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Mechanisms in open innovation: A review and synthesis of the literature

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ABSTRACT

A large body of literature explores the role of context, structure, actors, and outcomes of open innovation (OI), yet pays little attention to the mechanisms underlying these relationships. In this review paper, we synthesize the OI literature using a context-mechanism-outcome approach to identify and classify the various mechanisms observed in empirical OI studies. Our findings demonstrate that the OI literature draws on a wide variety of mechanisms originating from the fields of management, sociology, economics, and psychology. The fifteen mechanisms most frequently observed in the literature fall into four categories: governance and policies; environmental dynamics and interactions; knowledge, skills, and capabilities; and learning by doing. Moreover, by examining the levels of analysis of these mechanisms, we observe substantial differences in how these mechanisms operate at the individual, project, firm, network, and society level. Finally, we identify various avenues for future research arising from our synthesis of the literature.

1. Introduction

Since Chesbrough's (2003) seminal book, open innovation has become an umbrella term for all innovation activities involving elements of an organization's external environment. For example, open innovation (from hereon: OI) includes leveraging the discoveries of others, collaborating with third parties on R&D projects, or profiting from innovation through out-licensing agreements (Chesbrough and Crowther, 2006). Accordingly, a rich stream of empirical studies has subsequently explored the inbound, outbound, and combined OI practices pursued by firms: these studies described the role and effect of the organizational context, the structure of the firm, collaboration agreements, the number and diversity of actors involved, and types of outcomes achieved (e.g., Pallot et al., 2013; Busarovs, 2013; West et al., 2014; Bogers et al., 2017; West and Bogers 2017; Frishammar et al., 2019; Stephan et al., 2019).

Nearly two decades of OI research have thus resulted in a significant body of literature. Yet, recent studies suggest that OI projects and activities still appear to be much more difficult to successfully create and execute than traditional innovation projects (e.g., Abhari and McGuckin, 2022; Audretsch and Belitski, 2022; Shaikh and Randhawa, 2022). To a large extent, the dearth of knowledge about how to make OI work arises from the diversity of generative mechanisms that drive OI patterns and outcomes. A *mechanism* here refers to the key element of an explanation, which depicts the driving force that generates a certain effect or outcome in a particular condition or setting (Hedström and Swedberg, 1998). As such, mechanisms can create or prevent change in a system (Bunge, 1997). Understanding these mechanisms is crucial to the identification of the causal processes underlying OI patterns and outcomes, which allow for making reliable predictions about the benefits, risks, and impacts arising from OI activities. Attempts to identify and codify these mechanisms also serve to respond to Bogers et al. (2019:89), who pointed at the need "to find out what exact mechanisms determine success or failure from open innovation". Providing an overview of the generative mechanisms therefore sheds new light on the various processes, conditions, and contexts that result in OI antecedents, execution, and outcomes. A systematic overview of mechanisms thus is conceptually relevant for revealing the different theoretical frameworks and managerial disciplines drawn upon and integrated in OI research, and it carries practical relevance by demonstrating the chain of processes, potential inhibitors, and boundary conditions for OI activities.

This study contributes to the OI literature by systematically

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identifying, synthesizing, and critically reviewing generative mechanisms in industrial OI research. We adopt the mechanism-based CMO framework (Van Burg and Romme, 2014), also known as CIMO (Denyer et al., 2008) or CAMO (Romme and Dimov, 2021) to recognize and classify referrals to mechanisms in the OI literature, a framework that has not yet been adopted in earlier reviews of the OI literature (e.g., West and Bogers, 2017; Frishammar et al., 2019). This framework is instrumental in distinguishing the *mechanisms* (M) through which actions lead to *outcomes* (O) while taking into account the *contexts* (C) in which these mechanisms operate (e.g., Denyer et al., 2008; Kuechler and Vaishnavi, 2008). Mechanisms thus provide the generative link between context and outcomes. We apply the CMO framework to a systematic analysis of 160 empirical OI studies published in major management and innovation journals since the concept of OI was introduced in 2003.

This study contributes to the OI literature by providing a systematic overview of mechanisms driving OI engagement, activities, and outcomes. Our findings advance the extant body of knowledge on the theoretical foundations and frameworks underlying the relationships between OI antecedents, execution, and consequences. The review demonstrates how mechanisms vary by their nature, level and stage at which OI activities are investigated, while giving rise to rather consistent outcomes. The classification of the most common mechanisms into four major categories serves to codify the variety of research disciplines brought together in OI. This substantial diversity also implies a lack of integration across levels and stages, which calls for more mechanism-driven studies of OI.

2. Theoretical background

2.1. Open innovation

Chesbrough (2003) introduced the OI approach as an alternative to the practice of closed innovation. The latter involves investing in internal R&D by hiring the best and the brightest people and providing them the best equipment, so that they can develop ideas and technologies leading to new products or processes. Various factors such as an increasing mobility of skilled workers, the growing presence of venture capital, and the rising role of external knowledge suppliers have been eroding the closed innovation paradigm (Chesbrough, 2003, 2012). The OI paradigm thus serves to expand innovation efforts beyond the boundaries of the firm, by building upon external knowledge and combining it with internal competences to improve the success of these efforts (Chesbrough, 2003; Chesbrough and Crowther, 2006).

In the past near-twenty years, industrial OI practices have been studied from various angles. Scholars have focused on specific industries or organizational types, such as knowledge-intensive industries (Natalicchio et al., 2017; Audretsch and Belitski, 2022), SMEs (Hossain and Kauranen, 2016), and start-ups (Spender et al., 2017). The review of the OI literature by West et al. (2014) concluded that there is a need for newer and better approaches to measuring OI as well as new governance forms, to support managers in mitigating the potential risks arising from OI practices. A subsequent review by Bogers et al. (2017) served to identify different levels of analysis as well as several contexts for OI practices: intra-organizational (e.g., individuals, projects, teams and business units), organizational (e.g., firm, strategy, business model), and inter-organizational (e.g., networks, alliances, ecosystems) and resulted in similar recommendations to pursue further research along these levels of analysis. These and subsequent discussions of the OI literature (Bogers et al., 2019; Hutton et al., 2021) also pointed to the importance of identifying mechanisms in OI relationships to better understand when entities engage with, participate in, and benefit from OI activities. We respond to this call for future research by developing a mechanism-based review.

2.2. Mechanisms

Mechanisms, also known as *generative* or *social mechanisms* (e.g., Blom and Morén, 2011; Hedström and Swedberg, 1998), are the underlying processes that link a set of antecedents to specific consequences (Cornelissen, 2017; Sørensen, 1998). While other fields of science are often looking for absolute relationships, that is, a fixed set of antecedents that always lead to a specific outcome, social scientists tend to relate a set of antecedents to the likelihood or magnitude of a particular outcome, due to the complexity and unpredictability of human nature. These antecedents can be contextual or structural and are unintentional or intentional in nature—such as specific actions or interventions. Similarly, consequences can cover a variety of elements including temporary or permanent changes. The underlying mechanism provides the causal explanation of why specific outcomes occur and whether these occur at the same level as the antecedents or outcomes, or at a different level (Coleman, 1994). For example, changes in organizational structure could influence the firm's innovation performance through mechanisms (such as employee mobility) at the team or individual level (Barney and Felin, 2013).

The identification of mechanisms is important for several reasons. Conceptually, identifying mechanisms helps to understand the relation between antecedents and consequences, that is, how a specific set of antecedents is likely to result in a specific outcome (Van Burg and Romme, 2014). The identification of mechanisms also has a strong practical value: insight into these mechanisms can help managers avoid the pitfalls and risks in OI (cf. Alexy and Reitzig, 2012; Frishammar et al., 2015; Manzini et al., 2017). Identifying mechanisms also helps managers to better understand when and how a specific action (not) has the intended effects, because a mechanism-based analysis provides insight in the boundary conditions of cause-effect relationships, that is, the contextual conditions under which the antecedents do affect the outcomes (Marti and Gond, 2018). Finally, understanding mechanisms can improve the efficiency and efficacy of achieving intended outcomes (Mitchell and James, 2001).

The role of mechanisms is particularly relevant for OI research. Such a maturing field is likely to benefit from critically reviewing and synthesizing the causal patterns and relationships arising from the large body of available literature. In addition, the identification of mechanisms can help understand conflicting results arising from prior research. For example, Henkel et al. (2014) studied several firms to find that waiving intellectual property rights (IPR) by a process of selective revealing has been very beneficial for these firms, whereas Manzini and Lazzarotti (2016) concluded that IPR is critical for successfully implementing OI. Uncovering and defining the generative mechanisms at work here can help explain the origins of such divergent results.

3. Methodology

To better understand mechanisms in OI research, we performed a systematic search of the literature on OI over the past eighteen years. A multi-step selection process to systematically identify and analyze the most relevant prior literature was used (similar to Tanskanen et al., 2017). Fig. 1 provides a visual summary of how studies were selected and analyzed.

3.1. Literature search

As a first step, we extracted all articles that include "open innov*" in their title, keywords, or abstract over the period between 2003 and 2020 using Clarivate's Web of Science. This resulted in 18,963 studies from various disciplines and published in a large variety of outlets.

We limited this large number of results using two selection criteria. First, we selected studies published in journal articles in specific journals. Following earlier studies (Van Burg and Romme, 2014; Oliveira and Lumineau, 2019), we selected twelve main journals in the field of

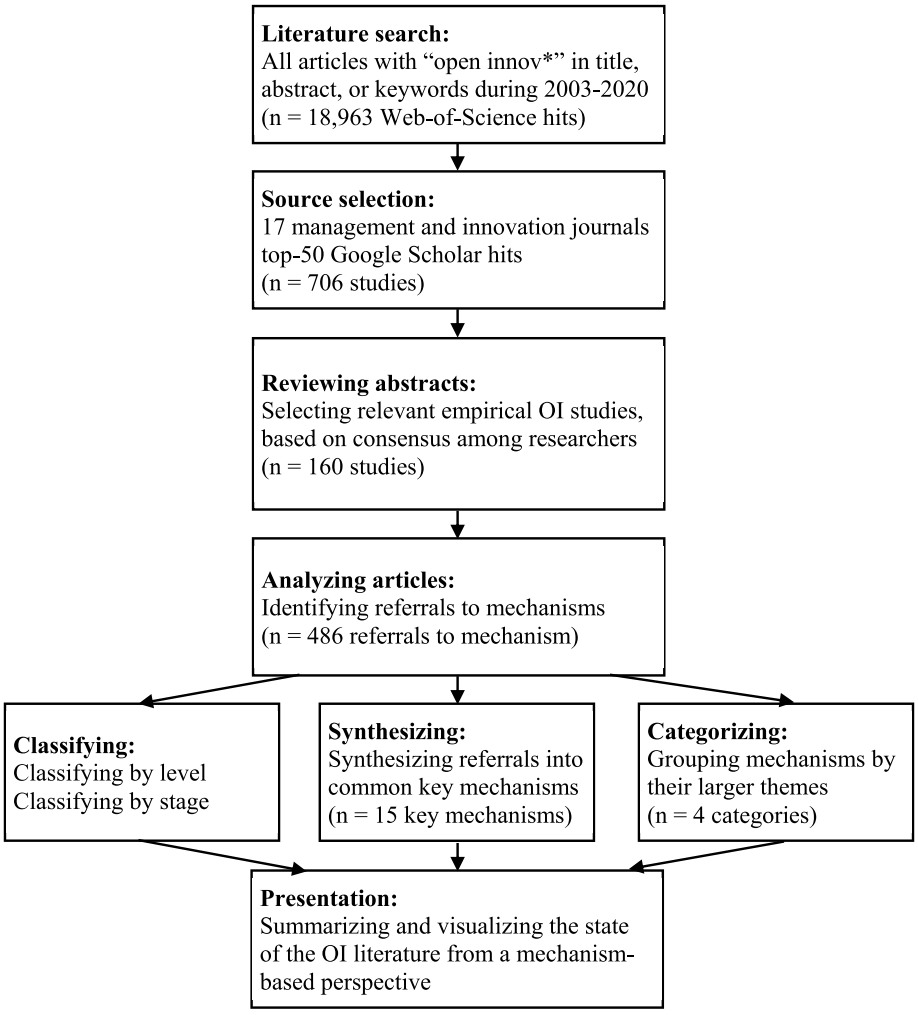

Fig. 1. Research methodology.

management as well as five disciplinary journals in the area of innovation, based on their classification in the ABS and CNRS journal rankings. Second, we added the 50 most-cited OI studies, based on a Google Scholar search using "open innovation" as the main query. We made this addition to include key OI studies that were published as book chapters or in other journals (than those previously selected).[1] In total, these two criteria and associated selection steps resulted in a set of 706 relevant OI studies.

3.2. Study selection

To ensure that the articles are insightful for a mechanism-based review, we scanned these 706 publications and used two criteria for inclusion. First, the study should have an empirical component. That is, to provide insights on mechanisms, the study has to draw on qualitative or quantitative data. Conceptual work, simulation models (without empirical data) and other non-empirical studies were thus excluded. Second, the empirical part of the study must include some form of firm-centered inbound or outbound OI activity. As such, we removed studies that exclusively explore internet-based forms of OI, like crowdsourcing, crowdfunding, and open-source projects. We made this choice because the nature of the latter projects and activities are very different from firm-centered inbound and outbound OI activities (Chesbrough and Crowther, 2006). In this respect, the fast-growing literatures on crowdsourcing OI practices (e.g., Ghezzi et al., 2018) and open-source software development (e.g., Linåker et al., 2018) merit a dedicated review and synthesis, one that is outside the scope of this paper.

This selection processes resulted in a final set of 160 studies from twenty-three different journals and a number of (edited) books. Table 1 provides an overview of the sources of the selected studies. Appendix A, available online, provides the complete list of studies selected.

3.3. Mechanism analysis

3.3.1. Mechanism identification

We employed a synthetical approach involving a mechanism-based review approach (Denyer et al., 2008; Van Burg and Romme, 2014; Romme and Dimov, 2021) to all publications selected. As such, we adopt an inclusive approach, inspired by Aristotle who distinguished multiple 'causes' of why things come into being (Ross, 1981; Romme and Dimov, 2021): the so-called final cause, that is, the purpose of the change; the efficient cause, that is, the agency initiating the change; the formal cause, referring to the mechanism that operates as the shaping force; and the material cause in terms of the context providing the immanent elements. While the agent as the 'efficient' cause in Aristotelian terms is often rather obvious, the other three 'causes' tend to be more difficult to identify and disentangle (also from each other).

[1] We thank an anonymous reviewer for this suggestion.

Table 1
Article selection.

Publication:	Initial selection	… *of which 2003-2008*	… *of which 2009-2014*	… *of which 2015-2020*	Final selection
R&D Management	117	*13*	*45*	*59*	**38**
Technovation	76	*9*	*36*	*31*	**33**
Research Policy	167	*29*	*64*	*74*	**33**
Journal of Product Innovation Management	79	*6*	*37*	*36*	**17**
Long Range Planning	30	*5*	*7*	*18*	**7**
Industrial and Corporate Change	27	*5*	*5*	*17*	**5**
Organization Science	28	*8*	*14*	*6*	**4**
Strategic Management Journal	29	*5*	*5*	*19*	**4**
Management Science	29	*12*	*8*	*9*	**2**
Strategic Organization	14	*0*	*4*	*10*	**2**
Strategic Entrepreneurship Journal	8	*0*	*2*	*6*	**2**
Journal of Business Venturing	8	*1*	*0*	*7*	**2**
British Journal of Management	7	*0*	*1*	*6*	**1**
Academy of Management Review	4	*0*	*3*	*1*	**0**
Journal of Management Studies	13	*7*	*2*	*4*	**0**
Administrative Science Quarterly	6	*1*	*0*	*5*	**0**
Organization Studies	13	*3*	*5*	*5*	**0**
Other journals	29	*10*	*15*	*4*	**6**
Other studies (chapters, white papers, etc.)	22	*11*	*11*	*0*	**4**
Total:	**706**	*125*	*264*	*317*	**160**

In analyzing the final sample of publications, we therefore sought to extract the *Contexts* (i.e., material causes in Aristotelian terms), *Mechanisms* (i.e., formal causes), and *Outcomes* (i.e., final causes) of OI-practices. We gave specific attention to validated hypotheses and other empirical answers to research questions, as they explicitly or implicitly refer to specific contexts, mechanisms, and outcomes. Throughout this exercise, referrals to mechanisms were identified as generative processes that lead to one or more specific outcome(s), including the actors involved and the context in which it took place. For example, a well-known phenomenon in the OI literature is the 'not-invented-here syndrome' (e.g., Gesing et al., 2015; Enkel et al., 2017; Hannen et al., 2019), in which a company has access to new and relevant knowledge (i.e., *context*), but its scientists and engineers decide to disregard that knowledge (*outcome*) because they undervalue the potential significance of external information (*mechanism*). Another example is the presence of specialized knowledge transfer units at universities (Perkmann and Schildt, 2015; Miller et al., 2016), where universities possess unique knowledge stemming from basic research (*context*) that can be turned into commercial applications (*outcome*) if dedicated structures are set up to match scientists with corporations (*mechanism*).

Per study, we captured at least one, but often multiple statements referring to contexts, mechanisms, and outcomes. The lead author of this paper performed the initial analysis, inferring 486 individual statements from the reviewed publications. For statements labelled as "ambiguous" by the lead author, one of the coauthors conducted an independent analysis. The two scholars then compared their statements, discussed any major differences, and agreed on the final (set of) statement(s). We also sought to achieve theoretical saturation in coding the publications selected; this saturation was very likely accomplished, because the last 20 studies coded did not add any additional mechanisms.

3.3.2. Mechanism classification

We mapped the resulting referrals to mechanisms in various categories using three consecutive steps (cf. Bogers et al., 2017). First, by studying the empirical evidence in the sample of selected studies, we observed a large variety of mechanisms. These referrals stemmed from several theoretical fields, for instance, mechanisms related to rational and financial cost-benefit analysis (from economics), the effects of various public policies (from political science), social capital (from sociology), and individual traits and attitudes (from psychology).

Second, within each level, we observed three different stages prevailing in specific OI studies: prerequisites for OI, main activities in OI, and outcomes of OI practices. Whereas levels largely related to the context, the stages largely point to differences in the outcomes studied. For example, studies explaining openness to external knowledge deal with OI prerequisites, whereas those predicting financial impact address the outcomes of OI.

Third, we noticed rather distinct levels of analysis in the reviewed studies: individual, project/team, organization, inter-organizational, and society level. Understandably, the mechanisms tend to vary across these different levels, with those grounded in psychology being more strongly present at the micro-levels and those originating from economics more prevalent at the macro-levels.

3.3.3. Cross-level mechanism analysis

In the last step of our review process, we performed a cross-level analysis identifying overarching key mechanisms and mechanism categories. We classified the referrals to mechanisms (identified in the studies) into proper theoretical mechanisms, and these theoretical mechanisms into larger categories. This allowed us to go from the nominal mechanisms as they were formulated in the various studies to the underlying mechanisms, and then to the different streams of literature these mechanisms stem from. The mechanisms, and the larger categories they are part of, together constitute a conceptual framework that may inform future research in this area.

3.4. A framework for classifying mechanisms in OI

The three steps outlined previously result in a framework with two dimensions, namely (a) the level of analysis at which the empirical study is conducted and (b) the stage of the OI process. The first dimension contains five distinct levels for addressing and explaining the context in which mechanisms operate: the (1) individual, (2) project, (3) firm, (4) network, and (5) society level. The *individual level* contains mechanisms influenced or activated by individuals whereas the *project level* contains mechanisms active within (temporary) projects. The *firm level* contains mechanisms observed at the level of a particular firm or other organization and mechanisms at the *network level* are those involving inter-organizational relationships and clusters of collaborating organizations. Mechanisms at the *societal level* involve regulations and structures applicable to an entire society. The second dimension of the framework represents three consecutive stages of development. The first stage, called *antecedents to OI*, considers the mechanisms that lead to engagement in OI activities. The second stage, *executing OI*, pertains to the mechanisms at play during OI activities, that is, how individuals, project teams or firms work on OI activities. The last stage involves *consequences of OI*, pertaining to how actors at various levels are affected by the OI

activities performed. In the next section, we will discuss our findings in terms of this framework.

4. Results

This chapter discusses the referrals to generative mechanisms observed in the 160 empirical OI studies using the analyzing framework described above (summarized in the external Appendix B).

4.1. Referrals to mechanisms at individual level

Referrals to mechanisms at the individual level relate to personal attitudes, actions, capabilities, and decisions.

4.1.1. Individual-level antecedents to OI

Individual-level mechanisms explaining the origin of OI activities relate to personal beliefs, individual orientation, and competences. Regarding *personal beliefs*, Enkel and Bader (2016) found two factors related to an expert's behavioral intention to participate in cross-industry innovation. The first factor concerned the extent to which an expert had positive expectations from cross-industry innovation. The second factor was perceived behavioral control, or an expert's perception of certain skills, which is essential as experts need to personally believe in their capability to deliver relevant knowledge. These both explained the motivation of individuals to engage in OI (Enkel and Bader, 2016).

Orientation of an individual appears to be specifically relevant for key decision makers. Having a more explicit strategic or long-term orientation in innovation and R&D activities enhances individual openness to external sources of knowledge and the effectiveness of OI in general (Cheng and Huizingh, 2014; Salter et al., 2015). An entrepreneurial orientation creates a fertile setting for OI, especially when the firm's CEO has this orientation (Ahn et al., 2017).

Finally, several studies found specific *personal competences* to stimulate the engagement of professionals in OI: social competences in brokering solutions increase the effectiveness of OI activities by individuals (Chatenier et al., 2010) and patience and educational background are pivotal in facilitating OI in SMEs (Ahn et al., 2017).

4.1.2. Individual-level execution of OI

Several studies point to the role of *boundary spanning* during OI activities. This relates to the communication activity within an innovation system, linking the organization's internal networks with external sources of information (Fleming and Waguespack, 2007; Holmes and Smart, 2009). Boundary spanning activities increase trust and mutual understanding between parties, especially in cross-industry innovation, as they link different technological areas (Fleming and Waguespack, 2007). They also lead to higher levels of interactions and linkages with third parties, especially when performed more informally and thus little directed by senior managers (Holmes and Smart, 2009).

The mechanism of *absorptive capacity* (Cohen and Levinthal 1990) was found in several studies (Ter Wal et al., 2017; Enkel and Bader, 2016). This mechanism underlines that any individual effort combining external search with assimilation and utilization activity will lead to more effective absorption (i.e., learning) from external knowledge, thereby positively affecting the overall OI results. Even activities which cost little effort, such as attending physical community meetings, can already be beneficial as they increase the likelihood, especially for startup entrepreneurs, to receive capital investments through public offering or acquisitions (Waguespack and Fleming, 2009).

4.1.3. Individual-level consequences of OI

The individual-level benefits of OI all relate to non-monetary professional and personal improvements, in particular (1) gained trust and (2) developed competences. These lead to personal career growth and new opportunities for OI. A first benefit is *trust*: individuals who commit to boundary spanning activities inherently receive more trust, specifically compared to those involved in brokerage activities (Fleming and Waguespack, 2007). Boundary spanning activity generally does not produce direct benefits but enables new opportunities to arise, whereas brokerage activities, in which someone links people and firms, are more likely to be performed in exchange for direct financial payments (e.g., Chatenier et al., 2010; Galán-Muros and Plewa, 2016). Also, boundary spanning requires that one understands experts in multiple areas, increasing the chance of making technical contributions. This makes it more likely for boundary spanners to advance to leadership positions. In general, working in OI teams helps professionals to learn how to deal with low reciprocal commitment; it often results in (new) contacts which in turn may provide new OI opportunities (Chatenier et al., 2010; Miller et al., 2016; Lee et al., 2010; Galán-Muros and Plewa, 2016).

A second benefit is *competences developed*. Enkel et al. (2017) concluded that working in OI teams tends to increase absorptive capacity at the individual level in three dimensions: the individual ability to (1) identify valuable knowledge external to the existing environment of the firm, (2) assimilate the external knowledge in the organization's identity, and (3) advocate the utilization of the external knowledge within an organization.

4.2. Referrals to mechanisms at the project level

The project level contains referrals to mechanisms observed in and around teams and their projects. They are triggered within the scope of a single project and thus temporary, though the outcomes may permanently (directly or indirectly) influence innovation performance.

4.2.1. Project-level antecedents to OI

Mechanisms that explain how projects organize for OI can be split into two groups: (1) the governance of project teams, including the project management methods employed, and (2) the composition of the project team and its tasks.

First, there are several studies exploring the role of governance of OI projects: project management, knowledge matching, and procedures for managing the flexibility of size and constellation of the project team (Lakemond et al., 2016; Manning, 2017). Concerning project management, Gesing et al. (2015) distinguished two governance modes for OI projects, namely *informal self-enforcing* versus *formal-contractual governance*. Whereas both types of governance have their benefits and disadvantages, OI projects with a more formal governance style are more associated with innovation success than their informally governed counterparts, especially in a market-focused context (Gesing et al., 2015). By contrast, projects in a more science-focused context benefit from a more *informal project management style* (Gesing et al., 2015). Thus, science-based R&D projects involving researchers from universities and knowledge institutes show better financial performance when they are relatively loosely managed. This underlines the idea that there is no 'one size fits all', that is, the type of project management approach should be adapted to the composition of the project team (Du et al., 2014). In addition, Cassanelli et al. (2017) found that it is beneficial for OI projects to *split R&D management and project management* in two distinct roles. This allows experts to add value to R&D by drawing on their knowledge and skills, without being bothered with the process too much.

A second category of mechanisms relates to the project team members and their tasks. For example, *team size, learning distance* and *relation of the project goal to underlying firm's main business* influence project-level openness, both inbound and outbound. Kim et al. (2015) found complex relations between team size and inbound openness: a team's engagement to gathering knowledge outside the project team first increases with team size as more labor is available for search, but ultimately decreases as team size grows because of a reduced need for external knowledge. The level of inbound openness also increases when there is *uncertainty within the project team regarding technology or market dynamics*. This effect is strong, especially when the project team's tasks are

closely related to the main business of involved firms. A *short learning distance* for the project team decreases the level of inbound openness, but on the other hand increases willingness to outbound share knowledge with others, especially when the task is further away or less important for firm's underlying business (Kim et al., 2015).

The success of inter-organizational project teams is positively influenced by *demographic variance within the team* (Iseke et al., 2015) and *partner breadth* (Lakemond et al., 2016). When a company's strategy is based upon excellent internal competencies and knowhow, not protected by means of formal intellectual property protection mechanisms (such as patents, trademarks or design), an open approach might not be the best approach for an R&D project (Cassanelli et al., 2017; Manzini et al., 2017). This resonates with Veer et al.'s (2016) finding that projects are sometimes too open and that contracts cannot always prevent imitation. We will return to this finding when discussing the mechanisms in benefiting from OI projects.

4.2.2. Project-level execution of OI

During the OI project itself, various factors influence success of outcomes such as (1) the project approach and (2) project environment dynamics. Regarding the project approach, Bogers and Horst (2014) showed that *collaborative prototyping* can be effective, as this requires active engagement of various stakeholders across functional, hierarchical, and organizational boundaries in developing a product. Kohler et al. (2009) found that *using a virtual world* can also help to overcome problems in the real world, especially when it aims to capitalize users' innovative potential and knowledge.

Regarding project environment dynamics, the role of decision-makers is vital. When the CEOs of participating firms have a *positive attitude* towards a project, it greatly helps the project (Ahn et al., 2017). Problems occur when a decision maker's *attention is distributed between managing internal and external knowledge* (Ghisetti et al., 2015). The project team itself is then dealing with greater dynamics and risks around the project. When the team has to cope with *high technological uncertainty* by identifying and studying external knowledge sources, the project's success can be affected (Kim et al., 2015). Too volatile dynamics can result in a *not-invented-here syndrome* in case of inbound OI projects or a *not-shared-here syndrome* in case of outbound OI projects, thereby decreasing the level of openness within the project (Burcharth et al., 2014). Hannen et al. (2019) also studied the not-invented-here syndrome among R&D professionals and described its negative effects on R&D project success.

4.2.3. Project-level consequences of OI

We earlier discussed the influence of firm policies and strategies on the success of inter-organizational projects. For example, *policies regarding intellectual property rights* (IPR) generally work well as governance mechanisms influencing the relationship between R&D cooperation and imitation, whereas contracts do not (Veer et al., 2016). *Policies on patenting* also influence the extent of openness within a project, as the presence of patents increases a new entrant's (average) number of OI relationships (Zobel et al., 2016). The extent of openness of an R&D project, however, also depends on the *strategic importance of the innovation project* (Kim et al., 2015) and the *stage of technology development* (Bianchi et al., 2011). In order to manage variety in underlying policies and other dynamics regarding inter-organizational projects, connecting to a project network organization is found to be very effective, especially in situations with high project diversity, high degree of specialization and dependence on geographically dispersed resources (Manning, 2017).

Many benefits from OI projects are similar to the benefits for the firms involved, especially when participating firms have a good *mix between intramural and extramural R&D*: Wadhwa et al. (2017) reported an inverted U-shape relationship between reliance on extramural R&D and innovation performance. When looking at individual projects, Knudsen and Mortensen (2011) demonstrated that an open approach may result in higher cost and worse timing for a specific project. At the same time, they also found that following a *collaborative strategy* in general has positive effects on new product performance, compared to a single firm strategy. Better use of external knowledge leads to improved quality of developed products in the long run (Knudsen and Mortensen, 2011).

4.3. Referrals to mechanisms at the firm level

At the level of the firm, mechanisms focus on a single organization, thus exceeding the level of single projects. These mechanisms are controlled and influenced by individual firms.

4.3.1. Firm-level antecedents to OI

Many mechanisms leading to OI practices are affected by firm design. We have categorized these mechanisms into (1) 'attitude and policy mechanisms' associated with managerial and governance decisions, (2) mechanisms related to 'internal firm dynamics', and (3) mechanisms regarding the way a firm's organizational structure is designed or 'structural mechanisms'.

The first category, *attitude and policy mechanisms*, relates to knowledge flowing 'inside-out' as well as knowledge flowing 'outside-in'. Regarding knowledge flowing inside-out, a widely used concept is openness, including policies for patents and other IP. Choosing an integrated standardization strategy analogous to the patenting strategy leads to the most beneficial outcomes in knowledge transfer and creativity (Groβmann et al., 2016; Rohrbeck et al., 2009). Henkel et al. (2014) also conclude that, despite OI often being facilitated by strong intellectual property rights (IPRs), it may even be boosted when firms deliberately waive some of their IPRs. In this respect, Salter et al. (2015) identify an inverted U-shaped relation between openness and the number of ideas passing through the implementation gate, thus suggesting an optimal level of openness. Core knowledge can, to some extent, leak without negative effects particularly in highly rivalrous environments. Opening up can even reshape markets by weakening competitors (Frishammar et al., 2015; Alexy et al., 2018; Xing and Sharif, 2020). Firms then significantly improve their performance as (1) opening resources reduces their cost base, while (2) strongly increasing demand for their still-proprietary resources (Alexy et al., 2018).

Regarding knowledge flowing outside-in, a policy of collaborating with universities or Research & Technology Organizations (RTOs) and increasing the variety of incoming knowledge in other ways helps to identify novel technological opportunities (Belderbos et al., 2014; Giannopoulou et al., 2019). This is related to earlier actions by firm representatives leading to positive effects on innovation performance (Belderbos et al., 2014). The outcome was found in developing as well as already developed markets. However, it is mainly firms with currently low innovation performance that benefit from increased variance (Egbetokun, 2015; Wadhwa et al., 2017; Berchicci, 2013).

Second, there are mechanisms triggered by *internal firm dynamics*, that is, internal forces leading to a situation where firms tend to choose for a more open approach. Several studies observed firms to be more likely to engage in OI when internal innovation activities are confronted with impediments, intraorganizational forces such as inertia occur, major financial pressures arise, or leadership actively encourages knowledge to flow across organizational boundaries (Keupp and Gassmann, 2009; Bhaskarabhatla and Hegde, 2014; Monteiro et al., 2017). Ili et al. (2010) highlighted the role of the firm's leadership in a study in the automotive industry where cost pressure motivated key agents within the firm to look for external sources to increase their innovativeness: this only led to better R&D productivity when these agents were actively supported by top management.

Third, there are *structural mechanisms* such as (1) a distinct division or venture with its own budget and financial responsibilities, (2) a separate new product department, (3) a new product committee, and (4) formalized partnerships being beneficial for the outcomes of their

innovation efforts (Markham and Lee, 2013). This is in line with the evidence that having a dedicated R&D unit (Bianchi et al., 2016) or an independent unit for managing interfirm innovation projects (Chiaroni et al., 2010) results in successful inbound OI. Multiple studies also emphasize the importance of the availability of specific knowledge and roles within the hierarchical structure of the organization. For example, the presence of an OI champion (Chiaroni et al., 2010), a single person as technology gatekeeper (Whelan et al., 2010), the combination of gatekeepers that connect external search to assimilation effort, and shepherds that connect assimilation to utilization efforts (Ter Wal et al., 2017) are found to have positive effects on OI success.

4.3.2. Firm-level execution of OI

Knowledge flows in OI increase when there is an adequate combination of activities regarding (1) strategic planning and (2) dynamic management. Regarding *strategic planning*, technology road mapping is beneficial (Müller-Seitz, 2012) especially in situations where new technologies are pushed (Caetano and Amaral, 2011). A strategic venturing approach also serves to enhance knowledge flows, by obtaining access to knowledge of experienced entrepreneurs outside the firm (Chesbrough and Bogers, 2014). Moreover, Rohrbeck (2010) found that building technology foresight is beneficial, specifically by actively resorting to technology scouting. In addition, Cruz-González et al. (2015) observed that, in the context of high dynamism technological environments, only a deep, focused search is beneficial; a large breadth of search can even be counterproductive, as it increases the risk for splintered attention. Here, a high level of search depth was found to be more beneficial in incrementally improving products, whereas a high breadth in search was more effective for radical product innovations (Chiang and Hung, 2010). Both search depth and breadth are found to be beneficial for innovation speed (Zhu et al., 2019).

Other mechanisms relate to *dynamic management* activities within a firm. Tan and Zhan (2017), for example, concluded that working in parallel teams with different speed levels and on different elements, yet supervised by the same project leader, improves the entire project's performance in terms of costs, creativity and speed. Additionally, using ad-hoc specialist knowledge providers—such as consultants, private research organizations, or academic scholars—strengthens the impact of inbound OI (Tether and Tajar, 2008; Bianchi et al., 2016). An alternative is to acquire knowledge by take-overs. However, when searching for potential firms, besides the presence of knowledge, physical locations are also relevant. Ardito et al. (2018) found an inverted U-shape relation between the geographical dispersion of resources after the acquisition and the success of the acquisition. High levels of dispersion can even lead to negative returns, especially when the acquiring firm already was highly technologically diversified before the acquisition.

4.3.3. Firm-level consequences of OI

Empirical studies identify the realization of benefits through (1) the value of developed products and (2) the capabilities of the firm specialists developing the products; however, (3) not only benefits, but also costs arise from OI.

Concerning the impact of a firm's OI practices on *the value of developed products*, multiple studies found that technology licensing in itself and past experience with out-licensing increase firm revenues and therefore the value of the firm's product base (Chesbrough, 2003; Sikimic et al., 2016; Bianchi et al., 2016). The same effect is observed when firms have extensive in-licensing experience (Sikimic et al., 2016). Social status and the number of commercial alliances formed earlier also contribute to this effect (Hu et al., 2015). Developing products with other firms leads to improved competitiveness of the product portfolio as well as product novelty (Zobel, 2017; Dunlap-Hinkler et al., 2010; Franke et al., 2014; Chatterji and Fabrizio, 2014). So, various forms of OI increase the value of a firm's product portfolio.

OI practices influence firm value through their impact on *firm capabilities*. For example, openness in product development increases innovative sales not only in the current period, but also provides the basis for learning effects and therefore improved capabilities with firm specialists (Love et al., 2014). External corporate venturing instruments such as accelerator programs or working with incubators, positively impact firm's *dynamic capabilities* (Enkel and Sagmeister, 2020). A specific capability that is often mentioned in relation with OI is again *absorptive capacity*, yet now at the firm level: this is the firm's ability to recognize the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990). Firms lacking absorptive capacity can collectively cope with distributed knowledge and innovation by setting up shared research centers (Spithoven et al., 2010). Not only is the absolute level of absorptive capacity beneficial for innovation output at the firm level, but also the level of absorptive capacity relative to the firm's innovation partners (Wang and Li-Ying, 2014). When a licensee firm is compared to a licensor, the firm with higher absorptive capacity was found to benefit more from new product development than its counterpart. Complementary to absorptive capacity for receiving knowledge, firms also develop capabilities for knowledge outflows. So-called *desorptive capacity* is a firm's ability to exploit its knowledge externally; multiple studies confirm that OI supports the development of both absorptive and desorptive capacities (Müller-Seitz, 2012; Sikimic et al., 2016).

Developing OI capabilities can also come at a cost. Multiple papers describe a relation between (both inbound and outbound) openness and the increase of costs. Christensen et al. (2005) report higher transaction costs due to OI practices, especially for small firms who have to engage in negotiating and cooperating with one or more of the heavyweight incumbents. Cassiman and Valentini (2016) expected to find that 'open firms' would be able to reduce some of the relevant (cognitive, transaction and organizational) costs, but found that R&D costs increased disproportionally to the rise in sales.

4.4. Referrals to mechanisms at the network level

The network is the level of economic cooperation for innovation activities in which legally independent, but financially and technologically interdependent organizations collaborate in such a way that rather stable relations are established (Duschek, 2002). Here, the mechanisms occur within the scope of (semi-)organized ties and relations.

4.4.1. Network-level antecedents to OI

Network-level mechanisms leading up to OI include (1) the way the network is organized and (2) governance-related mechanisms. Regarding the *organization of the network*, Manning (2017, p. 1) describes the shift from project-based firms (PBFs) to project network organizations (PNOs) as follows: "As a result of organizational specialization, PNOs have emerged as generic organizational forms combining the coordination capacity of PBFs with the resource richness of networks." The shift to PNOs is to connect legally independent, yet often operationally interdependent individuals and organizations in strategically coordinated sets of core project teams and flexible partner pools that sustain beyond singular projects. Radnejad et al. (2017) describe the positive influence of an industry-founded and not-for-profit innovation intermediary with a moderate level of stratification. A focus on exploitation within a network requires stronger ties and a more closed model, whereas networks focusing on exploration are best served with weaker ties and a more open model (Radnejad et al., 2017).

Multiple studies discuss the *governance of innovation networks*. In the context of university-industry collaborations, Young et al. (2008) researched how university-controlled research centers differ from company-controlled R&D centers regarding incentive mechanisms and the preference of formal IP. In addition to university-industry collaboration, multi-partner consortia and networks can act as a boundary organization. OI can especially be triggered when there is a dedicated university-based knowledge transfer organization (KTO) in place, as it increases the attractiveness of industry-informed agendas for scientists

(Perkmann and Schildt, 2015; Miller et al., 2016). KTOs also facilitate mediated revealing, in which firms disclose their R&D problems selectively, thus minimizing adverse competitive consequences while still enabling themselves to open up for external knowledge to address these problems (Perkmann and Schildt, 2015). Holgersson et al. (2018) also discuss knowledge revealing and note that shaping complementary and substitute appropriability regimes can be vital in dynamic and systemic innovation contexts, such as managed ecosystems, innovation networks, and platforms. This regime could be the basis for knowledge sharing in networks, helping to build long-term relations and stabilize collaborations when they build and expand on knowledge and capabilities from previous (interfirm) projects (Manning, 2017), especially when participants invest strategically in these technologies (Masucci et al., 2020). Specific platforms for open funding can be installed to increase the (external) funding capacity of activities (Chesbrough and Bogers., 2014).

4.4.2. Network-level execution of OI

The network-level effects during OI activities relate to (1) the development of innovation networks, including (2) role-based mechanisms and (3) financial mechanisms.

Firstly, Harryson (2008) distinguishes three types of *innovation networks*: creativity networks with mainly exploratory goals, transformation networks as an intermediate form, and process networks explicitly focusing on exploitation of knowledge and innovations (process networks). These networks vary in their goals and their development over time. Gilsing et al. (2016) performed a longitudinal study of the evolution of multiple technology-based alliance networks, to show that network development does not follow a path of linear progression, but instead resembles a non-linear sigmoid pattern during which goals are updated along the way.

Secondly, various *roles* can influence speed and success by enhancing the development phases of a network. There are technology scouts that help in identifying external discontinuous technological change and assessing the necessity to develop an appropriate reaction to this change (Rohrbeck, 2010). In addition, boundary spanners connecting technological areas as well as social brokers connecting otherwise disconnected actors enhance knowledge distribution and therefore learning within the network (Fleming and Waguespack, 2007; Rosenkopf and Nerkar, 2001). Lastly, a network board can operate as a governing mechanism, facilitating proper and timely decision-making as well as increasing chances for success (Wincent et al., 2009; Lee et al., 2010; Klerkx and Aarts, 2013; Masucci et al., 2020).

Thirdly, the availability of *financial means* also influences network-level OI activity. An effective innovation network requires network-level funding, not only because several network roles need to be present, but also due to higher transaction costs arising from complex interactions between various network partners (Christensen et al., 2005). Galán-Muros and Plewa (2016) describe the difficulty for networks to get appropriate funding and conclude that a lack of funding leads to lower results on mobility, R&D, and commercialization. The presence of corporate venture capital may help to overcome these costs, especially when venture capitalists choose to occupy a central network position (Anokhin et al., 2011). This will only be an option when the goal of the network is sufficiently in line with a venture capitalist's interests. In general, Chesbrough (2003) observed that joint interfirm programs themselves are perceived to be more relevant and therefore lead to better access to funding.

4.4.3. Network-level consequences of OI

The OI literature substantiates that actively participating in innovation networks benefits the partners, as they (1) increase their access to knowledge and resources due to (2) increased trust and better external relations, which in turn increase speed, flexibility and ability to adjust to changed market conditions.

Firstly, regarding *access to knowledge*, one of the main goals of innovation networks is to lower uncertainty (Camagni, 1991) by enabling easier and more flexible access to technologies due to intensified contact with clients and markets and long-term bonding of suppliers, clients and end-users (Dilk et al., 2008; Brown and Mason, 2014). For technology-driven start-ups, even simply attending network meetings can increase their chances to get access to external capital, because it increases the likelihood of receiving public offerings (Waguespack and Fleming, 2009).

Secondly, regarding *trust*, the network may enable engagements with like-minded actors (Kennedy et al., 2017; Halbinger, 2018). This allows trust to grow between innovation experts (Cook and Brown., 1999; Brown and Duguid, 2017) Especially in conditions of change, innovation networks offer speed, flexibility and the ability to adjust smoothly to changing market conditions (Dittrich and Duysters, 2007).

4.5. Referrals to mechanisms at the society level

At the highest level of aggregation, we identify the mechanisms for OI activities outside organized entities.

4.5.1. Society-level antecedents to OI

Several studies discuss elements affecting the innovative power of a region. Some of these mechanisms can be influenced by public policies and are therefore endogenous. Other impactful factors are not created or influenced by anyone, and therefore exogenous. For example, macroeconomic downturns (Ahn et al., 2017), market uncertainty in an industry (Chiaroni et al., 2010; Kim et al., 2015), and advancements of technological fields (Whelan et al., 2010) have strong effects on the rate of engagement with OI in a region, but are not affected by regional policies.

The OI literature also provides evidence of situations where *public policies* can indeed matter, either directly or indirectly. Radnejad et al. (2017) identify social or environmental pressures, for example, as the primary drivers for adopting OI. Such pressure can be created or at least supported by formal legislation. De Medeiros et al. (2014) identify legislation as being one of the factors impacting innovation activities in general. Moreover, the surrounding market dynamics, such as the strength of competition or openness of networks, influence innovation performance (Roper et al., 2013). Elements in the direct geographical environment of a firm can specifically play a role, such as the knowledge endowment in the region where a company is located (Wang et al., 2014) or the proximity of company-based or university-based research centers (Young et al., 2008). Roper et al. (2013) found that public policies or legislation promoting OI strengthen competition and/or increase knowledge diffusion, and therefore positively influence innovation results.

Lee et al. (2012) studied several countries implementing national OI policies, to conclude that facilitating a *positive innovation climate* may generate many new projects and also grows the value of government data, due to more extensive inside-out exploitation efforts. Cano-Kollmann et al. (2017) observe that public support can also indirectly support innovation performance when aimed at increasing openness. This study reports that public support improved OI results, both in terms of the number of external partners with whom firms collaborate and the number of OI activities performed. Dittrich and Duysters (2007) demonstrate that well-functioning technology networks in a region operate as important stimulators for OI practices and innovation success.

4.5.2. Society-level execution of OI

When in action, OI is strongly affected by *public* support *systems*. Support from the government can be monetary and non-monetary, but evidence suggests that non-monetary public support has a larger impact (Cano-Kollmann et al., 2017). Belussi et al. (2010) studied openness from a regional perspective and introduced the concept of 'open regional innovation system', building upon earlier work on regional innovation systems (Braczyk et al., 1998; Cooke et al., 1997; Iammarino, 2005). In

this respect, regions are meaningful loci of innovation, especially when they have developed into industrial clusters. Such regional innovation systems are fostered by direct and indirect linkages, cooperation and synergies among local economic actors and institutions. Based on empirical evidence in an Italian region, Belussi et al. (2010) concluded that public policies aiming to increase openness tend to positively impact the regional innovation system.

4.5.3. Society-level consequences of OI

Finally, we observe how OI activities affect society-level outcomes.

Table 2
Key mechanisms in current OI literature.

Category	Mechanism	Definition	Referrals
Governance & policies	1. Formal contracting	The negotiation process leading to a legal binding agreement that establishes a collaboration between two or more parties and specifies the rights and obligations of each party, including ownership, resource commitment, IPR, exclusivity, and termination procedures, as well as the structure and process of collaboration (Hagedoorn and Zobel, 2015).	2.5; 2.13; 2.21; 2.22; 3.18; 3.19; 3.21; 3.22; 3.27; 4.3; 4.5; 5.7; 5.9; 5.11; 5.14
	2. Organizational permeability	The degree of organizational openness, that is, the extent to which external ideas, trends and/or actors can affect and change operational, strategic or other key characteristics of the organizational system, e.g., firm, ecosystem, value chain (Aldrich and Herker, 1977; Colignon, 1987; Power, 2018).	2.7; 3.3; 3.4; 3.5; 3.6; 3.7; 3.28; 3.29; 4.1; 4.3; 4.9; 4.19; 4.25
	3. Value capturing	The strategies, practices, and processes of securing financial or non-financial returns from joint value creation activities (Chesbrough et al., 2018).	2.13; 2.17; 2.21; 2.22; 3.1; 3.3; 3.18; 3.19; 3.20; 3.27; 3.30; 4.4; 4.5
	4. Collaborative IP protection	The set of instruments available to protect critical ideas, technology and know-how while still enabling the originating entity to use them in open innovation collaborations (Manzini and Lazzarotti, 2016).	2.4; 2.5; 2.13; 2.21; 2.22; 3.6; 3.19; 3.25; 3.28; 4.3; 4.5; 5.7; 5.9
	5. Risk reduction and sharing	A set of practices intended to reduce the likelihood or impact of foreseeable adverse contingencies on open innovation projects (Bowers and Khorakian, 2014).	2.13; 2.14; 2.21; 3.15; 4.4; 4.5; 4.18; 5.7; 5.9; 5.10; 5.11; 5.13; 5.14; 5.15; 5.16; 5.18
	6. (Integrated) standardization	The process of developing and implementing technical standards based on the consensus of different parties that include firms, users, interest groups, standards organizations and governments to facilitate a normalization of formerly custom processes or new, not yet existing processes (Blind, 2004; Xie et al., 2016).	1.4; 2.11; 3.1; 3.19; 3.30; 4.5
Interactions & dynamics	7. Entrainment	The synchronization of activity cycles of one system to those of another, by matching speed and aligning phases to accomplish temporal fit between various actors and their activities (Ancona and Chong 1996; Khavul et al., 2010).	1.4; 2.1; 2.2; 2.3; 2.4; 2.14; 2.15; 2.18; 3.1; 3.7; 3.8; 3.9; 3.20; 5.4; 5.7; 5.11; 5.13
	8. Orchestration	The activities to purposefully build a semi-permanent interfirm innovation network, aimed to ensure the creation and extraction of value by leveraging dynamic capabilities related to knowledge mobility, innovation appropriability, and network stability, without the benefit of hierarchical authority (Dhanaraj and Parkhe, 2006; Klerkx and Aarts, 2013).	1.1; 1.2; 1.3; 1.4; 1.5; 1.6; 1.7; 1.14; 2.6; 2.13; 2.15; 2.19; 2.22; 2.23; 3.2; 3.7; 3.31; 3.14; 3.25; 4.2; 4.13; 4.14; 4.16; 4.17; 4.19; 4.20; 4.22; 4.23; 5.19
	9. Scouting of technology, knowledge, and partners	The activity of seeking new ideas, knowledge, technologies and potential innovation partners for further development and commercialization, through a matching process between external resources and internal requirements of an existing organization for strategic purposes (Brenner, 1996; Holzmann et al., 2014; Rohrbeck, 2010).	1.9; 1.10; 2.16; 2.19; 3.12; 3.15; 3.17; 3.27; 4.15; 4.23; 4.25
	10. Innovation intermediation	Building temporary bridges by acting as broker between enterprises, universities and public research organizations, when some developers of new technologies are not well-connected to potential users or developers with complementary expertise, knowledge and resources (Howells, 2006; Katzy et al., 2013; Stewart and Hyysalo, 2008).	1.6; 1.7; 2.6; 2.13; 2.19; 2.22; 2.23; 3.2; 3.31; 3.25; 4.2; 4.3; 4.9; 4.14; 4.16; 4.17; 4.19; 4.20; 4.22; 4.23; 5.19
Knowledge, skills and capabilities	11. Absorptive capacity	The ability of a firm to recognize the value of new (external) information, assimilate it, and apply it to commercial ends, which is a function of the entity's prior related knowledge and structures and processes for scanning, selection, and application external knowledge (Cohen and Levinthal, 1990).	1.7; 1.8; 2.16; 2.17; 3.10; 3.12; 3.14; 3.15; 3.24; 3.25; 3.31; 4.3; 4.13; 4.15
	12. Endowed knowledge base	The breadth - range of fields - and depth - novelty or quality - of the available body of knowledge about technologies, products and markets (Van der Borgh et al., 2012; Zhang et al., 2007).	1.14; 2.19; 2.21; 3.14; 3.15; 3.16; 3.31; 4.10; 5.5; 5.6; 5.8; 5.12; 5.16; 5.17; 5.18
	13. Collaborative trust	A willingness to accept vulnerability based on positive expectation of a (potential) collaborator, related to the uncertainty stemming from the risk of failure or harm to the trustor if the trustee does not behave as desired (Piezunka and Dahlander, 2015; Wyrwich et al., 2022).	1.1; 1.2; 1.5; 1.14; 2.15; 2.17; 2.20; 3.5; 3.6; 3.32; 4.4; 4.8; 5.1; 5.2; 5.16
Learning by doing	14. Tacit knowledge transfer	The process of replicating tacit knowledge - intangible, practical, and context-specific knowledge - held by one individual, team, or organization to another individual, team, or organization (Ambrosini and Bowman, 2001; Szulanski, 1996)	1.7; 1.9; 1.10; 1.12; 2.9; 2.11; 2.12; 2.17; 2.23; 3.6; 3.10; 3.11; 3.12; 3.14; 3.15; 3.24; 4.10; 4.12; 4.13; 4.14; 4.15; 4.25; 5.10; 5.16
	15. Collaborative prototyping	The joint development of early-stage versions of a new product or service in order to test and evaluate its functionality, design, and production process, and to enable design team members, users and clients to gain first-hand appreciation through active engagement with the prototype (Bogers and Horst, 2014; Buchenau and Suri, 2000; Budde et al., 1992).	1.10; 1.11; 1.12; 2.11; 2.20; 2.23; 3.6; 3.25; 3.28; 4.6; 4.12; 4.20; 4.22; 4.25

In general, innovation performance in a region tends to increase when networks are functioning in ways that provide firms easier *access to knowledge* (Dittrich and Duysters, 2007). Government support can reduce so-called network failures (Jugend et al., 2018) and therefore can indirectly boost the innovation success of incumbent firms. Making government data and knowledge publicly accessible also supports the creation of new (social) service offerings and therefore leads to more societal value (Lee et al., 2012). In this respect, the promotion of OI practices through networks leads to positive externalities, such as improved knowledge diffusion and knowledge endowment in a region (Roper et al., 2013). This is, again, positively related to the innovation performance of firms located in that region (Wang and Li-Ying, 2014).

When considering direct financial support, the literature provides evidence for the impact of governmental support on OI. By bearing part of the risk for early-stage technologies, public co-funding reduces the risk for private investors, which in turn increases overall innovation output (Lokshin and Mohnen, 2012). Policy makers should be careful with direct financial support, as this can lead to 'crowding out' effects, especially for firms that are already very innovative. In these situations, public money can substitute internal investments within firms, without increasing overall research activity (Cano-Kollmann et al., 2017).

4.6. Synthesis into key mechanisms

The review of the empirical OI literature demonstrates a great variety of referrals to mechanisms. Yet, many of these referrals involve the same underlying mechanism, either in different terms or different aspects of the same key construct. To advance the OI literature in this area, we carefully grouped together identical and highly similar referrals to mechanisms. For several mechanisms, we found no (clear) labels and definitions in our database of 160 selected publications on OI. We therefore consulted various adjacent literatures to provide well-defined constructs for these mechanisms. Examples of key mechanisms that appear to be largely undefined and undertheorized in the OI literature are organizational permeability (Aldrich and Herker, 1977; Colignon, 1987; Power, 2018), risk reduction and sharing (Bowers and Khorakian, 2014), and entrainment (Ancona and Chong, 1996; Khavul et al., 2010).

These efforts to codify core OI mechanisms resulted in 15 generative mechanisms, together covering more than 90% of all referrals to mechanisms in our database. These 15 key mechanisms, listed and defined in Table 2, together fall into four larger categories: (1) governance and policies, (2) environmental dynamics and interactions, (3) knowledge, skills, and capabilities, and (4) learning by doing. The four categories and 15 key mechanisms can be mapped onto Chesbrough's (2003) original conceptual scheme for OI, as visualized in Fig. 2 and described in Table 3. Notably, Fig. 2 positions each mechanism at a specific stage of the OI process, although it may operate across multiple (if not all three) stages. As such, we have positioned each mechanism in the OI stage in which it appears to generate most impact, based on the literature review.

Governance and policies, as the first category of mechanisms, pertain to the structural and procedural processes established to enable, steer, and govern OI activities. These mechanisms include formal contracting (e.g., Hagedoorn and Zobel, 2015), organizational permeability (e.g., Aldrich and Herker, 1977; Power, 2018), value capturing (e.g., Chesbrough et al., 2018), collaborative IP protection (e.g., Manzini and Lazzarotti, 2016), risk reduction and sharing (e.g., Bowers and Khorakian, 2014) and integrated standardization (e.g., Blind, 2004; Xie et al., 2016). Governance- and policy-related mechanisms appear to operate at all levels, except the individual one. As one would expect, this category of mechanisms is most common in the pre-execution (antecedents) stage of OI activities, because governance structures and management procedures are usually designed upfront.

A second category of mechanisms, *environmental dynamics and interactions*, relates to the context in which OI activities take place. These mechanisms move beyond the immediate OI activity, yet have a significant impact on how OI projects and networks plan, operate, and perform. This category of mechanisms draws upon a variety of academic disciplines, including organizational adaptation, evolutionary theory, economic geography, and administrative behavior. The four key mechanisms in this category are entrainment (Ancona and Chong 1996; Khavul et al., 2010), orchestration (Dhanaraj and Parkhe, 2006; Klerkx and Aarts, 2013), scouting (e.g., Holzmann et al., 2014; Rohrbeck, 2010), and innovation intermediation (e.g., Howells, 2006; Katzy et al., 2013). These mechanisms occur at all levels except the individual one.

The third category involves mechanisms in the area of *knowledge, skill, and capabilities*, which are observed at all five levels of analysis. This category of mechanisms encompasses a variety of capabilities that enable OI activities, ranging from education at the individual level to boundary spanning capabilities at the network level. The three mechanisms defined in Table 2 are absorptive capacity (Cohen and Levinthal, 1990), endowed knowledge base (Van der Borgh et al., 2012; Zhang et al., 2007), and collaborative trust (Piezunka and Dahlander, 2015; Wyrwich et al., 2022). These three mechanisms have a reciprocal relationship with OI activities and outcomes: for example, absorptive capacity and collaborative trust increase the performance of OI activities, but the latter also enhances absorptive capacity and collaborative trust between OI partners. Knowledge, skills, and capability mechanisms are most frequently derived from the literatures of psychology and sociology, including concepts from research into human and social capital, personality and traits, organizational learning, and Marshallian economics. These mechanisms are particularly useful in explaining OI results at various levels of analysis.

Finally, the *learning by doing* category refers to mechanisms that incorporate aspects of learning which occur primarily through and from enhancing and deepening experience. This type of learning takes place in a variety of OI activities, ranging from work in open project teams or virtual environments to learning how to manage mergers and acquisitions for technology-related purposes. Table 2 defines the two key mechanisms in this area: tacit knowledge transfer (Ambrosini and Bowman, 2001; Szulanski, 1996) and collaborative prototyping (Bogers and Horst, 2014; Buchenau and Suri, 2000). OI studies using these mechanisms frequently build upon the literature about individual and organizational learning, the behavioral theory of the firm, and the knowledge-based view of the firm—using concepts like problemistic search, experimentation and discovery, and knowledge transfer. These learning-based mechanisms occur at all levels of analysis and are mostly used in explaining the execution of OI activities.

5. Future research avenues

The review of mechanisms in the empirical OI literature not only reveals the breadth and depth of the extant body of knowledge on OI antecedents, execution and outcomes, but also uncovers various gaps. Some of these gaps bear strong theoretical or empirical relevance and require further investigation. Table 4 provides a comprehensive overview of the avenues for future research arising from the OI mechanisms identified and defined earlier.

In the area of governance and policies, research opportunities arise regarding the origins and consequences of structures, contracts, and procedures. For example, future studies could analyze the effectiveness of various methods for increasing organizational permeability and how project teams (should) balance the tension between shared value creation and private value capture. On a larger level, there has been very little research on the role of interactions and dynamics in each of the mechanisms. This results in promising avenues for future research, drawing on questions such as: what methods for creating organizational permeability have the strongest effect on a firm's engagement with OI; how do networks create and renegotiate formal contracts to orchestrate their activities; how does the degree of formal contracting enable or inhibit individual learning by employees in ongoing OI projects?

In the area of dynamics and interactions, the reviewed literature

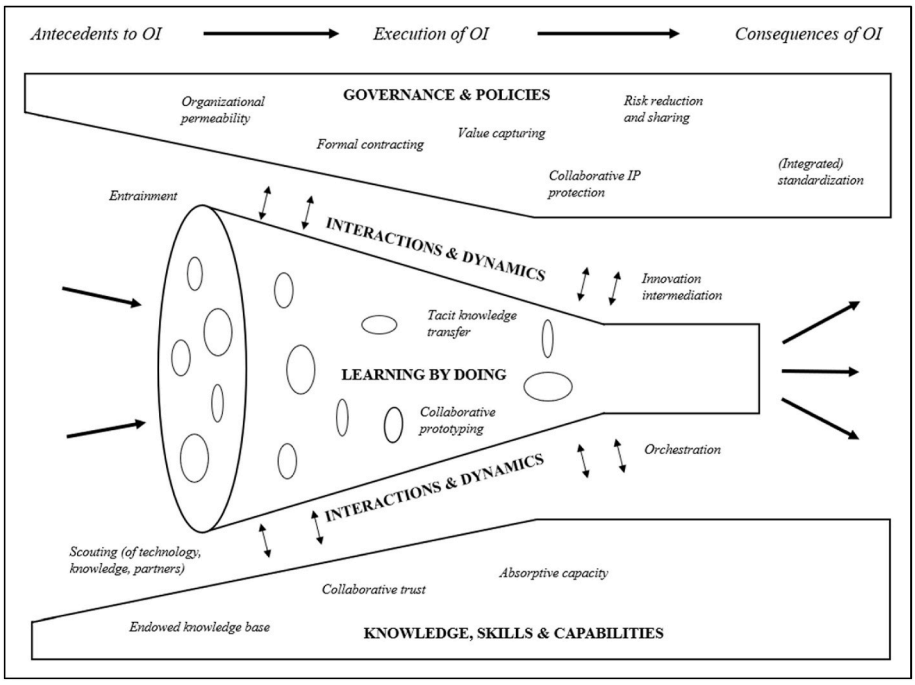

Fig. 2. Conceptual framework of OI mechanisms.

Table 3
Overview, definition and examples of categories of mechanisms.

Category	Description	Levels observed	Foundational theories	Key OI mechanisms (from Table 2)
Governance and policies	The way rules, norms, and actions are structured, sustained, regulated and embedded.	Project, firm, network, and society	Economics, (property and contract) law, strategy, game theory	Formal contracting, Organizational permeability, Value capturing, IP protection, Risk sharing, Integrated standardization
Environmental interactions and dynamics	The way a person, project, firm, network or society interacts with, or is affected by its environment	Project, firm, network, and society	Evolutionary theory, economic geography, administrative behavior, organizational adaptation	Entrainment, Orchestration, Scouting, Innovation intermediation
Knowledge, skills, and capabilities	Awareness or understanding about specific topics, capabilities or experiences	Individual, project, firm, network, and society	Psychology, Sociology, Social capital theory	Absorptive capacity, Endowed knowledge base, Collaborative trust
Learning by doing	Executing OI-related activities and outcomes	Individual, project, firm, and network	Organizational learning, Behavioral theory, Knowledge-based view	Tacit knowledge transfer, Collaborative prototyping

reports strong effects of scouting, intermediation, and orchestration activities (e.g., Rohrbeck, 2010), but there is hardly any knowledge on why and when firms decide to engage in (particular types of) scouting, intermediation, and orchestration. Similarly, the effectiveness and consequences of each of these mechanisms varies by project, organization, and context, and this variety deserves more attention. Moreover, alignment between collaborating parties has shown to be a necessary condition for successful OI (e.g., Gesing et al., 2015), but how this alignment is created or maintained is less well understood. Promising questions for future research related to the mechanisms identified in this category are, for example: how do collaborating entities synchronize and create temporal alignment at the start of a project; which scouting methods are most effective for finding new OI partners; how do OI partners sustain temporal fit in ongoing collaborative projects; are collaborators able to rebuild alignment when they are no longer synchronized, and how? Beyond the known mechanisms in this area, future work also can explore alternative mechanisms like conflict resolution and employee mobility.

Studies of mechanisms in the knowledge, skills, and capabilities category often provide a detailed chain of events to relate context and actions to outcomes. A promising avenue for future research involves the question how OI interacts with the endowed knowledge base. Whereas some studies have shown that engagement in OI offers opportunities for skill development and absorptive capacity building (e.g., Kim et al., 2015), others pose that successful OI projects require strong parties that already have the relevant knowledge and absorptive capacity (e.g., Enkel and Bader, 2016). As both statements seem plausible, future research needs to explore how these two cause-effect relationships interact during OI activities. Further questions for future research related to the mechanisms in this category include: how do OI project participants build collaborative trust; which elements of an endowed knowledge base foster or discourage initiating OI activities; and does collaborative trust affect the financial performance or strategic impact of OI projects? Additionally, whereas most research has focused on creating and benefiting from mutual trust (e.g., Fleming and Waguespack, 2007), less is known about what leads to mistrust or how trust can be restored.

Learning-by-doing mechanisms explain how experiences affect the engagement of individuals and firms with OI, shape the nature and governance of OI projects, and impact various OI outcomes (e.g., Rosenkopf and Nerkar, 2001). Interesting questions for future research in this area include: how can individuals with a lot of tacit knowledge be motivated to engage in OI activities; when do firms or networks engage in collaborative prototyping in the face of competition and imitation; under which conditions are teams less likely to share essential tacit knowledge; and does collaborative prototyping affect the range and

Table 4
Future research opportunities.

Category	Stage	Opportunity
Governance and policies	Antecedents	- What methods for creating organizational permeability have the strongest effect on a firm's engagement with OI? - How do networks create and renegotiate formal contracts to orchestrate their activities?
	Execution	- What risk-reduction methods are used at the various stage and levels of mature of OI projects? - How do collaborative teams deal with competing demands from value creation and value capture?
	Consequences	- Does collaborative IP protection result in similar-but-shared or rather different financial and strategic benefits? - How does the degree of formal contracting enable or inhibit individual learning by employees in an ongoing OI project?
Environmental interactions and dynamics	Antecedents	- How do collaborating entities synchronize and create temporal alignment at the start of projects? - Which methods of scouting new knowledge and technologies are most effective for finding new OI partners?
	Execution	- How do OI partners sustain temporal fit in ongoing collaborative projects? - Why and when do networks need an orchestrator instead of relying upon self-organization? - What is the sequence of activities that innovation intermediators perform to build bridges?
	Consequences	- How do orchestrators influence or change the value distribution among their networks of participants? - Are collaborating parties able to rebuild alignment when they are no longer synchronized, and how?
Knowledge, skills, and capabilities	Antecedents	- How do project teams build collaborative trust among their members? - What elements of an endowed knowledge base foster or discourage initiating OI activities?
	Execution	- When does a lack of absorptive capacity hamper OI activities? - What are the consequences of unequal absorptive capabilities for OI activities at operational levels?
	Consequences	- How do OI activities themselves affect the endowed knowledge base at the firm, network or regional level? - Does collaborative trust also influence the financial performance or strategic impact of OI projects?
Learning by doing	Antecedents	- How can individuals with more tacit knowledge be motivated to engage in OI activities? - When do firms or networks engage in collaborative prototyping in the face of competition and imitation?
	Execution	- Which conditions favor or impede the transfer of tacit knowledge across organizational boundaries? - How are the approaches for collaborative prototyping decided in networks?
	Consequences	- Under which conditions are teams less likely to share essential tacit knowledge? - Does collaborative prototyping affect the range and speed of implementation or adoption of OI?

speed of implementation or adoption of OI? At more aggregate levels, future research may focus on alternative mechanisms related to learning-by-doing, like individual and organizational (un)learning and exploration.

OI research also appears to be unevenly distributed across the various levels of analysis. As such, there appear to be ample opportunities for OI research at the network and societal level. At the level of networks, a small number of OI studies have addressed static network effects, such as the interaction between OI and network structure and governance (e.g., Manning, 2017; Radnejad et al., 2017; Young et al., 2008). Yet, networks evolve and change over time and these dynamics will influence OI mechanisms. These dynamic patterns constitute uncharted territory. Even fewer studies have been conducted at the societal level, which leaves many questions unanswered. For example, how do OI mechanisms operate within different national cultures is not well understood, but potentially significant. Similarly, Chesbrough (2003) already mentioned the importance of specific institutions, such as those in the area of contractual forms and IPR rules, but few studies have explored how these differences affect various OI mechanisms (Cassanelli et al., 2017; Manzini et al., 2017).

In addition, our review demonstrated a rather uneven distribution of empirical studies across different stages of OI: there is a substantial body of research on the 'antecedents to OI' stage, focusing on the organizational and policy-related choices to enable OI (e.g., Cheng and Huizingh, 2014; Salter et al., 2015; Lakemond et al., 2016; Manning, 2017; Groβmann et al., 2016; Rohrbeck et al., 2009), but far less on the stages 'executing OI' and 'consequences of OI'. Especially studies of the outcomes of OI are likely to provide novel insights. First, these studies may serve to classify outcomes into different types—related to financial, competitive, and innovative benefits—and the mechanisms leading to each of these. Second, limited research has been done on the negative outcomes of OI, such as asymmetric distributions of value captured between firms (e.g., Wang and Li-Ying, 2014; Xing and Sharif, 2020). This type of work may pinpoint to the importance of the underlying mechanisms for creating successful OI outcomes.

There are also ample research opportunities for cross-level and cross-stage research on OI mechanisms. With a few exceptions (e.g., Ahn et al., 2017; Zobel, 2017; Veer et al., 2016), research on the mechanisms in OI focuses on one specific level (e.g., individual or project). Yet, initiating and successfully accomplishing OI requires participation and support at multiple levels. Future research can therefore study how mechanisms at one level influence outcomes at another level, and how mechanisms at different levels interact and jointly influence OI. Likewise, specific mechanisms such as collaborative trust operate at multiple levels of OI. Future work in this area, therefore, needs to systematically scrutinize the effects of a single mechanism at different levels. Finally, the antecedents to OI will influence the ways in which OI activities are executed as well as the consequences of OI. Consequently, it is important to understand how the mechanisms operating in different stages relate to and (possibly) trigger each other, resulting in cross-stage research.

6. Concluding remarks

This study sought to identify the prevailing mechanisms in OI, also in relation to their contexts and outcomes. Our extensive literature review suggests that mechanisms are widespread in OI, grounded in constructs from economics, psychology, sociology, and other disciplines. Four categories of mechanisms were identified: governance and policies; environmental dynamics and interactions; knowledge, skills, and capabilities; and learning by doing. These mechanisms vary across the various stages of OI activity, but also between levels of analysis. Moreover, several key OI mechanisms appeared to be largely undefined in the extant literature, and we thus consulted adjacent branches of literature to develop a clear construct and definition for each of these mechanisms.

This review and synthesis exercise resulted in defining (at least) 15 fundamentally different mechanisms driving the success and failure of OI efforts (visually mapped in Fig. 2), which in turn serves to develop a systemic perspective on the barriers and difficulties that focal firms encounter in initiating and executing OI projects (e.g., Abhari and McGuckin, 2022; Audretsch and Belitski, 2022). Many opportunities for future research on OI mechanisms appear to arise from this broad overview of the OI territory, within as well as across the various stages or levels of analysis.

Our findings bear both practical and theoretical implications. A deep understanding of the (multiple) OI mechanisms at work can help practitioners to better predict and anticipate the consequences of specific

actions and strategies adopted. Our review shows that various mechanisms, for example in the governance of OI activities, give rise to a diverse set of consequences for individuals, teams, firms, and networks. Conceptually, this study synthesized the broad OI literature into a systematic framework of mechanisms, which in turn was instrumental in mapping promising areas for future research.

This review study has several limitations. First, we have been restrictive in the selection of empirical studies on OI. While we accomplished theoretical saturation in coding and classifying a set of mechanisms, additional mechanisms can possibly be inferred from studies not included in this review. Future reviews should therefore include a broader set of journals and other types of publications. Second, we have deliberately excluded crowdsourcing, open-source and related OI activities from our review, because they involve fundamentally different mechanisms than firm-centered OI effort and thus require a dedicated literature review and synthesis.

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Supplementary data

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