data was collected meticulously. In addition, as the data was originally collected by the authors of this paper there was no risk of 'secondary analysis' (recontextualization and reconstructing data), as described by McAllister (2018). We regard the data relevant and useful to the current research objective and research questions. Furthermore, the passage of time has also allowed us to assess the innovation outcome more accurately and conduct follow-up on the impact of the innovation activities. Hence, the innovation outcome of the studied living labs is not only dependent on the views of the informants, but also on archival data documenting the outcome and its long-term impact.

We applied a holistic approach to studying innovation outcomes rather than differentiating between the phases leading to the outcome. In contrast to this approach, De Felice and Petrillo (2013) argue that innovation should be examined based on the different phases in the process. Therefore, we suggest that future studies include a detailed examination of the innovation process phases themselves. While we have focused on analyzing ex-post rather than ex-ante living lab activities, researchers such as Dziallas and Blind (2019) call for processual analysis of both ex-post and ex-ante living labs. In addition, research focused on knowledge flow between stakeholders in living labs could enhance our understanding of open innovation networks. Similarly, studying how a shared spirit can be fostered or hindered in potentially time- and resource-intensive innovation endeavours would provide valuable insights.

An important limitation of the regression analysis is that it is not a causal analysis but rather an assessment analysis. The goal therefore is to develop a mathematical formula for making informed assessments about the innovation outcome variables, based on the observed values of the variables. In causal analyses, the variables are regarded as causes of the outcome variables. Establishing causal relationships is much more complex and requires making sign significant assumptions that are not applicable to our dataset. Since we are not conducting a causal analysis, we cannot interpret the coefficients of the variables as causal effects on the outcome variable.

The variables in our regression equation are ordinal variables, where we have given the variables a score from 1 (nonsignificant) to 5 (very significant), and the outcome variable O a score from 1 (trial not conducted) to 5 (novelty innovation in global development). Ordinal variables are less suitable for a linear regression than variables on an interval scale, as we assume that an increase of one unit on the scales means the same no matter where we start (Allison, 1999).

It is important to note that our study is based on limited data from 26 cases covering a limited time. Therefore, future research could include a larger longitudinal data set consisting of multiple innovation examples (also including radical innovations). However, our observations regarding radical innovations align with existing studies on living labs, indicating that such innovations are rare (cf. Hossain et al., 2019). We identified only one example of a globally developed novelty innovation. Further, our study, although based on a limited number of cases, identified an inverted

U-shaped relationship between the number of participants and passion. We thus call for further research making use of large data sets to replicate and confirm this relationship between passion and the number of participants in innovation activities.

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Appendix A: Overview of living lab cases and variables

Living lab case	Country	Living lab context	Informant position (n=136)	Driven by	S	P	n	K	R	O
Case 1	Finland	Development of new digital services	Project manager	Utilizer	4	2	5	4	2	1
Case 2	Finland	Development of products and services that enhance welfare	Project manager	Utilizer	5	4	10	4	3	4
Case 3	Finland	Concept development for digital payment services within health care	CEO	Utilizer	1	2	5	2	2	1
Case 4	Finland	Concept and service development of media services in user home environments	Business development manager	Utilizer	3	3	10	4	2	2
Case 5	Finland	Development of product and service innovation processes, with a focus on client and end-customer collaboration	CEO	Utilizer	5	3	5	4	3	3
Case 6	Finland	Development of mobile ticketing services in public transportation	Business area director, consultant, usability expert	Utilizer	4	4	16	4	3	3
Case 7	Finland	Development of mobile gadget services based on augmented reality	Director, research director, project manager (1, 2), senior market analyst, chief evangelist	Utilizer	5	4	30	5	3	5
Case 8	Finland	Development of services and service concepts for an electric car	Project developer (member of the user community)	User	4	4	20	4	1	3

Living lab case	Country	Living lab context	Informant position (n=136)	Driven by	S	P	n	K	R	O
Case 9	Sweden	Empowerment and support of communities, including marginalized individuals such as immigrants	Living labs manager	User	3	5	45	4	2	3
Case 10	South Africa	Services for developing countries with a focus on areas of social disadvantage	Director, project manager, social entrepreneur, user developer (1, 2, 3), user (1, 3, 4, 5)	User	4	5	26	2	1	2
Case 11	Finland	Development of the intersection of physical, virtual, and social space in urban areas	Professor, head of product category	Provider	4	4	22	5	3	4
Case 12	Finland	Usability studies and the integration of digital services and products in student curricula	Principal lecturer (1, 2), student	Provider	4	3	23	4	2	2
Case 13	Finland	Learning environment for the development of restaurant services, products, and concepts	Director, director for education, research director, principal, development manager, (1, 2), principal lecturer (1, 2), restaurant manager, kitchen manager, trainee supervisor (1, 2, 3)	Provider	4	3	115	3	2	3
Case 14	Spain	Support for the creation of new living labs, including their architectures and methods	Project manager, research scientist (1, 2)	Ptovider	5	3	10	4	3	3

Living lab case	Country	Living lab context	Informant position (n=136)	Driven by	S	P	n	K	R	O
Case 15	Finland	Digital services and digital service development processes	Professor	Provider	5	3	50	4	3	4
Case 16	Finland	Retail business (future services), electronic and mobile business (prototypes, concepts)	CEO (1, 2), business area director, development manager, principal lecturer (1, 2, 3), consultant, user expert (1, 2, 3, 4, 5, 6)	Provider	3	4	48	4	3	3
Case 17	Finland	Focus on wireless technology and related services	CEO, CTO, director, marketing manager, project manager	Provider	4	3	30	5	3	3
Case 18	Finland	Ideas and concepts for service and product development with time and space constraints, such as the duration of a long-distance train ride	PhD student, student	Provider	3	5	16	3	2	3
Case 19	Finland	Development of future learning environments	Principal	Provider	4	4	50	3	3	3
Case 20	Finland	Wellness-TV, including service concepts and services for the elderly	Director, principal lecturer, project worker, student	Provider	5	4	20	4	3	4
Case 21	Spain	New communication and information technologies for a medical center (proof of concept and social space for research) to enhance community members' well-being	Project manager, research scientist (1, 2)	Enabler	5	4	30	4	3	4

Living lab case	Country	Living lab context	Informant position (n=136)	Driven by	S	P	n	K	R	O
Case 22	South Africa	Development of innovation skills and competences among businesses and individuals in developing countries, with a focus on private and public support services	Research director (Professor), program manager, project manager, principal researcher, PhD student,	Enabler	5	4	30	4	3	4
Case 23	Finland	Testing of health care products and services at a health center, including both customers and practitioners	Project manager, researcher, project coordinator, product test specialist	Enabler	5	3	14	4	3	3
Case 24	Spain	Agricultural services and products in rural areas, including manufacturing	Director, project manager	Enabler	5	4	50	3	3	3
Case 25	Spain	A location-based GPS system for monitoring rural livestock	Director, project manager	Enabler	5	4	23	3	3	3
Case 26	Finland	Metropolitan district development aiming at enabling communities to improve everyday life and activities	CEO (1, 2, 3, 4), business area director, research director, project manager (1, 2), researcher	Provider	4	4	60	4	2	3

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