Interactions between formal structures and knowing communities: What does open source community involvement mean?

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Abstract

The purpose of this paper is to study the interactions between formal structures and knowing communities and to show how formal structures can support external communities. Indeed, the literature reveals the critical role of external knowing communities for innovation. This research is based on a sequential mixed-method research design with a multi study sequential approach. Three studies are performed to analyze the interactions between IT formal structures and open source communities. Study 1 and study 3 are quantitative and rely on the same sample of 157 IT business managers. Study 2 is qualitative and is based on four managers of three formal structures deeply rooted in open source communities. These studies show that the use of open source within the formal structure has an impact on the three forms in which formal structures involve themselves in external knowing communities: formalized, result-oriented and inter-connected involvement. They also reveal the difficulties and possibilities of inter-connected involvement and highlight the central role of formalization in community involvement.

Keywords

Community involvement; knowing communities; open source use; formal structures; mixed-method research; PLS-SEM

Highlights

- Establishes three forms of involvement of formal structures in knowing communities
- Establishes that the use of open source affects each form of community involvement
- Reveals the central role of formalization in community involvement

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1 Introduction

Managing innovation is a key driver of the performance of organizations (West et al., 2014) and the management of knowing communities around formal structures is central to that process (Crespin-Mazet et al., 2019; Sarazin et al., 2017), especially in the fast development of IT organizations (Linåker et al., 2018). Most of the literature study qualitatively how formal structures provide support and are involved in external communities. Empirically, these researches mostly rely on case studies of a few successes (Dahlander et al., 2021, p. 2).

This paper focuses on the involvement of IT organizations in open source knowing communities and studies quantitatively and qualitatively how the use of Open Source by formal structures affects the different forms of interaction between these formal structures and external open source knowing communities.

Formal structures are organizations characterized by high levels in terms of rules, procedures, coordination and control mechanisms[1]. They have been studied from the very origins of organizational theory (Sine et al., 2006). Typical examples of formal structures are well established organizations that have become more structured over the years. In the IT industry, examples are small or big organizations that edit and/or integrate software, like Windows, IBM or Smile.

Knowing communities are informal networks where participants repeatedly interact, exchange and build knowledge (Goglio-Primard et al., 2020). They are "a voluntary association of actors, typically lacking an a priori common organizational affiliation (i.e., not working for the same firm) but united by a shared goal - in this case, creating, adapting, adopting or disseminating innovations" (West & Lakhani, 2008, p. 224). These communities can be compared with communities of practices (Wenger & Wenger-Trayner, 2020) and can evolve within, across or outside the boundaries of formal structures. We define open source communities as groups involving "software developers at many locations and organizations sharing code to develop and refine software programs" (Lerner & Tirole, 2002, p.197). They are an exemplary case of external knowing communities.

Formal structures work more and more with external innovation communities (Bogers et al., 2019; Sarazin et al., 2017). The main reason for interacting with such open communities is to contribute or/and benefit from the innovations developed in the community. Empirical studies highlight the importance of these external knowing communities in the process of creation and innovation within formal structures (Cohendet, et al., 2008; Crespin-Mazet et al., 2019). However, recent studies have insisted on their difficult cooperation (Wolf & Bernhart, 2022; Ciesielska & Westenholz, 2016; Lauritzen & Karafyllia, 2019), because of specific and new forms of interorganizational relationships. How to implement responsive collaboration practices remains unclear (Germonprez et al., 2017). Moreover, Drees & Hengens (2013) emphasize the need to extend the theory of resource dependence by exploring all the different forms of interorganizational arrangements that can have an impact for formal structures to reduce

[1] APA Dictionary of Psychology, https://dictionary.apa.org/formal-organizational-structure (last visited 2022-05-30).

their dependence and exercise some control over their direct environment. Participating in knowing communities may allow them for greater stability in their resource exchanges. It could also lead them to adapt their management practices to foster the emergence of these knowing communities, benefit from them and contribute to their innovation potential (Harvey et al., 2015).

The research gap is based on three considerations.

First, sharing innovation with communities is so far more studied from the point of view of the community than the one of formal structures (Kim et al., 2022). Besides, existing research on the interactions between formal structures and open source communities has qualitatively highlighted different forms of involvement for these formal structures in open source communities. This research has so far focused mainly on case studies. The different forms of categorizations proposed according to the cases studied do not allow ~~us~~ to identify a unified structure of forms of involvement, quantitatively validated at the level of the industry itself.

Second, researchers have identified a variety of categorizations that all combine aspects of use of open source software and aspects of community involvement, but differ in terms of the number of dimensions and characteristics. There is no consensus regarding the categories of community involvement and how they relate to the use of open source within formal structures. Scholars also disagree on categorizations regarding the highest level of community involvement (Ciesielska & Westenholz, 2016). In this respect, we examine the various categories of community involvement and how they can be achieved.

Last, there is a lack of knowledge about the internal adaptations needed to work with these external knowing communities. Indeed, "more concrete propositions for how the parties can implement such responsive reflection are still missing" (Wolf & Bernhardt, 2022, p. 351). By internal adaptations we mean the implementation of formalized methods, processes and tools.

We adopted a sequential mixed research design with a multi study sequential approach. Three studies are performed in order to analyze the interactions between IT formal structures and open source communities. Study 1 and study 3 are quantitative. They rely on a sample of 157 IT business managers and use structural equation modelling. Study 2 is qualitative and rely on interviews of four top managers working in three formal structures deeply rooted in open source communities.

Three main contributions on interactions between formal structures and knowing communities are suggested. Our first contribution is to add clarity on existing categorizations and on how they are associated with the use of open source within formal structures. Our second contribution is to shed light on the most advanced levels of community involvement, showing the difficulty for formal structures to be inter-connected with all the communities they work with. It also reveals the critical role of formalization to ease an inter-connected approach with communities, highlighting boundary practices boosting innovation. Our third contribution is to confirm the fact that organizations need to formalize their involvement with the knowing communities by using some boundary objects, to be inter-connected with the ones on which they depend, thus extending the findings of Ciesielska & Westenholz (2016).

The paper is structured in 4 main sections. In section 2, the literature presents the state of the art related to formal structure involvement in external communities by focusing on the involvement of IT organizations in open source knowing communities. In section 3, the research design, the hypothesis development and the data collection are presented for our three studies. In section 4 we present the findings of each study and in section 5, we discuss our theoretical and managerial contributions.

2 Formal structure involvement in external communities

Knowing communities are creative informal networks that interact and exchange knowledge to foster creation and innovation (Goglio-Primard et al., 2020). They are made up of individuals who belong to various entities and are willing to connect and produce new knowledge together. As an object of research, they have received various names such as "innovation communities, knowledge producing communities, online communities, scientific communities, technical communities, user communities, virtual communities or communities of practice" (West & Lakhani, 2008, p. 224) or even "grassroots communities" (Wolf & Bernhart, 2022). These communities play an active role in the innovation process by contributing at various levels: capitalization of good practices, problem solving or development of new ideas (Cohendet et al., 2008; Crespin-Mazet et al., 2019; Goglio-Primard & Soulier, 2018). Among these different categories of communities, we focus on innovation communities outside the boundaries of formal structures.

Formal structures have long used a closed way of performing innovation but, nowadays, open innovation has become very popular (Bogers et al., 2019). The question of sharing innovation with communities was theorized (West et al., 2014) but mainly studied from the point of view of the communities rather than from the point of view of the formal structures (Kim et al., 2022). Moreover, the interactions have often been studied for a formal structure with "its" knowing community: Schneider-Electric, Decathlon, Ubisoft, etc. (Goglio-Primard & Soulier, 2018). They are less understood for formal structures interacting with several external knowing communities. Therefore, there is a need for research focusing on the interactions between a formal structure and knowing communities from the perspective of the formal structure.

The open source movement is a good example of formal structures interacting with several external knowing communities. Open source appeared in the software industry in the early 1980s and is a new organization structure that involves "developers at many locations and organizations sharing code to develop and refine [software] programs" (Lerner & Tirole, 2002, p. 197). At first a community-based software development movement (West & Gallagher, 2006), it has "reshaped the ways how software-intensive firms develop products and deliver value to customers" (Linåker et al., 2018). Well-known formal structures like Apple, Google, IBM or Microsoft use open source components and therefore cooperate through diverse manners with open source communities (Bogers et al., 2019; Dahlander et al., 2021; West & Gallagher, 2006). However, recent cases between AWS and Elasticsearch[2] or with mongoDB[3] highlight that interactions between a formal structure and knowing communities are sometimes difficult (Lauritzen & Karafyllia, 2019; Wolf & Bernhart, 2022).

Numerous scholars have studied formal structure involvement in open source communities. Most of them have created categorizations that mix dimensions on internal use of open source and dimensions on community involvement (Ciesielska & Westenholz, 2016; Grand et al., 2004; Hauge et al., 2010; Link et al., 2017; Lundell et al., 2017). Fewer authors have concentrated either on the internal use of open source (Marsan et al., 2012; Stol et al., 2011) or on community involvement (Dahlander & Magnusson, 2008; Germonprez et al., 2017; Morgan et al., 2013; Schaarschmidt et al., 2015). Lastly a few authors have created categorizations on

[2] https://www.lemondeinformatique.fr/actualites/lire-le-changement-de-licence-chez-elastic-fait-debat-81685.html (Last visited 2021-02-24)

[3] https://www.lemagit.fr/actualites/252450928/MongoDB-une-nouvelle-licence-open-source-pour-eviter-les-abus-des-fournisseurs-de-Saas (Last visited 2022-09-08); https://www.zdnet.com/article/mongodb-open-source-server-side-public-license-rejected/ (Last visited 2022-09-08)

community involvement as part of business model components (Lisein et al., 2009; Mouakhar & Tellier, 2017; Sims & Seidel, 2016; Stam, 2009). As each of these categorizations has their own coding structure, we chose to separate the use of open source from the community involvement and to "over-code" all categories to be able to compare them. For the sake of simplicity, first we will present the internal use of open source (1) and then community involvement (2).

(1) A large range of internal use of open source have been studied (Ciesielska & Westenholz, 2016; Grand et al., 2004; Hauge et al., 2010; Link et al., 2017; Lundell et al., 2017; Marsan et al., 2012; Stol et al., 2011). In order to characterize this internal use of what is created by external knowing communities, we have determined the following "over-codes": "end user", "use rules", "use components", "use methods" and "use tools". The use of open source means the use as an end user, but also more specifically the use of open source rules, tools, methods and components. Table 1 describes these modes of use of open source.

Table 1 - How formal structures use open source

Our coding	Description	Authors
End user	Use open source software for internal use, final user	Grand et al., 2004; Hauge et al., 2010; Link et al., 2017
Use rules	Use rules to make open source compatible with software practices inside organizations	Marsan et al., 2012
Use tools	Use open source development tools	Hauge et al., 2010; Link et al., 2017; Lundell et al., 2017; Stol et al., 2011
Use methods	Use open source methods, "inner source" software development practices	Ciesielska & Westenholz, 2016; Hauge et al., 2010; Link et al., 2017; Lundell et al., 2017; Stol et al., 2011
Use components	Use and integrate open source components in software offers and systems. Open source software as a complementary asset	Grand et al., 2004; Hauge et al., 2010; Link et al., 2017; Lundell et al., 2017; Stol et al., 2011

(2) Several categorizations for community involvement have been identified (Ciesielska & Westenholz, 2016; Dahlander & Magnusson, 2008; Germonprez et al., 2017; Grand et al., 2004; Hauge et al., 2010; Lerner & Tirole, 2002; Lisein et al., 2009; Lundell et al., 2017; Morgan et al., 2013; Mouakhar & Tellier, 2017; Schaarschmidt et al., 2015; Sims & Seidel, 2016; Stam, 2009; Stol et al., 2011). Some of these categorizations aim at graduating formal structure involvement in open source communities (Ciesielska & Westenholz, 2016; Grand et al., 2004). They describe formal structures, ranging from a simple use of open source to a use coupled with an increasingly deep involvement in open source communities. Other categorizations (Dahlander & Magnusson, 2008; Germonprez et al., 2017; Morgan et al., 2013) differentiate two to four categories, from opportunistic formal structures to deeply embedded formal structures.

As each of these categorizations has their own coding structure, we have determined the following "over-codes": "community consumer", "community formalize and settle rules", "community lead and influence"; "community participate and contribute". We decided to remove the category "community consumer" because it describes formal structures that do not get involved at all with open source communities. We have obtained a list of three dimensions for community involvement, that are described in table 2. Formal structures could have either a formalized involvement where they formalize and settle property rules, a result-oriented

involvement where they try to lead and influence communities, or, lastly, an inter-connected involvement where they actively participate and contribute to communities.

Table 2 - How formal structures get involved in open source knowing communities

Our coding	Involvement	Description	Authors
Formalize, settle rules	***Formalized***	Set rules to codify how to manage engagement with communities, how to pay employees for time spent in communities and how to foster contributions Create and lead open source software projects and communities	Ciesielska & Westenholz, 2016; Germonprez et al., 2017; Sims & Seidel, 2016; Schaarschmidt et al., 2015
Lead, influence communities	***Result-Oriented***	Seek to develop leadership and resource control towards communities, in order to get recognition, to influence direction of development or to hire project leaders from communities Foster employees to contribute to communities Ask help from communities	Ciesielska & Westenholz, 2016; Dahlander & Magnusson, 2008; Germonprez et al., 2017; Link et al., 2017; Lisein et al., 2009; Mouakhar & Tellier, 2017; Schaarschmidt et al., 2015; Sims & Seidel, 2016
Participate, contribute to communities	***Inter-connected***	Participate in Open Source projects led by communities, provide feedback and code to the community, support project Understand the co-management functioning of communities, reciprocity - "Gift/counter gift" values Let employees participate to communities Provide help to fellow partners inside community consortiums	Ciesielska & Westenholz, 2016; Germonprez et al., 2017; Grand et al., 2004; Hauge et al., 2010; Lerner & Tirole, 2002; Lisein et al., 2009; Lundell et al., 2017; Morgan et al., 2013; Mouakhar & Tellier, 2017; Stam, 2009; Sims & Seidel, 2016; Stol et al., 2011

Literature reveals that categorizations for community involvement are fragile. Nevertheless, they all agree that involvement in open source knowing communities is associated with the use of open source within formal structures. This link between use and involvement is also suggested by previous research on the learning path to understanding open source communities (Nagle, 2018; Shaikh & Levina, 2019).

We will now present the overall research design and the three studies that comprise this research.

3 Research Design, hypothesis development and data collection

3.1 General design: a mixed-method research with a multi study sequential approach

Knowledge on the functioning of knowing communities is still developing and proposes a variety of approaches and viewpoints. Following the rationale proposed by Reilly and Jones (2017), we both need to test relationships between some variables through quantitative research and to deepen these results by giving them more meaning through qualitative research.

Therefore, this research uses a mixed-method approach. The aim is to create a holistic picture of the phenomenon by combining strengths of different qualitative and quantitative research methods (Täuscher & Laudien, 2018, p. 322). The research adopts a sequential design, mixing an explanatory research design and an exploratory sequential design (See figure 1 in Reilly & Jones, 2017, p. 188). This multi-study sequential approach increases the accuracy of the results and provides a comprehensive picture of an exploratory phenomenon by combining different collection methods for a coherent set of ideas (Beck et al., 2020; Bezzina et al., 2017; Creswell, 2014; Täuscher & Laudien, 2018).

In study 1, we performed a quantitative analysis in order to develop and validate our scales and test the effect of the use of open source on community involvement. In study 2, we participated to professional meetings with open source general managers and we interviewed four top managers that were working in formal structures, deeply involved in open source communities in an inter-connected form. We wanted to better understand the different categorizations, especially the most advanced categories of community involvement. In study 3, based on our qualitative results, we re-examined our quantitative data of study 1. The objective was to explore the central role of formalization in community involvement and possibly identify steps in the involvement of open source communities. The research design is summarized in table 3.

Table 3 - Sequential mixed-method research design

Research question	Study	Approach	Objective	Data and methods
What does it mean to be involved in external communities and how does the use of open source affect this involvement?	Study 1	Quantitative	Develop and validate the scales and test the effect of the use of open source on community involvement	Data set: 157 business managers Scales: Exploratory and confirmatory factor analyses Test of the relations: Structural equation modeling – PLS-SEM approach
	Study 2	Qualitative	Examine the most advanced categories of community involvement	Analysis of 3 formal structures deeply rooted in open source communities with inter-connected involvement: 4 semi-directive interviews with IT managers Participation to professional meetings and secondary data Content Analysis
	Study 3	Quantitative	Explore the central role of formalization in community involvement	Same data set and scales as study 1 Exploration of the mediation of formalized involvement by using structural equation modeling - PLS-SEM approach

3.2 Study 1- Hypotheses development and quantitative data collection

3.2.1 Hypotheses development

The central hypothesis of the research is that formal structures tend to involve more in open source knowing communities when increasing their internal use of open source. This central hypothesis relies on the conceptual background presented earlier. We summarize here our conclusions and arguments for that hypothesis development:

This relationship has been suggested by several researchers (Ciesielska & Westenholz, 2016; Grand et al., 2004; Lisein et al. 2009; Nagle, 2018; Shaikh & Levina, 2019). They all consider levels or steps in the use of open source, the involvement in communities coming after the simple use of open source. In their scale for open source adoption, Grand et al. (2004) explained that "at level 1, the firm is primarily a user rather than a developer", whereas at level 4, "firms must contribute significantly to open source software" (Grand et al., 2004, p.596-599), meaning that they must involve in open source communities on a regular and long-term basis. Ciesielska & Westenholz (2016, p.347) have had a similar but more detailed approach, with six steps going from using open source software to becoming inter-connected members of open source software communities. Lastly, Lisein et al. (2009, p.23) described one level of pure-sufficiency and three levels of community involvement. These authors suggest that the use of open source by the formal structure is a first step before being involved in knowing communities but they do not state it clearly as they do not conceptually distinguish them. In this research we separate the use of open source from the involvement in knowing communities, to propose measurement scales for each and to distinguish three forms of involvement, all of this at the theoretical and empirical levels. As for Nagle (2018) and Shaikh & Levina (2019), they establish a learning path to understanding open source communities, that is a positive link between the use and the involvement, but they do not separate different forms of involvement.

Our literature review shows that there is a variety of interactions between formal structures and knowing communities and that the categorizations are fragile. We conceptually classified community involvement into three dimensions (see table 2) as follows: formal structures tend to domesticate communities by formalizing their involvement through a "formalized" involvement (a); formal structures have also an opportunistic attitude that we call "result-oriented involvement" (b); lastly, they can be more engaged within communities, which we call an "inter-connected involvement" (c).

Our hypothesis that the more formal structures use open source, the more they get involved in open source communities is subdivided into three as follows:

H1: The more formal structures use open source, the more they involve with communities through a "formalized involvement" (H1a), a "result-oriented involvement" (H1b) and an "inter-connected involvement" (H1c).

3.2.2 Quantitative data collection

In order to look at categories of community involvement more specifically and to study their more advanced categories, we sought to work with mature communities. The criteria for determining the maturity of a community relate to experience and expertise in working with open source and in being used to work with a variety of stakeholders.

50 years after the invention of open source, today all formal structures from the IT sector use open source components and interact with open source communities in a way or another. In 2021, 78% of the 2400 businesses surveyed by the Synopsis software company acknowledged that their commercial codebase was based on open source[4]. Collaborative tools like StackOverflow or referencement platforms like GitHub or SourceForge have enabled an exponential development of open source projects and communities. The platform for collabora-

[4] https://www.synopsys.com/content/dam/synopsys/sig-assets/reports/rep-ossra-2022.pdf (last visited 2022-08-23)

tive support StackOverflow has 4 million developer users and 11 million answered questions[5]. The GitHub platform has 31 million developers in 2019[6]; the most popular project on GitHub received 24202 contributions in 2020, and the 10th project received 9030[7]. Open source communities are now mature, and formal structures are used to interacting with them. Therefore, the IT sector is perfectly adapted to study the interactions between formal structures and external open source knowing communities.

We performed a survey in France together with IT main professional associations (CNLL, Paris Open source Summit, Syntec Numerique, Cigref, Systematic Paris cluster) in 2017-2018. Respondents were formal structures editing and deploying open source software. Both editors and service providers make similar license choices, have similar values and propose similar services. Therefore, it is better to study them as a whole (Bonaccorsi et al., 2006). The survey was performed online and sent to all members of the IT French professional associations in October 2017.

157 business managers, being specifically editors and/or service providers of open source offers, answered to the survey. Respondents were either executives or IT managers of the formal structures (Appendix A). We removed respondents that did not answer all the questionnaire, as well as outliers, either based on the absence of variance in their responses or on the Mahalanobis distance. After removing these missing data and outliers, we obtained a final sample of 126 open source editors and service providers.

To assess our measures and structural model, as our sample is relatively small and our approach is exploratory, we used PLS-SEM approach with SmartPLS4 (Hair et al., 2019). PLS-SEM method is based on variance and a partial least square algorithm. It is particularly recommended for "unobservable and abstract constructs and reflects a more holistic and less overtly causal interpretation of real-world phenomena representing social interactions and artifacts." (Massaro, Dumay, & Bagnoli, 2015, p. 498, cited in Cegarra-Navarro et al., 2020).

3.3 Study 2 - Research question, qualitative data collection and analysis

3.3.1 Research question

There is a lack of agreement on the most advanced categories of community involvement. Indeed, literature reveals that scales disagree on the ultimate levels. For instance, the “visible hand” highest level of Lisein is equivalent to the level 4 “companies leading open source software projects” in Ciesielska & Westenholz (2016) scale. Moreover, their level 6 “inter-connected members of open source software communities” is equivalent to level 2 “invisible hand inter-connected” in Lisein et al. (2009) scale.

Facing this situation, we decided to perform a second study. The objective is to enhance our knowledge in the different categorizations and in particular to understand why in some cases the “inter-connected” involvement is considered as the ultimate level (Ciesielska & Westenholz, 2016), and why the “formalized” involvement is the ultimate level in other scales

[5] https://en.wikipedia.org/wiki/Stack_Overflow (Last visited 2021/02/24)

[6] https://itsocial.fr/enjeux/production/developpements/100-millions-de-repositories-confirment-lattrait-github-lopen-source/ (2018-11-13, last visited 2021/02/24)

[7] https://kamranahmed.info/githunt/ (Last visited 2021/03/02, data based on a whole year from 2020-03-02 to 2021-03-02)

(Lisein et al., 2009). Inter-connected involvement is the most documented and theorized category of open source involvement so far (Ciesielska & Westenholz, 2016; Germonprez et al., 2017; Hauge et al., 2010; Lerner & Tirole, 2002; Lisein et al., 2009; Lundell et al., 2017; Morgan et al., 2013; Mouakhar & Tellier, 2017; Sims & Seidel, 2016; Stam, 2009; Stol et al., 2011). However, it appears at the highest level in the scales of involvement. That's why we focused on inter-connected involvement, to understand why it is a "graal" and not yet a common reality.

3.3.2 Qualitative data collection and analysis

The qualitative study consists in case studies with three formal structures involved in professional open source associations, in open source knowing communities and respectful of the open source values (see table 4). These formal structures are characterized by an inter-connected involvement.

We performed semi-directive interviews with their general managers and new product development managers, insisting on their interactions with open source knowing communities. In addition, we collected secondary data to learn about their offers, their activities and their community and professional association involvements. We also participated into professional meetings and read professional press about open source management to get a global view of the current challenges at field level.

Table 4 - Three case studies of formal structures involved in open source communities

	Characteristics of the formal structure	**People interviewed**
Firm 1	Created in 2012 by an experienced person in open source development, this firm is an editor of free applications for collaborative management, dedicated to competitiveness clusters and universities. In 2018 they had 5 employees and 4 BtoB customers. Research and development represented 50% of sales and was funded by national or European subventions. They chose the L-GPL license for their products, in between permissive and restrictive licenses. They have their own community of 4 contributors in 2018. The founder has been actively involved in several professional open source associations for twenty years.	Founder of the formal structure
Firm 2	Created in 1991, this firm concentrated on open source in 2001. In 2018, it was the first European open source service provider, leader of open digital solutions. 65% of their activity is based on digital platforms, the rest is based on business apps, infrastructure and embedded IoT. They have published 35 white books on open source, with more than 100,000 downloadings per year. In 2018, there were 900 employees in France and 300 in other countries (Luxembourg, Switzerland, Netherlands, Morocco, Ukraine, …). They participate to numerous events to foster open source.	General manager of the firm
Firm 3	Created in 2006, by aggregating small formal structures. In 2015, they partnered with a bigger group. In 2017, they had 150 employees and sales amounted to 15 million euros. Their two main activities are developing web platforms and housing and maintaining computer activities. They have been participating in R&D projects to finance their innovation since 2007. The founders of the formal structure are actively involved in several professional open source associations.	Founder of the firm + R&D innovation manager

We performed a content analysis using the open source qualitative thematic analysis RQDA[8] in R (Chandra & Shang, 2017). To ensure data accuracy, we offered the transcript back to the interviewers for review (Smith et al., 2018). Altogether, interviews amount to 41964 words. We coded all answers following the dimensions identified for our scales (see Table 2) to understand how managers from inter-connected formal structures think and behave. We triangulated our interviews with information coming from business meetings with open source managers and from professional press, in order to check our construct validity.

3.3 Study 3 - Reframing study 1 results based on study 2 results

After quantitatively exploring how formal structures interact with knowing communities, the qualitative interviews have allowed us to enhance our knowledge in the interaction mechanisms with these communities. The interviews highlighted various tools, practices and mechanisms of interaction between formal structures and several communities. This research design is inspired from Bezzina et al. (2017) in trying to understand how managers interpret our quantitative results and how they assess the different forms of interactions between several knowing communities.

Study 3 adds a step to our approach by testing, with the initial data set, a new model built after the qualitative phase. In this new model we position formalized involvement in knowing communities as a mediator between the use of open source and the two other forms of involvement. As Beck et al. (2020), we build a new hypothesis based on our qualitative results and justify our hypothesis in the finding section of study 3.

4 Findings

This section presents the findings of the three studies.

4.1 Study 1 findings - The link between use of open source and community involvement

We first developed scales and assessed the measurement model. Then, we assessed the structural model.

4.1.1 Scale development, EFA and Measurement model assessment

We followed the Churchill paradigm to create and validate our measurement scales (Churchill, 1979; MacKenzie et al., 2011). For the scale development, our primary challenge is to separate the use of open source from the community involvement as they are most often mixed in the literature. We therefore created two separate scales based on literature review (see tables 1 and 2), and we transformed the scales into items through exploratory research with six managerial and academic experts. We presented the items to the IT main professional associations to make sure they represented the intended meaning. We tested the items of both

[8] HUANG Ronggui (2016). RQDA R-based Qualitative Data Analysis. R package version 0.2-8. http://rqda.r-forge.r-project.org/

scales on members of open source professional associations and slightly modified some items afterwards.

The comprehensive measure for formal structure use of open source includes six items. For formal structure community involvement, we use 17 items. All our questions are 5-point Likert assertions.

We performed an exploratory factor analysis (EFA) with R software to identify the dimensions of the scales and assess how much each item is useful to explain each dimension, then purified our scales for the use of open source and for community involvement. We estimated the optimal dimensions amount for our two scales, by using the eigenvalue test, the "scree" test and the minimum restitution test. It is advised to stop extracting when 60% of the explained variance has been extracted (Hair et al., 2006). We performed several rounds for each scale using Varimax rotations. We removed items, one after another, if they had a communality lower than 0.5, if they loaded on several factors or if their loadings were too small. The communalities and loadings of the exploratory factor analysis after scale purifications is presented in Appendix B.

One factor was identified for the independent variable "Formal use of open source". This factor represents 64% of the total variance and includes four items. The formal structure use of open source refers to a use of open source components, methods, rules and tools.

Three dimensions were identified for formal structures community involvement, which represent three different inter-organizational arrangements. "Formalized involvement" represents 28% of the total variance consisting in four items describing formal structures that settle rules to ensure good coordination with various contributors and pay them fairly, adapt work contracts and values inside the formal structures. "Inter-connected involvement" accounts for 21% of the total variance and consists of two items describing organizations that are members of several communities and consortia and active contributors. "Result-oriented involvement" represents 21% of the total variance consisting in two items describing organizations that seek to influence community decisions and hire best contributors for their internal purposes. As a whole these three dimensions explain 70% of the total variance, which is satisfactory.

We assessed the reflective measurement model by following Hair et al. (2019) recommendations (see Appendices C and D). We examined the indicator loadings. Loadings above 0.708 are recommended, as they indicate that the construct explains more than 50 per cent of the indicator's variance, thus providing acceptable item reliability. We removed one item from our independent variable because of a value below 0.708. We also checked the internal consistency reliability by using Jöreskog's (1971) composite reliability. The composite reliability index ranged from 0.853 to 0.891. "Values between 0.70 and 0.90 range from "satisfactory to good" Hair et al. (2019, p.8). The reliability of the measuring scales was also verified through the Cronbach alpha coefficient, ranging from 0.701 to 0.744. A value greater than 0.7 is considered acceptable in the literature. Then, we checked the convergent validity of each construct measure. The average variance extracted (AVE) revealed that all the reflective constructs exceeded the 0.50 limit (Fornell & Larcker, 1981). At last, we evaluated and confirmed the discriminant validity of the measures (see appendix E) as suggested by Fornell & Larcker (1981). Discriminant validity was also assessed following the heterotrait monotrait (HTMT) criterion (Henseler et al., 2015). All HTMT values are lower than 0.85, indicating discriminant validity. Consequently, all the variables exhibited suitable discriminant validity. To conclude, the model has good convergent validity, reliability and discriminant validity.

4.1.2 Hypotheses and structural model-assessment

Our hypotheses proposed that the use of open source tools, methods and components implies a strong community involvement. To test our hypotheses, we controlled for organizational size (i.e., number of employees) and experience (i.e. personal experience of the respondent) in our analyses (Sims & Seidel, 2016).

The model showed sufficient model fit: The standardised root mean square residual was 0.076, which is in line with Hu and Bentler's (1998) criterion of a value lower than 0.08. P-values are all significant at 0.01 and R^2 evolve from 7.2% for "Inter-connected involvement", 10.7% for "Result-oriented involvement" to 30.4% for "Formalized involvement". All the results are presented in Table 5. As summarised in Table 5, we validate hypotheses H1a, H1b and H1c.

Table 5 - Results of the structural model for study 1 (H1a, H1b, H1c research hypotheses)

	Standardized Path Coefficients	**Standard deviation**	**t value**	**P-values**	**f^2 values**	**Confidence interval**	
						LL	**UL**
Use of open source → Open source community involvement							
H1a: Use of open source → Formalized involvement	0.561***	0.065	8.490	0.000	0.397	0.408	0.663
H1b: Use of open source → Result-oriented involvement	0.307***	0.086	3.476	0.001	0.092	0.097	0.445
H1c: Use of open source → Inter-connected involvement	0.263***	0.086	2.967	0.003	0.063	0.061	0.401
Nb Employees → Formalized involvement	0.301***	0.082	3.632	0.000	0.116	0.129	0.447
Nb Employees → Result-oriented involvement	0.205**	0.078	2.625	0.009	0.042	0.047	0.354
Nb Employees → Inter-connected involvement	0.166	0.093	1.747	0.081	0.026	-0.037	0.335
Personal Experience → Formalized involvement	0.020	0.095	0.211	0.833	0.001	-0.163	0.206
Personal Experience → Result-oriented involvement	0.052	0.092	0.557	0.577	0.007	-0.079	0.235
Personal Experience → Inter-connected involvement	0.085	0.080	1.051	0.293	0.003	-0.134	0.229
SRMR = 0.076 *Formalized involvement (R^2=30.4%); Result-oriented involvement (R^2=10.7%); Inter-connected involvement (R^2=7.2%)* *Note: ***p < 0.001 **p < 0.01 *p < 0.05 based on a Student's t(4999) distribution with one tail [t(0.05. 4999) - 1.645. t(0.01. 4999) - 2.327. t(0.001. 4999) - 3.092)].* *Bootstrapping based on n - 5.000 subsamples;*							

LL - Lower bias corrected bootstrap 95% confidence interval; 2.5%

UL- Upper bias corrected bootstrap 95% confidence interval 97.5%

The use of open source tools, methods and components has a strong positive and significant impact on the "formalized involvement" dimension (β=0.561. p=0.000). The use of open source tools, methods and components has a positive and significant impact on the "Result-oriented involvement" dimension (β=0.307. p=0.001). The use of open source tools, methods and components has a positive and significant impact on the "Inter-connected involvement" dimension (β=263. p=0.003). Therefore, the more formal structures use open source tools, methods and components, the more they take advantage of the open source environment in the sense that they get involved in open source knowing communities in three different inter-organizational arrangements. The most represented involvement is the formalized one. (see figure 1).

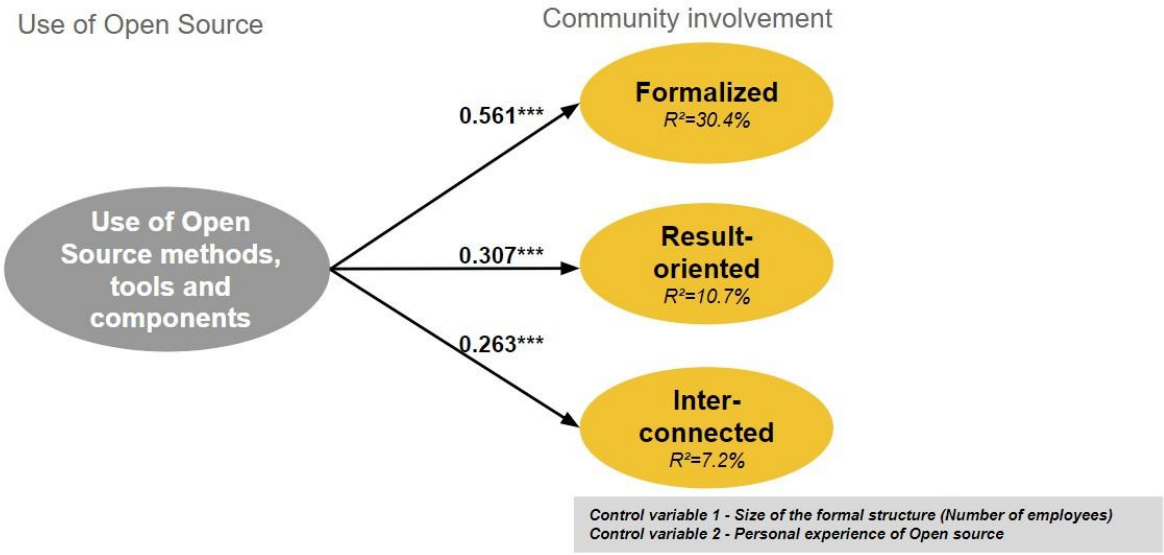

Figure 1 – Graphical representation of study 1 results (H1a, H1b and H1c hypotheses)

The results of this first study led us to deepen our research by focusing on the most advanced category of community involvement.

4.2 Findings of study 2 - In-depth look into the Inter-connected involvement

The second study clarified the most advanced categories of communities' involvement, that is the "inter-connected involvement", and how it can be achieved. This one is surprisingly little chosen by formal structures, even though the previous categorizations have all insisted on this implication as one of the most advanced, considering that there are different levels of involvement. We used characterizations of involvement to clarify what they mean for formal structures.

4.2.1 **Full inter-connection with communities appears to be a myth that can't really be achieved**

Concerning the use of open source tools and methods, the literature proposed that formal structures use open source as final users or get involved in communities. Our quantitative

study 1 demonstrated two facts: First that the use is "large", that is not an everyday use of open source software like LibreOffice or Mozilla, but rather a use of methods and tools; Second, that the inter-connected involvement is characterized by membership and contribution to external communities. The qualitative study enabled us to better understand the two fundamental aspects of this involvement, membership and contribution.

Concerning membership, formal structures explained that they are members of several communities, but not as many as the number of components they use. Our case studies highlight that it comes from the software itself. Formal structures can't create a software entirely on their own. They need to rely on many software projects to be able to build their own offers. Therefore, formal open source structures rely on many open source knowing communities, slowing down inter-connection.

> *"In our products, there are 20.000 or 30.000 lines of code that we wrote. and there are between 100.000 and one billion lines that we did not write, depending on the systems that we sell. (...) In a whole, there might be a ratio of 1 to 10 between what we created and what we integrated" (Firm1, manager 1).*

> *"Having a community is an important factor in choosing software, almost more important than the product itself. For example. yesterday I had to choose between two Python libraries: I checked the number of developers for each project in Github, the pace of development, who participates (Firm1, manager 1).*

Concerning contribution, interviewed managers explained that they help a few of these open source knowing communities when they have innovative value to add and give back to the project.

> *"We are integrators, so we carry out lots of innovating projects, but not only. If tomorrow, we are asked to set up a new website, we'll use Drupal, we will integrate code, and there's nothing new that will be interesting for the community. On the other side, when we work out something [new], our contribution is always open source" (Firm 2, manager 2).*

> *"Open source is the best, because it is accessible to everyone, it can be disseminated very quickly, it creates cross-cultural communities, collaborative work methods and collective intelligence, it will be a booster for digital innovation" (Firm 3, manager 3).*

> *"To me, rewarding the community is contributing. That's the real win-win of open source technology" (Firm 3, manager 4).*

By contribution, we mean providing infrastructure, helping the ecosystem as a whole by funding events, and even employing members of communities without giving them any order of what to do. In our case studies, the size of the firms appears to be a relevant criterion regarding contribution, differentiating Firm 1, a small firm participating from time to time when they find a bug on a component they want to use, and Firm 2, a major firm participating by providing a continuous expertise on the subject they tackle.

> *"I contribute a little to the Python community, by organizing Py-Paris conferences, by participating occasionally to discussions in the mailing lists on language evolution. On the other hand, we have a policy, which is normal but that some firms haven't and we say, that when we find a bug, we write a "bug report", when we have the correction, we write the patch, we will spend the time we need, [even if] we won't spend a week" (Firm 1, manager 1).*

> *"In all communities, in all products that we integrate, we are also contributors. For instance, perhaps three years ago, the Cultura firm asked to set up Magento. The problem was that Cultura had around four million products and Magento was unable to register so many products. Therefore, we edited Magento by the book, we replaced the Mysql database with a Nosql model of database, and we pushed it to the community. And if Magento today is being used by all large accounts, it is because three years ago, we pushed ahead the state of the art of Magento" (Firm 2, manager 2).*

Both have an inter-connected involvement with some open source knowing communities, but the extent of the support provided to the projects is different.

Therefore, in the three cases, it is impossible for formal organizations to work in full inter-connection with all communities they rely on. We confirm that the term "full inter-connection" is to be understood as a very high level of coordination and exchanges between actors in a knowing community.

4.2.2 Formalization can be considered as a pre-requisite to other implications, specifically inter-connected involvement.

The inter-connected managers we interviewed confirmed their use of various tools, either to organize contributions or to facilitate innovation by integrating various contributions on the run. This is corresponding to the description of the formalized involvement demonstrated by study 1: adapting work contracts and processes for internal and external contribution.

> *"Among our working tools, we have a guide that we published. it is called our developer guide. It is both an internal guide -in which we could include work hours- and a contributor guide to our projects*[9] *"(Firm 1, manager 1).*

> *"GitHub has proved a real revolution. There was a philosophy and a bunch of tools that were popularized and industrialized by GitHub about the way we co-work on code. GitHub, it works well in a closed context, but it also works in a context where people come and leave, have a bug, make a proposal. Tools like GitHub enable larger teams to make distributed development" (Firm 1, manager 1).*

These inter-connected managers specified that formalization should not be understood as bureaucracy, but rather as necessary governance rules that formal structures must implement to facilitate involvement without being too intrusive, the more so if they are creating and leading their own community.

> *"These are things that firms must do, it has nothing to do with bureaucracy, it is essential to work with open source communities" (Firm 1, manager 1, after our presentation of scales and structural modeling results).*

> *"For a cloud solution like mine, not having that [the GitHub organization space and this strong strategy of communication], is a death sentence, maybe it's a little romantic, it's really fun to say we made it open source, we had fun, but clearly it doesn't give the opportunity to be used by the community" (Firm 3. manager 4).*

In this way, managers referred to the specific mediating role of formalized involvement. According to them, formalization is a prerequisite to achieve inter-connected involvement. It takes time to recognize the innovating value potential, to learn how to interact with the knowing community, how to use the methods and tools to contribute.

> *"People start by using LibreOffice on their PC, and perhaps see some bits of Linux or Gimp, and they don't even realize that they're working with open source tools. And little by little, it spreads. They start understanding the value of it. It takes time. (...) It is an approach that goes towards innovation and that is extremely complicated to implement. I understand that those who do not have this in their genes find it extremely complicated. (...) If you're a Tech, you would like to contribute to Drupal, how do you proceed? The community codes, how you go, how you contribute, it has to be learned, to be transmitted, it is not enough to read a book on the subject." (Firm 2, manager 2)*

To conclude on our second study, the interviews first revealed that it is very difficult for formal structures in the IT industry to get inter-connected with all their communities they work with when they develop and maintain their products. Second, formalization appears to be necessary for formal structures to open paths for stronger involvement. In this respect, formalized

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[9] *This guide refers to the 2014 Contributor Covenant (https://www.contributor-covenant.org/version/1/4/code-of-conduct/). The Linux code of conduct is also based on it and now serves as reference for all communities (https://www.kernel.org/doc/html/latest/process/code-of-conduct.html).*

involvement could be considered as a prerequisite and a possible mediator for inter-connected involvement.

4.3 Findings of study 3 – Exploring formalized involvement as a mediator

We have decided to refine our model by testing quantitatively the possibility of the formalized involvement to act as a mediator in the initial model.

Indeed, Shaikh & Levina (2019) have shown the importance of a strong meritocratic governance based on clear rules in bringing companies and their communities together around common goals. Moreover Henkel et al., (2014) demonstrated the importance of the learning process in adopting open practices. These rules and engagement practices are also seen as enabling formal structures to gain influence on the communities (Linåker et al. 2019). A formalized involvement therefore could be a good entry point to communities. The mediation would correspond to the idea of a learning process enabling an inter-connected involvement as well as a result-oriented involvement. This means that a formalized involvement would provide the framework for inter-organizational relations between formal structures and external knowing communities. This framework would in turn allow formal structures to have an inter-connected or a result-oriented involvement with these knowing communities.

We formulate this through a new hypothesis subdivided in two:

H2: "Formalized involvement" with communities mediates the relationship between formal structure use of open source and both a "result-oriented" involvement (H2a) and an "inter-connected" involvement (H2b).

Table 6 and figure 2 present our findings. The model showed sufficient model fit and the R^2 values have increased, to range from 14.1% (Result-oriented involvement), 24.8% (Inter-connected involvement) to 30.4% (Formalized involvement).

All paths are significant, which tends to show that formalized involvement partially mediates the relationship between the use of open source and inter-connected involvement on the one hand and result-oriented involvement on the other hand. Considering "formalized involvement" as a mediator, the direct links "use of open source" to "result-oriented involvement" and to "inter-connected involvement" are still significant. "If the rank order of the constructs' relevance, when explaining a dependent construct in the structural model, differs when comparing the size of the path coefficients and the f^2 effect sizes, the researcher may report the f^2 effect size to explain the presence of, for example, partial or full mediation" (Hair et al., 2019, p. 11). Thus, we took the f^2 into account, in order to give a more accurate view of the mediation test.

Table 6 - Results of the structural model for study 2 (H2a, H2b mediation hypotheses)

Hypothesized paths	Standardized Path Coefficients	Standard deviation	t value	P-values	f^2 values	Confidence interval	
						LL	UL
Formalized involvement mediation in the relationship: Use of open source → Open source community involvement							
H1a: Use of open source → Formalized involvement	0.559***	0.067	8.229	0.000	0.395	0.401	0.667

H1b: Use of open source → Result-oriented involvement	0.303***	0.088	3.429	0.001	0.024	0.110	0.458
H1c: Use of open source → Inter-connected involvement	0.258***	0.086	2.921	0.004	0.001	0.071	0.407
Formalized involvement → Result-oriented involvement	0.227*	0.109	2.050	0.040	0.040	-0.020	0.411
Formalized involvement → Inter-connected involvement	0.506***	0.092	5.487	0.000	0.235	0.078	2.630
Nb Employees → Formalized involvement	0.300***	0.083	3.614	0.000	0.116	0.127	0.448
Nb Employees → Result-oriented involvement	0.203	0.078	2.630	0.009	0.000	0.005	0.157
Nb Employees → Inter-connected involvement	0.168	0.092	1.801	0.072	0.018	-0.020	0.343
Personal Experience → Formalized involvement	0.020	0.092	0.219	0.827	0.001	-0.156	0.198
Personal Experience → Result-oriented involvement	0.085	0.082	1.024	0.306	0.007	0.049	0.351
Personal Experience → Inter-connected involvement	0.051	0.089	0.584	0.560	0.002	-0.120	0.231
SRMR= 0.076 *Formalized involvement (R^2=30.4%); Result-oriented involvement (R^2=14.1%); Inter-connected involvement (R^2=24.8%)* *Note: ***p < 0.001 **p < 0.01 *p < 0.05 based on a Student's t(4999) distribution with one tail [t(0.05. 4999) - 1.645. t(0.01. 4999) - 2.327. t(0.001. 4999) - 3.092)].* *Bootstrapping based on n - 5.000 subsamples;* *LL - Lower bias corrected bootstrap 95% confidence interval; 2.5%* *UL- Upper bias corrected bootstrap 95% confidence interval 97.5%*							

The use of open source has a strong effect on formalized involvement (β=0.559, p=0.000). The f^2 effect size (f^2=0.395) is large.

The use of open source and the "formalized involvement" have a positive and significant impact on the "inter-connected involvement" dimension (respectively β=0.258, p=0.004; β=0.506, p=0.000). The f^2 effect size from "formalized involvement" to "inter-connected involvement" (f^2= 0.235) is close to large, whereas the effect size from use of open source to inter-connected involvement (f^2=0.001) is very weak.

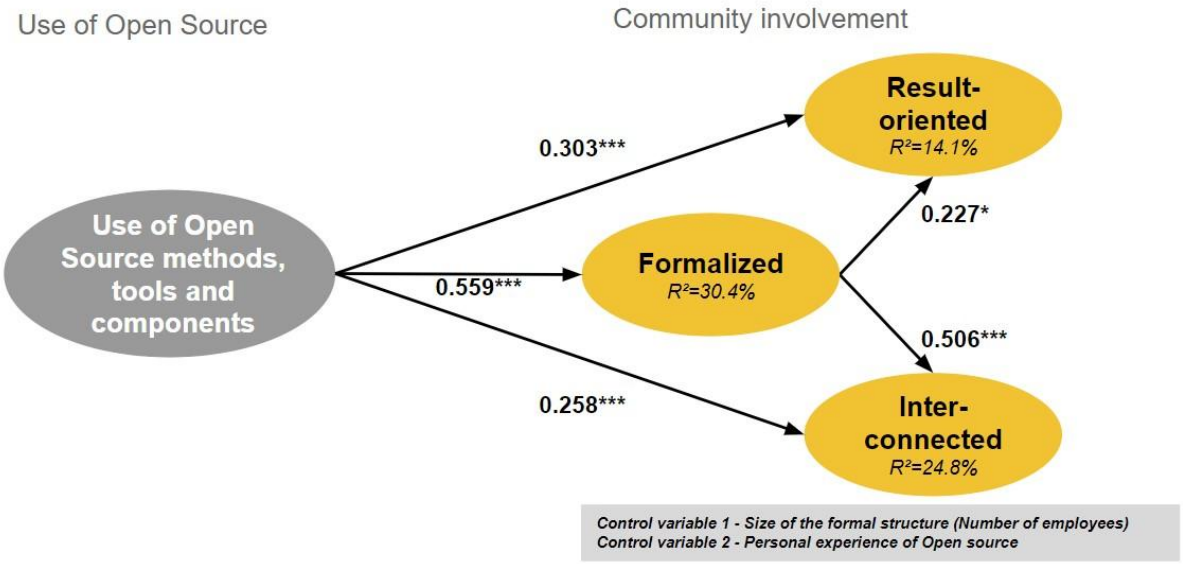

Figure 2 – Graphical representation of study 2 results (H2a and H2b mediation hypotheses)[10]

The use of open source and the "formalized involvement" have a positive and significant impact on the "result-oriented involvement" dimension (respectively β=0.303, p=0.001; β=0.227, p=0.040). The f^2 effect size from "formalized involvement" to "result oriented involvement" (f^2= 0.040) is small but larger than the effect size from use of open source to result oriented involvement (f^2=0.024).

To conclude, the formalized involvement partially mediates the relationship between the use of open source and the two dimensions of open source community involvement, that is the "inter-connected" and the "result-oriented involvement".

This last study confirms the importance of formalization in terms of involvement in knowing communities. This result sheds light on a possible form of sequential approach in interorganizational arrangements for involvement in communities.

5. Discussion

5.1. Link between use of open source and community involvement

Study 1 adds clarity to the use of open source and to categorizations of community involvement. The literature described the use of open source under several aspects (Hauge et al., 2010; Lundell et al., 2017) and often mixed this use of open source with the involvement in external communities. We demonstrate that the use of open source needs to be understood as one lone dimension the extensive use of open source tools, methods and components. Thus, we deepen the concept of use which is central in the innovation process (Goglio-Primard & Crespin-Mazet, 2015). Use means more than a simple use of several lines of code in the open source industry. It also means using the work methods of knowing communities. As such, it

[10] The size effects (f^2) are discussed in the text and reveal a different order than the path coefficient for the result-oriented dependent variable.

can be considered as a boundary practice, an internal arrangement necessary to take advantage of the open source environment and innovate. The use of open source practices developed by knowing communities makes it possible to integrate knowledge that in turn refines the internal practices of companies. Moreover, we clarify the categorizations of community involvement, and we show that three dimensions characterize this involvement: formalized, result oriented and interconnected involvement. They can also be considered as boundary practices.

Then, we validate hypothesis 1, confirming the positive relation between the use of open source and each form of involvement in the community. This result echoes with the positive relationship of the use of open source with the creation of "social ties" with communities that was empirically identified by Sims et Seidel (2016), and the learning path to involvement in communities (Nagle, 2018; Shaikh & Levina, 2019). We quantitatively demonstrate that this learning path is associated with an internal use of open source rules, methods and components.

At last, the effect of the use of open source with the "formalized involvement" is nearly twice higher than the two other relations. The relation with the "inter-connected involvement" is the lowest one. As the software industry is mature, following existing graduations of involvement (Ciesielska & Westenholz, 2016; Grand et al., 2004), we would have expected "inter-connected involvement" to be more represented. The two following studies were helpful in giving meaning to these results.

5.2. Understanding high- level of involvement in external knowing communities

Study 2 contributes to a better understanding of the most advanced categories of community involvement in external knowing communities. Interviews suggest that the inter-connected involvement in open source knowing communities is difficult to achieve for various reasons. A recent study confirmed that only one out of four business models is truly committed to open source, with the other three definitely in a merchant logic (Charleux & Mione, 2018), suggesting different levels of membership and contribution as mentioned earlier. Our research implied the impossibility for any company to get inter-connected with the many communities they depend on for all the components they insert in their final offers. This may explain why some previous studies found out that many organizations were opportunistic and none of them lived in real symbiosis with open source knowing communities (O'Neil et al., 2021). The symbiosis, understood as an extreme level of inter-connection with knowing communities (Dahlander & Magnusson, 2005), seems to be a myth. Lower levels of inter-connection, namely being a member and active contributors to several external communities, seem to be a more realistic approach to inter-connected interactions between formal structures and open source knowing communities.

This study also revealed the critical role of formalization to inter-connect with external communities. Formalization aims at clarifying who does what and how. This formalization of rules and guidelines such as contributor's guides give direction to responsive inter-organizational collaboration practices (Germonprez et al., 2017) These guides could be considered as boundary objects, in the sense that they are artefact resources that enable interorganizational arrangements and are part of boundary practices (Goglio-Primard & Crespin-Mazet, 2015). They may enable a smoother cooperation between formal structures and knowing communities and boost innovation (Ciesielska & Westenholz, 2016; Harvey et al., 2015; Lauritzen & Karafyllia, 2019; Wolf & Bernhart, 2022). It could characterize a sequential and growing form of involvement in communities.

5.3. Mediating effect of formalized involvement

Study 3 goes back to our quantitative data and demonstrates the partial mediating effect of formalized involvement as a former enabler to the two other involvements. Thus, this research validates hypotheses H2a and H2b. It confirms previous qualitative studies on this subject (Linåker et al., 2019; Shaikh & Levina, 2019) and sheds light on the previous works that develop categorizations of community involvement.

Indeed, the results of our study are close to those advocated by Ciesielska & Westenholz (2016) by not considering formalized involvement as the ultimate level of involvement. When graduating involvement, result-oriented involvement categories are often positioned below the formalized and the inter-connected categories (Ciesielska & Westenholz, 2016; Grand et al., 2004). The mediating role of formalization highlights a gradual approach with formalization as a prerequisite for other forms of involvement. This leads us to think about a more general step-by-step process that would be characterized by an increasing involvement in communities through an extensive use of open source rules, methods and components. This result shows the importance of acquiring a certain level of knowledge about how to interact with knowing communities before moving to other forms of involvement. We confirm the importance of experience and of learning to contribute (Henkel et al., 2014; Nagle, 2018) for formal structures to be fully engaged with knowing communities and understand their potential for value creation (Shaikh & Levina, 2019).

Moreover, the literature on knowing communities explains that the difficulty for formal structures to interact with them results from the confrontation of two logics: the horizontal and informal logic of the knowing communities, and the vertical and formal logic of formal structures. Formal structures tend to keep their formal hierarchy rules. Even if they are used to open innovation practices, they have difficulties in adapting to the way communities operate, which is more open, more horizontal, and where people contribute voluntarily and not because they have been told to do so. Two main solutions were proposed for formal structures to soften their boundaries with external communities. The first one is human and implies to settle governance methods with a sponsor and a manager to interact with the communities. The second one is organizational and consists in fostering middle grounds, like hackathons or forums that will ease the co-creation of common knowledge (Crespin-Mazet et al., 2019; Sarazin et al., 2017). Our quantitative results on mediation indicate that there could be a third solution: formalizing the boundary relations between communities and formal structures through boundary objects, such as rules, contributor's guides and adapted working contracts. Formal structure experience in contracting and organizing open operations for innovation could prove an asset to develop these boundary objects and achieve an inter-connected or even a result-oriented involvement.

Last, the theory of knowing communities explains that, on the one hand, formal structures should not let communities do what they want, but on the other hand, they should not control these communities. Rather, they should support them to facilitate innovation and value creation (Wenger & Wenger-Trayner, 2020). It seems to us that formal structures with an inter-connected involvement have fully understood the value of this delicate inter-organizational balance between facilitating the functioning of communities and directing development that would reduce the capacity to generate ideas through more controlled interactions. This can be done through boundary objects such as contributor's guides. They enable formal structures to formalize their involvement, and by consequence facilitate an inter-connected involvement.

Rather than a domestication or an attempt to organize the property of what is done together, this facet of involvement offers a new insight on the importance of facilitating the involve-

ment through a sequential approach. Formalized involvement can be understood as a boundary practice, based on boundary objects that allows for the development of the two other forms of involvement: the inter-connected involvement that takes advantage of the communities by contributing to them, and the result-oriented involvement that takes advantage of the communities by being very opportunistic.

This may help formal structures to better cope with interdependencies and integrate changes in their environment in order to boost innovation.

6. Conclusion

The objective of this exploratory research was to analyze the innovation interactions between formal structures and knowing communities, through the mobilization of a mixed-method research design composed of three complementary studies, two quantitative (study 1 and 3) and one qualitative (study 2).

Our research contributes to literature in several ways. First, we create two measurement scales: one for the use of open source components, methods and tools, and one for the involvement of formal structures in open source knowing communities. Previous research had mixed these two aspects. Our approach will allow future research to clearly differentiate between these two aspects as distinct boundary practices. Then, our research establishes a formal link between the use of open source components, methods and tools and the three different forms of involvement in open source communities. Finally, we extend existing research by showing that formal structures can't be fully inter-connected with all the communities they depend on for their components and product development. More specifically, we suggest that formalized involvement is an effective mediator to reach other forms of involvement, as interconnected involvement. Formalized involvement could be considered as boundary practice based on boundary objects enabling the two other involvement forms.

Therefore, this research contributes to the resource dependency theory (Drees & Heugens. 2013; Ozturk, 2021). First, the involvement of formal structures in these knowing communities allows them to reduce the uncertainty linked to the environment. Indeed, the companies that interact with these knowing communities will participate in a certain number of innovation projects where they will share their resources and develop "technological bricks". They will activate a technological watch on new developments, they will establish interactions with other organizations close to their industry, etc. Our research highlights the need for these organizations to follow a certain number of rules related to participation in these communities, but also the existence of levels in the way they get involved in a knowing community. These levels of involvement could allow organizations to better manage their mutual dependence and insure an optimal interaction. Second, our research also brings an extension to the resource dependency theory. On the one hand, knowing communities, which we can consider as boundary structures, make it possible to limit the negative effects of symbiotic interdependence (dependence between formal structures linked in a value chain) and competitive interdependence (dependence between formal structures in competition). On the other hand, knowing communities can reduce dependence on certain formal structures by multiplying the sources of knowledge and improving sharing practices that allow the integration of external knowledge, thus supporting innovation. Future research can further explore these relational practices that can be considered as boundary practices.

This research has also several practical and managerial contributions, the more so as open source software is emerging in all industrial sectors thanks to their digitalization. This re-

search could provide formal newcomers with specific guidance in interacting with knowing communities. First, open source is not only the use of components, but it rather means the use of open source methods and tools as well. This consideration leads to more global reflections concerning the functioning of open source and the innovation results that can be expected. Second, this research highlights the role of experience for interacting with knowing communities, thus emphasizing a gradual knowledge acquisition. Third, there are three ways of interacting, innovating with communities and contributing to the development of the software. One of these is formalization, to which organizations are already accustomed through open innovation. Formalization seems a good boundary practice, based on specific boundary objects, to develop inter-connection with open source communities. It appears as a pre-requisite to more advanced forms of involvement.

This work has limitations, some of which offer avenues for future research. First, interconnected formal structures cannot be inter-connected with all the communities they depend on. Further research could aim at assessing the way formal structures spread the three community involvement boundary practices (Formalized, Result-oriented and Inter-connected) between all the components they use. In this respect, our research suggested the role of formalization as a mediator, a specific boundary practice to take advantage of the use of open source and achieve the two other categories of involvement. More research is needed in this direction to refine our knowledge and understanding of how communities do function and how firms can use different modes of involvement depending on what they expect from the community. Following this perspective, one idea could be to assess the performance of these three dimensions of community involvement. Prior research has already examined the performance of open strategies and settled their impact on innovation (Cheng & Huizingh, 2014; Greco et al., 2016). It could be highly relevant to do this work for formal structures interacting with external knowing communities to assess the effective effect of boundary objects and practices on innovation.

Besides, "corporate engagement with open source communities is a management of transitions, neither fully communal nor fully corporate" (Germonprez et al., 2017. p. 16). Therefore, the distinction between the "donate/counter donate" community logic and the classical "absorption/exploitation" formal structure logic (Goglio-Primard et al., 2020) needs to be studied in more detail. There might be a third way in-between these two logics, as demonstrated by the specific role of formalized involvement. Further studies could aim at studying the formalization through boundary objects more precisely.

Last, nowadays, communities become invisible due to the evolution of services. Formal structures tend to buy "functions as a service", thus, they can't see the work done by communities as they for instance buy one hour of function in a cloud service. Further research could work on this issue and study the strategies implemented by communities to remain visible.

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Appendix A – Sample characteristics (total 157)

Respondent profile	Number	%
Seniority		
From 0 to 2 years	31	20
From 3 to 5 years	33	21
From 6 to 10 years	49	31
From 11 to 15 years	30	19
16 years and more	14	9
Gender		
Female	15	10
Male	140	89
Not specified	2	1
Services		
General Direction. CEO	86	55
Organization and support Departments	46	28
IT Department	18	12
Research & Innovation Departments	7	5

Organization profile	Number	%
Size		
Fewer than 10 salaries	75	48
From 11 to 49	44	28
From 50 to 249	18	11
From 250 to 4999	11	7
5000 and more	9	6
Sector		
Editors	63	40
Service Providers	94	60

Appendix B - Projection of each item in 4 factors

Loadings EFA	Communality	Use of Open Source *AdopUse*	Formalized involvement *AdopComForm*	Inter-connected involvement *AdopComIC*	Result-Oriented involvement *AdopComRO*
AdopUse1	0.56	0.65	0.23	0.27	0.11
AdopUse2	0.63	0.78	0.07	0.11	0.06
AdopUse3	0.55	0.74	0.00	0.01	-0.10
AdopUse4	0.66	0.70	0.28	-0.17	0.26
AdopComForm1	0.79	0.24	0.84	0.13	0.14
AdopComForm2	0.58	0.01	0.75	0.02	0.12
AdopComForm3	0.71	0.32	0.63	0.46	0.04
AdopComForm4	0.62	0.18	0.71	0.25	0.14
AdopComIC1	0.86	0.01	0.15	0.91	0.08
AdopComIC2	0.67	0.04	0.21	0.72	0.32
AdopComRO1	0.82	0.11	0.12	0.12	0.88
AdopComRO2	0.76	0.02	0.16	0.17	0.84

Appendix C – Reliability of "Formal structure use of open source" measurement scale

Formal structure use of Open Source **(alpha = 0.716; rho = 0.839; AVE (Average Variance Extracted) = 0.635)**	
Items	**Loading >0.7**
AdopUse1 "My organization has a clear policy for using or publishing free and open source components" *(Marsan & al., 2012)*	0.861
AdopUse2 "My organization largely uses free and open source" *(adapted from Sims & Seidel. 2016)*	0.784
AdopUse4 "My organization uses free and open source community methods (modularizing. peer reviewing. code sharing. etc.) for our own projects" (*adapted from Hauge et al., 2010*)	0.740
Notes: Not selected items after EFA and CFA AdopUse3 "My organization uses free and open source tools for development of our own offers (Eclipse, Git, GCC, Python, PHP, PostgreSQL...)" (*adapted from Hauge et al., 2010*) AdopUse6N "My organization uses free and open source products for our daily management (LibreOffice, Mozilla, Drupal...)" (*adapted from Hauge et al., 2010*) AdopUse7N "My organization incorporates open source components in our final offer, by modifying them strongly" (*adapted from Hauge et al., 2010*)	

Appendix D - Reliability of "Open source knowing community involvement" scale

Open Source knowing community involvement	
Items	**Loading >0.7**
Formalized involvement (alpha = 0.774; rho = 0.853; AVE (average variance extracted) = 0.593)	
AdopComForm1 "My organization adapted working contracts to facilitate employees' participation to free and open source communities" *(adapted from Germonprez et al., 2017)*	0.823
AdopComForm2 "My organization settled an identification and reward process for external contributors to our free and open source projects" *(adapted from Schaarschmidt et al., 2015)*	0.698
AdopComForm3 "My organization is at the origin of one or more free and open source communities" *(adapted from Ciesielska & Westenholz. 2016)*	0.751
AdopComForm4 "My organization settled rules to manage various communities' involvement from customers and contributors for free and open source projects" *(adapted from Germonprez et al..,2017)*	0.801
Inter-connected involvement (alpha = 0.701; rho = 0.869; AVE (average variance extracted= 0.768)	
AdopComIC1 "My organization is a member of one or more free and open source consortiums (Ros-Industrial. ...)" *(adapted from Hauge et al., 2010; Ciesielska & Westenholz. 2016)*	0.849
AdopComIC2 "My organization contributes actively to free and open source projects run by consortiums (ex OW2. Eclipse Foundation) in relation to our own projects" *(adapted from Hauge et al., 2010; Ciesielska & Westenholz. 2016)*	0.903
Result-oriented involvement (alpha = 0.756; rho = 0.891; AVE (average variance extracted= 0.803)	
AdopCom_RO1 "My organization tries to identify key contributors to integrate them in our organization" *(adapted from Schaarschmidt et al., 2015)*	0.904
AdopCom_RO2 "My organization tries to identify key community contributors to influence the decisions taken by free and open source communities in which we participate" *(adapted from Schaarschmidt et al., 2015; Germonprez et al., 2017; Lisein et al., 2009)*	0.888
Notes: Not selected items after EFA and CFA **Inter connected involvement** AdopComIC3N "My organization participates and contributes actively to free and open source projects" (*adapted from Link et al., 2017*) AdopComIC4N "My organization participates to one or more multi-firm groups to share experiences on free and open source solutions" (*adapted from Hauge et al., 2010*) AdopComIC5N "A few employees from my organization (IT Department. …) interact a lot with one or many free and open source communities" (*adapted from Sims & Seidel, 2016*) AdopComIC6N "The values in my organization foster creating common goods and interacting actively with communities to meet their needs" (*adapted from Sims & Seidel, 2016*) AdopComIC7N "My organization helps actively other organizations from our communities" (*adapted from Sims & Seidel, 2016*) **Result Oriented** AdopComRO3N "My organization fosters employees to contribute to free and open source projects run by consortiums or communities (Docker. ...)" (*adapted from Linåker et al., 2019; Sims & Seidel, 2016*) AdopComRO4N "My organization often asks for help from free and open source communities" (*adapted from Sims & Seidel, 2016*) AdopComRO5N "The talks content inside communities is equivalent to the one my organization has with our collaborating partners" (*adapted from professional managers*) AdopComRO6N "Talks with communities and continuous product evolutions are a waste of time for my organization" (*adapted from professional managers*)	

Appendix E- Discriminant validity

	Use of open source	Formalized involvement	Inter-connected involvement	Result-oriented involvement
Use of open source	**0.797**	0.605	0.277	0.345
Formalized involvement	0.468	**0.770**	0.655	0.424
Inter-connected involvement	0.206	0.496	**0.876**	0.507
Result-oriented involvement	0.239	0.329	0.371	**0.896**

Notes:
Diagonal elements are the square root of the variance shared between the constructs and their measures.
Below diagonal elements are the correlations between constructs.
Above diagonal elements are the Heterotrait-Monotrait Ratio (HTMT) values.