BIG FISH, BIG POND? THE JOINT EFFECT OF FORMAL AND INFORMAL CORE–PERIPHERY POSITIONS ON THE GENERATION OF INCREMENTAL INNOVATIONS

Massimo Maoret

IESE Business School

Barcelona Spain

mmaoret@iese.edu

Marco Tortoriello

Bocconi University

Milan, Italy

marco.tortoriello@unibocconi.it

Daniela Iubatti

SKEMA Business School, Université Côte d'Azur (GREDEG)

Sophia Antipolis, France

daniela.iubatti@skema.edu

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ABSTRACT

In this paper we apply a core/periphery framework to an intra-organizational context to study the interplay between formal and informal core/periphery structures. Specifically, we consider how core positions occupied by inventors in the corporate R&D division of a large multinational high-tech company affect their ability to generate incremental innovations. We theorize and empirically observe that formal and informal core positions have positive and independent effects on the generation of incremental innovations. These effects have a multiplicative impact on innovative productivity when inventors who are core in the informal knowledge-sharing network are also affiliated with a core organizational unit. We also observe, however, that the positive effect of being located at the core of both the informal and formal structures is negatively moderated by individuals' distribution of knowledge ties when these reach outside the core of their informal knowledge-sharing network.

Keywords: Core–periphery; informal intra-organizational networks; innovation productivity; formal structure.

INTRODUCTION

Several studies have highlighted the importance of informal, intra-organizational networks for achieving a variety of individual and organizational outcomes, including generating and implementing ideas and innovations (Burt 2004, Perry-Smith 2006, Sosa 2011, Tortoriello and Krackhardt 2010, Tsai 2001). On a purely conceptual level, however, considering informal structures as the primary driver of individual and organizational advantages might not be entirely warranted, as it overlooks the impact of *formal* organizational structures on the same outcomes. It is clear that informal networks matter; they provide privileged access to and enable control over critical tangible (e.g., budget; manpower) and intangible (e.g., information, knowledge and status) resources (Burt 1992). However, formal organizational structures also designate access and control over these resources (Scott 1975, Thompson 1967). Thus, even though comparable (and potentially competitive) theoretical mechanisms may link both formal and informal dimensions to individual and organizational performances alike, management scholars have often tended to overemphasize the importance of one perspective at the expense of the other. In the words of McEvily and colleagues, research contributions regarding the role of formal versus informal structures have been like "ships passing in the night" (2014, p. 302).

Our objective in this paper is to propose and test an integrative framework that considers the interplay of formal and informal social mechanisms, in order to explain individuals' innovation productivity in organizations. We focus on innovation owing to the fact that past research in this area has often attributed the ability to generate innovations solely to the inherent characteristics of the informal intra-organizational knowledge-sharing network in which individuals are embedded (Burt 2004, Perry-Smith 2006, Sosa 2011, Tortoriello and Krackhardt 2010, Tsai 2001). Such an emphasis on the role of individuals' positions in the informal network provides only a partial – and potentially confounding – account of the "actual patterns of interactions through which actors access and mobilize resources" to accomplish their professional goals (McEvily et al. 2014, p. 312). In particular, it could entail an overestimation of both the importance and the explanatory power of informal ties, at the expense of other enabling mechanisms that are driven by characteristics inherent to the formal structures of which innovators form a part. For example, access to financial resources or political support might stem from the fact that a focal individual belongs to a key organizational unit that is especially "central" to the overall activities performed by the organization (Astley and Sachdeva 1984, Ibarra 1993, Pfeffer 1981). Couple this with the fact that according to classical organizational theory, privileged access to resources, legitimacy and power clearly make it easier for people to reach their goals *irrespective* of their position in the informal social structure (Burns and Stalker 1961, Pfeffer 1978, 1981).

Heeding a recent call to integrate formal and informal views on organizational effectiveness and performance (McEvily et al. 2014), we start by putting the two approaches on an equal footing, both theoretically and in terms of the empirical analysis that ensues. In this sense, our study is different to previous ones that have looked at the contingent role that either team membership (Reagans and Zuckerman 2001) or formal roles (Burt 2004, Srivastava 2015) have on informal networks. Our study is also unlike those prior studies that have conflated the formal and informal dimensions by looking at how the former (in the form of functional or business units) is embedded in the latter (in the form of centrality in a knowledge-sharing network; Hansen 2002, Tsai 2001). Instead, our goal in this paper is to develop an integrative theoretical framework that explains the concomitant performance effects that arise not only when individuals occupy specific positions in informal knowledge-sharing networks, but also when they are affiliated to prominent organizational units in the formal organizational structure. To consider formal and informal structures together, as well as their impact on the development of innovative capabilities, we theorize and empirically test for the importance of occupying a core or a peripheral position in either dimension. The core-periphery framework has played an equally important role in organizational research applying to the study of informal structures (e.g. Cattani and Ferriani, 2008; Dahlander and Frederiksen, 2012; Fonti and Maoret, 2016) as it has to studies of formal structures (e.g. Siggelkow, 2002; Romanelli and Tushman, 1994; Thompson, 1967). Our contribution to these existing research streams is the theoretical development and application of a core-periphery framework that is applicable to formal and informal dimensions alike, and equally so in an intra-organizational context. We have chosen the R&D division of a large high-tech company.

Our setting is unique because it allows us not only to consider core and peripheral positions for individuals in the informal knowledge-sharing network, but also to consider the core or peripheral positions of the different formal organizational units in which these individuals operate. In particular, organizational units (such as the different laboratories that our R&D division comprises) might be core or peripheral in the *formal* organizational structure; and individual inventors (the engineers operating in the different R&D laboratories) might also be core or peripheral in the *informal* intra-organizational knowledge-sharing network. The question is: which combination of these two dimensions – being core/peripheral in the informal network or operating from a core/peripheral laboratory – determines the distribution of advantages that drive inventors' innovative productivity? And, are these advantages (and their related mechanisms) competitive and mutually exclusive, or complementary and additive?

These questions suggest how extending the application of a core–periphery framework to the study of formal *and* informal dimensions in an intra-organizational context opens up new lines of inquiry and enables substantive theoretical developments. Therefore, we explore and theorize the distinctive mechanisms that link both formal and informal core positions to innovation productivity within organizations, showing how both dimensions are independent and complementary, with multiplicative effects on innovation productivity. Our findings show that most prolific inventors occupy a core position in the informal intra-organizational knowledge-sharing networks *and* are also affiliated with core organizational units, highlighting the presence of separate and additive mechanisms that operate distinctively at both the formal and informal level. We further observe that in addition to occupying a core/core position, the distribution of individuals' knowledge-sharing ties also matters. In particular, core/core inventors with ties to the periphery of the knowledge-sharing network exhibit lower levels of innovative productivity. By contrast, those who concentrate their knowledge-sharing ties on colleagues located in the core of the informal network exhibit higher levels of innovative productivity.

THEORY

Extending the theoretical scope of core-periphery analyses

Core-periphery structure has been used in organizational research to explain a variety of outcomes at both the individual and organizational levels. Using the lenses and methodologies of social network analysis (Borgatti and Everett, 1999), the impact of core-periphery structures has been studied in different social systems and organizational contexts. Cattani and Ferriani (2008), for instance, investigated the creativity of crew members in the Hollywood movie industry as a function of their position in the core–periphery continuum which was based on their collaboration patterns. Dahlander and Frederiksen (2012) considered the core–periphery position of individual users in the communication network within and across online communities, in order to predict their innovativeness. Fonti and Maoret (2016) examined the direct and indirect performance effects on the stability of core–peripheral task-based interactions among individual members of basketball teams. While such studies advance our understanding of the mechanisms by which core–periphery structures affect different outcomes, they also rely on a single characterization of what the core and the periphery constitute. In these studies, and also in those investigating the role of centrality[1] on individuals' and organizational groups' performances (Ancona and Caldwell 1992, Hansen 2002, Smith-Doerr et al. 2004, Tsai 2001), core and periphery are determined exclusively by considering the distribution of one set of network ties among the specific social actors being investigated.

A different research stream inspired by evolutionary theory has used other criteria to identify organizational cores and peripheries. For instance, Romanelli and Tushman (1994) identified strategy, organizational structure, formal power and control systems as core organizational domains. This theoretical approach depicts organizations as formal arrangements of well-defined elements, such as management systems, sets of prescribed rules, hierarchical positions, resource allocation and reward systems that reflect the corporate strategy and mission, and identify *ex ante* what determines the organizational core (Burns and Stalker 1961, Chandler 1962, Mintzberg 1973, Tichy 1981; Baron et al. 1999). Although there is no standard definition of what represents the formal core vs. the periphery of an organization, there is a general consensus that a core organizational component is: 1) highly interdependent on other organizational units, and 2) highly influential towards the future development

[1] For a thorough distinction between network centrality and core positions, please see Borgatti and Everett (1999) and Dahlander and Frederiksen (2012). In synthesis, while core positions are also central, the opposite is not necessarily true, as central units/individuals can also be peripheral.

of other organizational units (Siggelkow, 2002: 127). Assuming this perspective, the resources and opportunities available for achieving specific goals are unevenly distributed within the organization and are more readily available for individuals affiliated with a core organizational component (e.g. a business unit, division or function) than they are for individuals affiliated with a peripheral component. Being part of the organizational core facilitates individuals' control over an organization's strategy for future development, its decision-making processes, its definition of control systems, and its budgeting processes (Pfeffer and Salancik 2003). In this sense, formal organizational structures can afford privileged access to resources and opportunities and offer incentives for those individuals located in (or closest to) core organizational components (Allen et al. 2007).

Social network and evolutionary traditions define organizational cores using different theoretical lenses. As such, they propose distinct mechanisms to link core positions to individual performance. These two research streams, by emphasizing the informal vs. the formal nature of core-periphery structures, have developed independently. As such, an opportunity has been missed to explore the possible positive – or indeed negative – complementarities that might exist between formal and informal structures in an organizational context[2] (McEvily et al., 2014). This means that formal organizational structures have remained "hidden" in informal accounts of how the core-periphery affects organizational outcomes. Likewise, informal network structures have also remained "hidden" in formal accounts of how core-periphery structures affect organizational outcomes. This mutual lack of acknowledgement about how one domain might affect the other is problematic for two reasons. Firstly, problems arise because in an organizational context formal and informal positions coexist and might form different combinations; indeed, while individuals can be core or peripheral with respect to the informal network of relations defined within an organization, the organizational units to which they belong can also be core or peripheral relative to other organizational units. It follows that being affiliated with core organizational units creates opportunities that are not available

[2] This is not necessarily the result of a conscious choice in terms of research design; for instance, some research contexts do not naturally lend themselves to a clear distinction between formal and informal organizational structures (e.g. Cattani and Ferriani, 2008). Thus, an important scope condition of our theoretical framework is that it applies in contexts where an easily distinguishable, dual-layered formal/informal organizational structure exists.

to individuals affiliated with more peripheral ones, irrespective of their position in informal network structures (Borgatti and Everett 1999, Hannan et al. 1996).

The second issue relates to the artificial distinction between formal and informal social structures brought on by past theories. Specifically, it is hard to determine where the advantages of core vs. peripheral positions come from. Is it the formal domain, the informal one or some combination of the two? Recent research, for instance, has conflated (and partially confused) organizational units' coreness with their centrality in the informal knowledge-sharing network, positing that central units within it possess privileged access to new and diverse knowledge developed elsewhere in the organization. This, it is hypothesized, enables them to achieve greater innovations and business performance (Hansen 2002, Smith-Doerr et al. 2004, Tsai 2001). Such an approach is problematic as it does not help to determine whether the advantages conferred by such positions are driven by formal attributions of these organizational units, and/or by their position in the informal knowledge-sharing network. Thus, our specific goal is to theorize and investigate individuals' innovation productivity not only as a function of their position in the informal network (Hansen 2002, Smith-Doerr et al. 2004, Tsai 2001), but also as a function of their position in the formal organizational structure.

The effect of formal and informal core/periphery positions on innovation productivity

There are important reasons why individuals' positions in organizational formal and informal structures should impact individuals' innovation productivity. Several studies have documented how organizational and individual innovative outcomes are affected by the degree of prominence that different formal organizational aggregates have within the larger organizational structure (Argyres and Silverman 2004, Arora et al. 2014, Bidwell 2012, Choudhury 2017). In particular, most prominent organizational units tend to influence the generation of innovative outcomes by determining priorities, devising the innovation strategy, assigning resources (staffing and budgeting), monitoring the development of activities, controlling the results, and sanctioning/rewarding the achievement of intermediate goals and milestones (Pfeffer and Salancik 2003). Studies on formal control and innovation have suggested that the use of control systems may positively impact innovation, especially in high-tech industries. For instance, in her study of R&D professionals in 57 pharmaceutical firms, Cardinal (2001) has shown that input, behavioral, and output controls increase innovation outputs, specifically incremental ones. This is because they enable organizations to manage the diversity of knowledge to which individuals have access, in order to (a) encourage innovation productivity through monitoring, and (b) promote the achievement of higher innovation goals using rewards. Core units perpetuate their advantage by controlling valuable resources and promoting a "commitment to previous decisions, [and the] institutionalization of beliefs and practices" (Arora et al. 2014, Burkhardt and Brass 1990, p. 105, Pfeffer 1981). Individuals belonging to core units could thus influence the process of defining strategies, goals and subsequent attributions of budgetary resources which might positively impact their innovative productivity. On the other hand, core positions likely entail more competition over securing resources, and could be defined by "winner takes all" dynamics that could hurt the average productivity of individuals working in core units. In this sense, peripheral formal positions could be shielded by such negative spillovers, and could facilitate collaborative environments that are less characterized by internal competition.

Similarly, when considering the *informal* network structure of work collaborations, the core/periphery framework may also introduce interesting tensions regarding the mechanisms leading to the development of innovations. The existing studies point to the idea that, on the one hand, being located at the core of the network favors the recognition and legitimacy of one's ideas (Cattani and Ferriani 2008, Dahlander and Frederiksen 2012, Perry-Smith and Shalley 2003). However, on the other hand this same position limits access to heterogeneous knowledge sources as it is more readily available at the fringe, or periphery of the network. In the same vein, while peripherally located actors have access to diverse and "fresh" knowledge that might spur creativity and new knowledge creation, by being far away from the core of the informal structure, they might encounter the lack of support and legitimacy that are critical for implementing their ideas (Burt 2004). The existing tension between core/peripheral positions in networks, however, hinges on two important assumptions. The first is the nature of the innovation type. While more creative and disruptive innovations do require exposure to diverse knowledge and perspectives (Hargadon 2003), for more incremental and cumulative types of innovation knowledge breadth might be less relevant. Second, existing studies were conducted at the field level (e.g., Cattani and Ferriani 2008, Cattani et al. 2013), where it is reasonable to assume that peripheral individuals have ties outside their primary professional field, increasing the diversity, and thus the novelty, of their ideas (Perry-Smith and Shalley 2003). In the Hollywood collaboration network, for example, peripheral actors are more likely to connect with professionals from other artistic disciplines, such as music or theater (Cattani and Ferriani 2008). This assumption, however, might not hold when we move the level of analysis inside organizations, since peripheral organizational members do not necessarily have greater access to external sources of knowledge than their core colleagues. Within an R&D function, for instance, peripheral engineers – by virtue of being more isolated – could become more specialized, and thus less open to exploring radically new ideas and more intent on exploiting existing ones.

The joint effect of formal and informal core positions on the productivity of incremental innovation

In this paper we complement prior organizational research on innovation, which has primarily focused on the development of new ideas (Burt 2004) and radical innovations (Hargadon 2003), by considering the joint effects of formal and informal core positions on the generation of incremental innovations (Collins 2004, Fidler and Johnson 1984). Incremental innovations are characterized by relatively minor changes in technology and are "associated with recombination that consists of combining improved components that are already connected within a technological domain" (Keijl et al 2016, p.1062). They are expected to be closely related to the firm's existing stock of knowledge (Yamakawa et al. 2011). In terms of individuals' abilities to develop incremental innovations, we anticipate that an *augmentative logic* (McEvily et. al, 2014) will link formal and informal core dimensions. Augmentative logic posits that "formal and informal elements build on and reinforce each other, amplifying their separate effects on the outcome variable of interest" (McEvily et al. 2014, p. 36). This amplification occurs because formal and informal core positions may impact the different phases required for developing innovations. Formal core positions offer the opportunity to (a) influence the innovation strategy pursued by the company, (b) secure more financial resources by being closer to the budgetary process, and (c) gain direct access to key tangible (manpower and equipment) and intangible (know-how, expertise and legitimacy) resources that enable inventors affiliated with core structures to develop their ideas into prototypes. Such benefits also apply to the subsequent idea implementation phase, in which inventors fully develop their prototypes into full-scale products (Perry-Smith and Mannucci 2017). Complementing these advantages, the consolidated knowledge present in the informal core may generate innovations that fall within recognized knowledge domains, thus making it easier to "champion" such new ideas internally thanks to the legitimacy afforded. Informal core positions might also help the actual implementation, given that close networks lead to the production of tangible outcomes by reducing individuals' perceived uncertainty, favoring collaborative relationships, and enhancing information sharing (Granovetter 1985, Lingo and O'Mahony 2010). The positive impacts of core formal and informal positions on different aspects of the "idea journey" should generate a multiplicative, augmentative effect (Perry-Smith and Mannucci 2017).

Thus, we expect that the augmentative logic underlying positions that are core in the informal network and affiliated to a core laboratory (core/core positions) should provide greater benefits in terms of incremental innovation productivity compared to peripheral positions in both the informal network and formal organization (periphery/periphery). The distinctions, however, become more subtle when comparing core/core positions with (a) inventors that are core in the informal network structure but are affiliated with a peripheral laboratory (core/peripheral), and with (b) inventors that are peripheral in the informal network structure but are affiliated with a core laboratory in the formal structure (peripheral/core). Let's take the example of an inventor who is core in the informal network but peripheral in the formal structure. It could be argued that s/he has enough clout to mobilize support informally and resources through his/her connections and core position in the informal social structure, perhaps also avoiding the intense intra-unit competition that sometimes characterizes core organizational units. However, operating from a peripheral laboratory might not allow him/her much of a say regarding either the innovation strategy or the budgetary process, putting him/her at a disadvantage when it comes to elaborating on his/her ideas internally and indeed implementing them (Choudhury, 2017). Indeed, this core/periphery case seems to be characterized by a supplementary rather than an augmentative logic (McEvily et al., 2014), where whatever is not offered in terms of advantages by the formal peripheral position might be at least in part, but not entirely, compensated by the advantages provided by the informal core position.

In a similar vein, there might also be advantages to generating incremental innovation for inventors who are peripheral in the informal network, but are associated with a core laboratory (peripheral/core). In such a position, an inventor might be able to delve deeper and autonomously exploit his/her existing knowledge base, by virtue of his/her peripheral position in the informal network. This continuous exploration could favor the development of incremental innovation (Ancona and Caldwell 1992, Allen et al. 2007, Magee and Galinsky 2008). Moreover, this inventor could also potentially leverage the benefits coming from the affiliation with a core laboratory in terms of legitimacy, access to resources, and ability to influence the innovation agenda. At the same time though, if this inventor is lacking strong and consolidated ties with his/her colleagues at the core of the informal network, he/she might not be able to generate enough consensus around his/her ideas and knowledge, and may not have enough clout/political capital to spend when budgets are defined and assigned. Moreover, recent research has shown that there are decreasing marginal returns to knowledge depth on the productivity of incremental knowledge (Kobarg et al. 2019), suggesting that the focus and potential hyper-specialization of peripheral inventors might, after a while, limit their ability to generate incremental innovations.

These arguments suggests that while there might be independent advantages to core/informal and core/formal positions for the individual productivity of incremental innovation, the ideal situation arises when core/informal positions are matched with core/formal positions. Hence our prediction that:

H1: Inventors who are located in the core of the intra-organizational knowledge-sharing network and are also affiliated with core organizational units exhibit greater productivity of incremental innovation than individuals who are at the core of either one alone.

Productivity implications of core/core individuals distributing ties across core and periphery

Although we expect informal-core/formal-core inventors to be more productive than inventors in any other combination of formal and informal positions, our reasoning does not necessarily imply that all the inventors located at the core of the informal *and* formal dimensions are equally productive when it comes to incremental innovation. To identify variations in the innovative productivity of core/core inventors, we introduce an important contingency to the proposed augmentative logic, arguing that different distributions of knowledge-sharing ties across the core-periphery network structure may substantially impact the productivity of core/core inventors (Allen et al. 2007, Dahlander and Frederiksen 2012, Tortoriello and Krackhardt 2010). In fact, core/core inventors could experience negative effects on their productivity of incremental innovation if they reduce the focus of their knowledge-sharing ties by distributing them too much toward the periphery of the informal knowledge-sharing network.

Core/core inventors are primarily connected to both formal and informal cores, but they might vary in how their knowledge-sharing ties are distributed toward other core or peripheral inventors. In principle, connections with different parts of the periphery of the network could extend the collaboration and knowledge breadth of the focal core/core inventor (Magee and Galinsky 2008, Tushman and Romanelli 1983). While this could prove beneficial for producing radical innovation (Kobarg et al. 2019), it might not necessarily help the productivity of incremental innovation, as it would increase the transaction and coordination costs associated with managing projects (Knudsen and Mortensen 2011). Moreover, the internal visibility of core/core inventors could be a quality sought after by potential collaborators, especially peripheral individuals or those located in peripheral units, trying to obtain advice, legitimacy or support for their knowledge production (Tushman and Romanelli 1983, Tushman and Scanlan 1981). Equally, they may be trying to develop ideas (Tushman and Romanelli 1983), or access critical resources (Pfeffer 1981).

Consequently, core/core individuals might have heavy demands on their network time and become distracted by relationships with colleagues located at the periphery of the network. However, as the proportion of network time devoted to members of peripheral groups increases, the ability of core/core individuals to focus their resources to produce more incremental innovations might start to decrease. As Dahlander and Frederiksen (2012) suggested, having ties across multiple groups might generate *decreasing* innovative performance, because of the difficulty of prioritizing and absorbing all the diverse knowledge they obtain. In addition, when engaging with the periphery, the costs of transferring knowledge to those who possess different knowledge bases increases (Tortoriello et al. 2012), shifting attention away from the development of incremental innovations that require knowledge redundancy and consolidation. The costs of sharing knowledge also depend upon the time and effort needed to communicate with the other party, which in turn are dictated by the diversity of knowledge shared and the difficulty of acquiring and integrating diverse knowledge (Reagans and McEvily 2003, Tortoriello et al. 2012). And so, although knowledge diversity favors highly creative outcomes, when ideas are ready to be developed into incremental innovations it might actually impede implementation activities (Ancona and Caldwell 1992). Concentrating one's ties in a core system of densely connected relationships represents the most favorable scenario because it enables the consolidation of the relevant knowledge for engaging in incremental innovation (Allen et al. 2007, Magee and Galinsky 2008).

Following this reasoning, we posit that the innovation productivity of core/core inventors is contingent on the extent to which they focus their network time and attention toward other core network inventors, rather than spreading themselves too thin by reaching out toward the periphery of the informal knowledge-sharing network. Consequently, we hypothesize that:

> *H2: The productivity of incremental innovation of inventors located at the core of the informal intra-organizational knowledge-sharing network and who are also affiliated with core organizational units decreases when their ties reach out to the periphery of the informal knowledge-sharing network.*

METHODS

To test these predictions, we used original data collected from the R&D division of a large multinational, multidivisional company in the semiconductor industry. The company structure features four main functions, including the R&D division, whose mission is to "provide the advanced knowledge necessary to establish [name of the company] as the leading company in the market for the next decade." Despite the flexibility that employees have in research interests and goals, the main objective of this division is to develop applied technologies that can be commercialized and eventually generate revenue for the company.

We collected questionnaires and archival data pertaining to 276 respondents who were part of the R&D division[3]. Senior managers identified these respondents as active in research and

[3] The network data was collected in 2005. At that time, the R&D division studied had been in operation for 6 years and it was at a phase of maximum development in terms of geographical and technological scope.

development activities. They were affiliated with 16 different laboratories (4 in the United States, 10 in Europe, 2 in Asia), and assigned to 21 different technological "roadmaps" (the company's lingo for technological expertise areas). These areas reflect the company's portfolio of industry-leading technologies. For each technological roadmap, the R&D division sought to identify new solutions for technological problems and pertinent products. Although the division was subject to overriding objectives in terms of technological advancements (such as lower energy consumption, higher speed, improved form factors on smaller chips, higher component reliability, and smaller ecological footprints), each roadmap represented a specific strategic move. Such moves were geared toward building knowledge, expertise, or solutions in a specific product domain, such as "power modules, wireless connectivity, automotive telematics and microcontrollers, digital set-top box, data converters, etc." In our sample, each individual's affiliation with the laboratories and areas of technological expertise was unique: he or she belonged to one lab and had one technological area of expertise only. The average lab and area of expertise consisted of 25 and 18 members, respectively. The population features mostly men (90%) who are highly educated (9% with doctorates; 78% with master's degrees; 13% with a college degree or less) and who have relatively low organizational seniority (average tenure is 5.2 years). The R&D division had been created relatively recently, so it continued to redefine its structure as the company pursued opportunities in various technological domains.

We obtained network data about the knowledge-sharing ties using a sociometric instrument, developed ad hoc. The response rate was 89% (245 actual respondents of 276 potential), and we took several steps to ensure the absence of non-response bias. First, a t-test revealed that non-respondents were not statistically different to respondents in terms of their innovation productivity, number of previous patents, laboratory location, area of expertise location, organizational tenure, or level of education (for more detail see Tortoriello and Krackhardt 2010; Tortoriello, McEvily and Krackhardt, 2015). Second, we treated missing data in several ways. To maximize the sample size, for non-respondents who were missing several control variables, we imputed the missing data with either the average values for the whole sample for each missing variable or with a 0 and an additional indicator variable that assumed a value of 1 if the respondent was missing (Allison 2002). Both methods produced similar results. In addition to network and human resource data from the company, we had access to all internal monthly reports of the R&D division issued six months before and twelve months after the administration of the network survey. These reports detailed each employee's innovation achievements and progress, which we used to obtain the dependent variable.

Dependent variable: Innovation productivity

The applied focus of this R&D division, with an emphasis on its mission to develop technology that could be rapidly commercialized, led us to measure *innovation productivity* as the number of technological improvements to products contributed by each individual in our sample (Reagans and Zuckerman 2001). We gathered this information from an analysis of internal monthly R&D reports that the company used to monitor and assess employees' performance and justify resource allocations for each budgetary round.

We hand-coded all the available reports to identify instances of a product's technological improvement. The detailed reports identify the nature and type of improvement specifically, such as one technological improvement that noted, "[individual's name]: H.264 Optimized Decoder: code clean up and re-organization has speeded up the decoding process by about 20%," or another that read, "[individual's name] improved the power accuracy of the system-level power model; in this way the power becomes 'transaction accurate' and no longer 'clock cycle accurate'." A count of all the improvements, regardless of the number of products improved upon, associated with each individual in our sample provides the dependent variable for this study.

Most innovation studies rely on patent data to measure individuals' and organizations' innovativeness (Ahuja 2000, Fleming et al. 2007, Stuart 2000, Tortoriello and Krackhardt 2010). We chose to use actual improvements for three primary reasons. First, access to the monthly R&D reports enabled us to observe the richness and complexity of the daily activities people performed, with a level of detail and granularity that would not have been possible otherwise. These activities, which are not necessarily geared toward creating disruptive innovations nor patentable technologies, represent the bulk of what the individuals in the laboratories did daily, so that our dependent variable was highly meaningful in our empirical context (Baer, 2012; Reagans and Zuckerman, 2001; Scott and Bruce, 1994). Second, the achievements described in the R&D reports provide the justification for budgetary assignments. Showing progress at the end of each month justifies the activities performed by individuals and enables them to keep their projects alive. Third, as we theorized about the role of core positions in the formal and informal structure as providers of legitimacy, support, recognition, resources, and consolidated knowledge, the actual improvement of existing technology is an appropriate descriptor of the type of innovation that is relevant for our theory.

Independent variables

Core position in the informal knowledge-sharing network. To measure knowledge-sharing relations among the individuals in the R&D division, we used a name-generating/name-interpreting technique common in intra-organizational sociometric studies. First, by using a name generator respondents indicated all colleagues with whom they regularly collaborated, from a list of all members of the R&D division. Subsequently, through a name interpreter, we asked respondents to "Please indicate how often you generally go to this person for information or knowledge on work-related topics." All the responses were compiled into a single informal knowledge-sharing network, which we used to compute core–periphery measures with UCINET software (Borgatti et al. 2002). Borgatti and Everett (1999) provide an algorithm of a core–periphery bipartition of groups for discrete data, which fits the core–periphery model for network data, identifying which actors belong to the core or the periphery, as given by Equations (1) and (2):

$$\rho = \sum_{i,j} a_{ij}\delta_{ij}, \text{ and} \tag{1}$$

$$\delta_{ij} = \begin{cases} 1 \; if \; c_i = CORE \; or \; c_j = CORE \\ 0 \; otherwise \end{cases}, \tag{2}$$

where a_{ij} implies the presence or absence of a tie in the observed data; c_i constitutes the class, core or periphery, to which individual *i* belongs; and δ_{ij} signals the presence or absence of a tie in the ideal core–periphery model. Equation (1) is a normalized Pearson coefficient applied to matrices (Borgatti and Everett 1999, Panning 1982); Equation (2) is the second step of the algorithm applied to the informal knowledge-sharing network data, which indicates whether each individual belongs to the core or the periphery subgroup. Thus, the indicator variable *core position in the informal knowledge-sharing network* takes a value of 1 if the focal individual is structurally located at the core of the informal knowledge-sharing network and 0 if located in the periphery of that network.

Affiliation with a core organizational unit. The formal core–periphery structure refers to the core or peripheral position of distinct organizational units — in our case, R&D laboratories. To identify the formal core–periphery structure of the R&D division, we used a blended approach involving objective measures and interviews with several company informants, to understand and qualify the formal structure. The objective of the interviews was to generate evidence to distinguish the formal core/periphery positions qualitatively of the different laboratories of the R&D division. We triangulated these qualitative accounts with several objective indicators, in particular we considered: the age of the laboratory, the number of employees assigned to it, its technological breadth, authority structure and reporting lines, the location of the control system of the budgeting process, and the physical proximity to headquarters. Based on these dimensions, two out of the sixteen laboratories in the division stood out clearly. We corroborated this initial distinction with qualitative/anecdotal evidence obtained by interviewing the corporate VP in charge of the R&D division, the head of human resources, and the financial controller of the company alongside several lab heads including the directors of the two key laboratories. The VP, head of HR and financial controller were part of the team that spearheaded the development of the R&D division, governing its expansion and strategic focus at the time of the study. Notably, the R&D division studied has been growing slowly, adding laboratories over time. According to the head of the division:

> "*Laboratories were formally established whenever we achieved a critical mass on a new promising technology that deserved dedicated effort, or identified a technological area where we wanted to be present.*"

The specific geographical location of each laboratory, particularly the newest ones, depended on privileged access to critical knowledge (e.g., next to a research center or university with expertise in that area) and the company's international expansion policy. At the time of the survey, two laboratories had been added less than a year before; the oldest laboratories had been established about a decade earlier. The older laboratories were considered the "motherboard" and development platform of the entire division. According to the human resources manager responsible for staffing the different labs in the division:

"*The concept for the R&D division started with the establishment of the first two laboratories… these laboratories were the center around which, over time, we added all the other satellite labs.*"

The first two laboratories' pivotal importance was corroborated by the levels of dedicated resources assigned to them: as the first ones to be established, they grew faster in terms of manpower and technological breadth, even before other operations were added. For instance, taken together, these first two laboratories represented approximately 22% of the total R&D division workforce at the time of the study.

Their importance is also reflected in the breadth of technological areas (i.e. roadmaps) they cover; namely 13 distinct areas of technological expertise out of the 21 covered by the entire division at the time of the study. According to the financial controller:

"*Our technological strategy was entirely defined within [name of site where the two oldest labs are located]. It was from there that we decided where to invest and, most of all, how much to invest. Often we received proposals to develop new roadmaps or to enter through acquisition into a new roadmap. The approval and 'go-ahead' was given directly from there by the Head of the Division after we checked that the numbers would make sense and all his direct reports were on board.*"

This quote highlights another important point regarding these two core laboratories: the VP (Head of the Division) and 5 of his 7 direct reports operated directly from this location and the physical co-location and proximity to headquarters mattered a lot for how decisions were made and resources assigned. All of the VP's direct reports ended up spending a large portion of their time in the two core laboratories mingling with the heads of roadmaps and other engineers. In the words of the head of HR:

"Even though these two laboratories are formally distinct entities, since they were created at the same time and they were so proximate to each other and to the core [i.e. headquarters and main production site] of the company, it was not uncommon to refer to them as one site. We always considered [Laboratory x] and [Laboratory y] as the same thing."

Finally, the physical co-location of these laboratories with the main company's production site made it easier for engineers assigned to these labs to negotiate and obtain financial support from the business units. That is, since almost half of the budget for each lab came from "sponsorships" offered by the different business units to work on specific development projects, given the technological breadth represented by the two core labs and their physical proximity with production, it was comparatively easier for them to obtain resources compared to other peripheral labs.

In conclusion, after leveraging objective labs' characteristics and corroborating qualitative evidence provided by key company informants, we identified a clear core–periphery structure in the formal distribution of laboratories with two key laboratories at the core of the R&D division and all the others at the periphery. In turn, we created a new dummy variable for each individual, based on his/her affiliation with a given laboratory. This *affiliation with a core organizational unit* variable took a value of 1 if the focal individual was affiliated with a core laboratory and 0 if affiliated with a peripheral laboratory. With this variable, we can test whether individuals' affiliation with a core laboratory enables them to achieve higher innovation productivity than individuals affiliated with peripheral laboratories.

Tie distribution. We used an E-I index as an indicator of each individual's knowledge-sharing tie distribution across the core and the periphery of the network. This index measures the extent to which an individual's ties span different organizational subgroups (Krackhardt and Stern 1988). For each respondent in our sample, we considered the distribution of network ties within and across the informal intra-organizational knowledge-sharing network core and periphery. We calculated the E-I index for each individual *i* by taking the difference between the number of ties that were external and internal to the informal network core. With E_i and I_i as the number of external and internal ties, respectively, the E-I index for actor *i* is:

$$\text{EI index}_\text{i} = E_i - I_i/E_i + I_i, \quad (3)$$

This index ranges from –1 (all ties are internal) to +1 (all ties are external). A value of 0 indicates that the numbers of external and internal ties are equal for *i*. With this variable, we can account for individuals' tie distribution across the core and periphery of the informal intra-organizational knowledge-sharing network.

Control variables

Several variables control for individual- and network-level variables that might provide alternative explanations for our hypotheses. Using the company's archival data, we control for individuals' positions as *laboratory leaders*, to rule out the potential effect of higher formal hierarchical positions. We also note *job grade*, the level of *education*, and the *gender* of each respondent, because each of these factors could correlate with an individual's core position. In order to address the time that each individual spends within the organization and relationships with other members of the laboratory or the division, we include *seniority* (expressed in days), and the *network centrality* (outdegree) in the overall informal intra-organizational knowledge-sharing network. Hence we reflect the number of ties the individual has within the division or in the overall informal intra-organizational knowledge-sharing network, respectively. Individuals' past innovative performance might also correlate with a core position in the informal intra-organizational knowledge-sharing network, so we account for the effect of the *number of previous patents* that each respondent submitted to the patent office between 2000 and 2003. This control variable is important for excluding the alternative explanation that people who were able to file a patent in the past are more core to the informal intra-organizational knowledge-sharing network, able to develop such new products, and more productive in terms of innovation.

We control for the type and amount of external knowledge[4]. Two key sources of knowledge, according to a principal component factor analysis with Varimax rotation, are *scientific external knowledge* and *industrial external knowledge*. Industrial external knowledge comprises four items from the questionnaire (Cronbach's alpha = 0.76) and a first principal component explaining 63.2% of variance. Scientific external knowledge also includes four items (Cronbach's alpha = 0.81) and a first principal component from a factor analysis accounting for 58.4% of the variance. The regression analysis includes the mean of the four-items measures as indicators of the sources of external knowledge. Controlling for the access to external knowledge enabled us to exclude the alternative

[4] Specifically, we ask respondents the extent to which they have used the following sources of external knowledge in their research activities: funded projects, standardization committees, collaboration with clients, collaboration with suppliers, participation to conferences, scientific journals, patents, collaboration with research institutions (for more detail, see Tortoriello, McEvily and Krackhardt, 2015)

explanation that greater connectivity of peripheral individuals outside their social networks may favor their creative outcomes, due to their exposure to diverse sources of knowledge (Tortoriello, et al., 2012; Cattani and Ferriani 2008, Perry-Smith and Shalley 2003).

Next, we control for the *specific laboratory* and the *area of technological expertise* to which each respondent belonged. We included fixed and random effects to control for unexplained heterogeneity attributable to idiosyncratic features of these laboratories and areas of technological expertise, which might be related to technological productivity. For example, one laboratory or area could tend to be more productive than another in terms of innovation, or it could focus on more mature or recent technological developments. Moreover, we control for various characteristics of the laboratory, such as *laboratory size* and the informal network position at the laboratory level, since previous studies have shown that laboratories that are more central in the knowledge-transfer network tend to have better access to knowledge and are thus more productive. And so we control for *laboratory centrality* (Smith-Doerr, Manev and Rizova 2004; Tsai 2001), intensity of *communication with other laboratories* (Ancona and Caldwell 1992) and *laboratory path lengths in the knowledge network* (using closeness centrality; Hansen 2002).

Finally, using UCINET, we control for *network density* by including each person's clustering coefficient (Borgatti et al. 2002) and for network redundancy by including each person's network constraint. The clustering coefficient is the number of realized ties among an ego's contacts, over the total number of potential ties. *Network constraint* (Burt 1992) is calculated as:

$$C_i = \sum_j c_{ij},\ i \neq j, \qquad (4)$$

where C_i is the network constraint for individual *i*, and c_{ij} is a measure of *i*'s dependence on individual *j* (Burt 1992). In turn, C_{ij} is expressed as:

$$c_{ij} = \left(p_{ij} - \sum_q p_{iq} q_{qj}\right)^2, q \neq i, j, \qquad (5)$$

where p_{ij} is the proportion of *i*'s network time and energy invested in the tie with j, as given by Equation (6):

$$p_{ij} = z_{ij} / \sum_q z_{iq}, \qquad (6)$$

and the variable z_{ij} measures the strength of the contact between i and j (Burt 1992). These last two controls capture potential alternative explanations that rely on the characteristics of the informal intra-organizational knowledge-sharing network to explain individuals' innovation productivity. A dense and closed informal network fosters knowledge redundancy and consolidation, which in turn favor implementation rather than creative activities.

Estimation strategy

Our dependent variable, innovation productivity, displays characteristics of a count variable: it cannot assume values below zero and its distribution is skewed. These features complicate the application of an ordinary least squares (OLS) regression model, as the variable does not likely satisfy the standard regression assumptions of linearity, homoscedasticity and normality of residuals. We therefore applied three remedies. First, we logged our dependent variable, which generally improves the theoretical applicability and reliability of standard OLS regression models. We also considered random- and fixed-effect models (when applicable) to ensure the stability of the coefficients of our explanatory variables within and across the formal organizational boundaries (scientific laboratories). Second, we employed robust estimators of variance, clustering errors at the level of the laboratory, which reduces concerns of heteroskedasticity. These modeling choices are important, because the variation of our outcome variable is likely clustered within scientific laboratories. Third, we employed negative binomial models to offer additional proof of the robustness of our results. Such models are particularly robust to the presence of overdispersion and excess zeros in the dependent variable, as in our case. These estimations produced results that are fully consistent with those reported below and are available on request.

RESULTS

Table 1 contains the descriptive statistics and bivariate correlation matrix of our set of main variables; Tables 2 and 3 illustrate the main findings of our regression estimations.

Insert Tables 1–2 about here

Baseline model and control variables

The baseline model includes all the control variables (Model 1). Three variables — lab size, seniority, and number of previous patents — show skewed distributions, so we took log transformations, which increases the linearity of the models and improves their fit. Using the untransformed versions did not substantially change the reported results. All control variables behaved according to our expectations. Notably, higher hierarchical positions have a stronger effect on individual innovation productivity. Both job grade and being a laboratory leader relate positively to the number of new products developed, though only the former offers statistical certainty ($p < 0.001$).

Structural positions in the informal intra-organizational knowledge-sharing network also seem to have the expected effect. Positions rich in structural holes exert positive influences on our dependent variable, as shown by the negative sign for the coefficients of egos' clustering coefficient and Burt's constraint ($p < 0.05$). Conversely, but in line with previous studies, network size does not show a statistically significant relation with innovation output ($p > 0.05$).

Testing the separate effect of formal and informal core positions on innovation productivity

We present our multivariate tests in Models 2-7 in Table 2. We first establish H1's two theoretical legs, i.e. the separate effect of formal and informal core positions on innovation productivity. Individuals that are core of the informal intra-organizational knowledge-sharing network exhibit greater innovation productivity -- as shown by Models 2 and 3. The two specifications feature different estimation techniques to control for unobserved heterogeneity at the scientific lab level: random-effects (Model 2) and fixed-effects (Model 3). Both specifications indicate that the coefficient for a core position in the informal intra-organizational knowledge-sharing network remains positive and statistically significant ($p < 0.05$). Model 4 indicates that individuals affiliated with a core laboratory also on average have higher innovation productivity ($p < 0.01$)[5].

Our qualitative evidence sheds light on some of the mechanisms underlying the positive coefficients. When commenting on the company's innovation strategy, one of the senior VPs argued that:

[5] Model 4 provides random-effects estimations (since affiliation with a given laboratory does not vary within labs, so a fixed-effect model is not applicable).

"Innovation goals have always been set up from the "core" of the organization. The core being [the main laboratories]. Here, the engineers in charge of different technological areas get together and agree on objectives to be developed in different laboratories and assign resources based on this agreement and vision."

This quote highlights how in this instance being part of the core let engineers be directly involved with the definition of the innovation strategy of the entire R&D division, thus facilitating the alignment of personal objectives with the division's goals. This also yielded important benefits in terms of financing, as confirmed by the company's financial controller:

"While half of the R&D budget comes from negotiations held centrally, most of the other half comes from business units that are willing to sponsor and support specific research initiatives. Since core laboratories are sitting right next to main business units, it is easier for engineers of core labs to have more and more frequent opportunities to meet with heads of units and explain how their research activities could help with a given product or families of products. This increases the likelihood of securing additional funding for activities carried out at core laboratories."

This statement is consistent with recent findings by Choudhury (2017) showing how important it is for R&D employees located far away from the formal core of the organization (i.e. the headquarters of a Fortune 50 multinational company) to have localized, face-to-face interactions with colleagues located at the core of the company in order to secure funding for their innovative projects.

Finally, the physical proximity of core laboratories to the main production and administrative sites may also afford additional benefits related to problem solving, as explained by the head of one of the main laboratories:

"While all labs have the same autonomy and freedom, being located in the main laboratory represented a clear advantage since it is close to everything [i.e. production, marketing, testing facilities, and the aforementioned key business units]. An inventor assigned to the main lab has, by default, access to the whole development process and has the ability to step in at any phase. This saves a lot of time and allows for problems and possible issues with the newly developed technology to be foreseen. Peripheral labs did not have this luxury."

This means that individuals in core units, by virtue of their position, are able to rely on more frequent interactions with other organizational actors, and to share consolidated knowledge with them, receiving the endorsement for their ideas to be developed into actual innovation (Balland et al. 2015, Cattani and Ferriani 2008, Collins 2004, Lingo and O'Mahony 2010). Therefore, if inventors occupying a core position in the network enjoy greater legitimacy, recognition and informal support compared to their peripheral colleagues, the following should act as multipliers of the informal benefits of core positions (McEvily et al, 2014): being able to participate and influence the definition of the innovation strategy; distributing physical and financial resources; and shaping the innovation process through direct and unmediated interactions with major stakeholders.

Hypothesis test: H1

Model 5 includes both formal and informal indicators and shows that both remain positive, statistically significant, and stable across different model specifications ($p < 0.05$). The inclusion of the two explanatory variables increases the overall model fit, raising the global variance explained by 2.9%. Most importantly, the coefficients of formal and informal core positions remain stable in magnitude when included together (as compared to the separate models), suggesting that the mechanisms generating the benefits of formal and informal coreness are additive and complementary, rather than substitutive. The lack of a temporal structure in our data may however raise some concerns about the causal identification of our theorized effects, especially pertaining to a core position in the informal intra-organizational knowledge-sharing network. For example, successful projects might in the past have established a cohesive informal network, and so being located at the core of such a structure could reflect past success, rather than an emergent knowledge-exchange pattern exogenous to innovation productivity. We thus ran a two-stage least-square (2SLS) regression; an approach commonly used to attenuate endogeneity concerns in social network analyses (Tortoriello, 2015). We select three variables as instruments — number of previous patents, seniority, and being a lab manager — with the assumption that these are proxies for past performance, tenure, and a high hierarchical position, and could exogenously drive collaboration patterns, thus rendering individual network positions artificially close to the core. Model 6 presents our two-stage, random-effect, instrumental variable estimations, with a core position in the informal intra-organizational knowledge-sharing network treated as endogenous[6]. The coefficients for formal and informal core positions in Model 6 follow a similar pattern, strengthening our confidence in the analysis by ruling out potential alternative explanations. Similar estimates using fixed effects *in lieu* of random ones confirm these findings (available on request).

We provide an initial test of the idea presented with H1 in Model 7, where we consider whether formal and informal core positions have an augmentative logic by introducing an interaction term between the two core position indicators. The interaction coefficient is positive and statistically significant ($p < 0.01$), empirically confirming the theoretical argument according to which engineers who are core in both the informal intra-organizational knowledge-sharing network and affiliated with a core laboratory achieve greater innovation productivity. H1, however, is proposing something more specific than what Model 7 showed. H1 is in fact proposing that greater effects on innovation productivity obtained when an individual who has a core position in the informal network also operates from a core laboratory *are greater than the effects observed when an individual has core position in either one alone*. Therefore, to compare the effects of different core positions, we include three new indicator variables in Models 8–13 (Table 3) and these allow us to unpack the different possible combinations of core/periphery in the informal/formal dimensions. In particular, we combined individual core and peripheral positions in the informal intra-organizational knowledge-sharing network with their affiliations with a core or peripheral laboratory. We described four different conditions in terms of formal/informal core/periphery: *core formal/core informal*, *peripheral formal/core informal*, *core formal/peripheral informal*, and a reference group of individuals who were peripheral in both formal and informal dimensions. We report this second set of analyses in Table 3.

Insert Table 3 about here.
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[6] Several tests confirm the validity of our instrument set. First, a significant under-identification test using Anderson's canonical correlations and Lagrange multiplier statistics rejects the null hypothesis that our instruments are weak ($p < 0.000$); they explain a large percentage of the variance in our first-stage model. The non-significant ($p > 0.05$) Sargan-Hansen test of over-identifying restrictions also strengthens our confidence that our instruments are valid and not correlated with the error term.

As can be seen in Model 8, all three combinations considered are positively and significantly associated with innovation productivity, relative to the reference group (excluded category) of peripheral/peripheral individuals ($p < 0.05$). However, by considering the coefficients of these three variables, it is possible to show that the coefficient for core/core individuals has a greater impact on innovation productivity compared to the other two combinations. In particular, the coefficient for a core/core position is statistically greater than the coefficient for a core formal/peripheral informal position (2.29 vs. 0.75; $p < 0.01$, F-test). In addition, the coefficient for a core/core position is also statistically greater than the coefficient for a peripheral formal/core informal position (2.29 vs. 0.68; $p < 0.01$). Taken together, the results presented in models 7 and 8 provide support for our first hypothesis.

Our second hypothesis (H2) predicted that the innovation productivity of individuals occupying a core/core position is affected by the distribution of their knowledge-sharing ties across the organization. Using the E-I index to capture individuals' propensity to distribute knowledge-sharing relations across the core and the periphery of the informal intra-organizational knowledge-sharing network, in Model 9 we observe that core/core individuals suffer a reduction in their innovative productivity to the extent that their connections reach out toward the periphery of the network. The negative, statistically significant coefficient ($p < 0.001$) of the interaction term supports our hypothesis that "focused" core individuals in core units outperform boundary spanners (H2).[7] As can be seen in the analysis, not only does the interaction term improve the model fit, increasing the overall explained variance by 0.8%, but the magnitude of the E-I index on individual innovation productivity is also of great interest. When core individuals in core units increase their E-I index by one standard deviation, their innovative output decreases by 0.52 standard deviations.

We conduct robustness tests to check H2. Fixed-effect estimations (Model 10) confirm our results and rule out an alternative explanation; namely, that specific laboratories might be more

[7] This interaction could be thought of as a three-way interaction among the formal core position, the core position in the informal network, and the E-I index. Thus, it is important to test the statistical significance of this interaction while taking into account all the two-way products across the three variables. With this robustness test, we affirm the statistical significance and stability of our interaction term ($p < 0.01$), even when considering all the two-way products of lower order. The magnitude of the interaction term remained the same. These results are available on request.

oriented toward innovation development due to their formal organizational mandate. Moreover, the theorized interaction pattern with the E-I index is valid only for positions at the core of both structures. To identify fully the interaction effect, we thus include two extra interaction terms, between the E-I index and the two other combinations (respectively, formal peripheral/informal core and formal core/informal peripheral) in Model 11. The results hold, deepening our belief that the theorized pattern applies only to core individuals in core units.

Additional robustness checks

In a further series of robustness tests, we seek to ensure the stability and validity of our reported findings across different model specifications. We first explore the potential presence of multicollinearity. Even in our most multicollinear model, Model 11, the variance inflation factor has a mean average of only 5.89, and every explanatory factor is below the threshold of 10. To affirm that the levels of significance for our explanatory variables are not artifacts of multicollinearity, we removed all control variables during an additional estimation, which in turn confirmed our reported patterns.

While innovation productivity in our models is attributed to individual engineers, it is reasonable to imagine that individuals in our sample could benefit from having formal or informal core individuals as members of their teams. We thus control for this potential alternative explanation by adding the number of formal and informal core colleagues in the focal engineer's team (Model 12). Results hold under this additional specification, revealing a partially significant effect ($p < 0.1$) and negative effect for the number of team members in formal core positions, hinting at a possible competitive effect on resource securing through formal channels that is consistent with our overall theoretical framework. Finally, we also conducted a full model specification (Model 13), from which we excluded 31 engineers who did not respond to our survey. In confirming these results once again, we can alleviate concerns about the potential for non-respondent bias.

In another series of additional analyses we took into account the distribution of residuals to make sure that this did not bias our estimates. We ran this robustness test with a negative binomial model, rather than its zero-inflated counterpart, for two reasons: (1) we have no reason *a priori* to assume that the probability process underlying the generation of zeros differs from that for other values; and (2) fully specified, zero-inflated Poisson and negative binomial estimations do not achieve convergence. Allison (2009) notes that the difference in fit between a negative binomial model and its zero-inflated counterpart is usually trivial because the latter is a special case of the former.[8] The results of a general linear model estimation, specifying the negative binomial as the underlying distribution, confirm our results.

Model extension and generalizability of findings

In addition to the analysis discussed so far, we also engaged in an exploratory analysis with a view to gaining further insights regarding the boundary conditions of our models. For instance, one notable extension of our theory would be to determine the extent to which the formal-informal core/periphery analysis proposed here is also helpful to capture variation on radical, as opposed to incremental, innovations. Although the type of work conducted in the R&D division studied was quite applied and the objective of the engineers surveyed was the constant improvement and refinement of current technologies rather than the identification of major technological discontinuities (Stokes, 2011), with the help of a company informant we went back to our monthly reports trying to parse "more radical" innovations, distinguishing them from more incremental ones. We applied a new coding protocol similar to that which we used for our main dependent variable, only more focused on new product releases, either software or hardware, that were considered novel for the firm and for the market (Dewar & Dutton 1986). In particular, we considered all those outputs that were not qualified as "improvement" or "extension" of pre-existing products or processes in the R&D reports and checked with the informant for dubious cases. Based on this new protocol, we were able to identify a limited number of non-incremental innovations (i.e. about 6% of the total innovations in the division). In Model 14, we then estimated the effect of formal and informal core positions on this new dependent variable. Estimates show a positive, significant effect of core/core and peripheral/core positions on radical innovation ($p < 0.1$), and a small, non-significant effect for core/peripheral positions ($\beta = 0.04$; $p = 0.75$). The statistically significant among coefficients of core/core and peripheral/core are not significantly different in magnitude ($\beta = 0.51$ vs. $\beta = 0.36$, respectively; t-test:

[8] Estimations employing a partially specified zero-inflated negative binomial model also confirm our results.

$p = 0.25$) suggesting that a) the effects of core formal and informal positions do not positively interact when affecting radical innovation and b) the whole effect of core positions on radical innovation is generated by informal positions. While we consider these results as exploratory and preliminary, they could be taken to indicate that the logic of interactions between formal and informal positions on the impact of radical vs. incremental innovation is likely to differ and may very well vary depending on the orientation towards innovation of the research site considered.

Another important step in evaluating the explanatory power of the proposed theory is to consider possible alternative explanations to the one we propose here. Our theory and findings suggest that core/core positions (and focused interactions) make engineers in our setting more productive in terms of incremental innovations. However, there might be alternative explanations as to why being part of a core laboratory boosts innovative productivity. For instance, there might be differences in terms of cultures across labs, or differences regarding incentive systems[9]. To rule out these potential alternative explanations, we performed an additional set of interviews with different lab heads, inquiring about KPIs and organizational culture within the R&D division and across different laboratories. In the words of the head of one of the two core laboratories:

> *"KPIs were the same for everyone irrespective of which lab you belonged to. [...] Rewards were given for the identification of something novel and useful for the company's core business development, and location did not matter at all."*

This claim was echoed by the head of one of the newly established labs who had experience working in a core lab prior to the new assignment:

"KPIs do not change based on laboratory or locations, and the way in which we are assessed is pretty much the same. We are all part of the same division as we all work for the same company".

Based on these comments, KPIs do not thus seem to vary across different labs. Indeed, the company's culture and incentive systems also seemed quite homogenous, as reported by the financial controller:

[9] We would like to thank an anonymous reviewer for this suggestion.

"We never had monetary incentives at [name of the company]; not in the R&D division for sure. Our engineers don't care much for extra money in their pocket; what they primarily value and care about is their freedom to invest in projects that matter to them. I know it sounds like a cliché but everyone in the division, from the most senior engineer to the latest intern, primarily wanted to pursue their research activities, and to have the freedom to do so."

This is not to say that there were no cultural differences within the division, a multinational organization itself. But as the head of HR put it:

"Obviously there were important cultural differences, we are a global organization! One thing is to work in [southern Europe] one thing is to work in [China]. However none of this impacted on the results achieved or on innovative productivity. Working styles were different but not in a way that compromised deliverables or objectives."

Although anecdotal and descriptive, once again these quotes are in line with our understanding of the context studied: the statistical differences we observed were not due to substantive differences in the cultures of the different units or in their incentive systems, but rather due to differences in the fundamental formal mechanisms of resource assignments, as we described.

DISCUSSION

A large body of social network research has investigated and shown the impact of intra-organizational networks on organizational and individual outcomes, particularly creativity and innovation (Burt 2004, Perry-Smith 2006, Smith-Doerr et al. 2004, Sosa 2011, Tortoriello and Krackhardt 2010, Tsai 2001). Such literature emphasizes the informal aspects of individuals' social relationships and how they affect behavior and actions, often overlooking how other organizational factors — such as the formal organizational structure in which individuals operate — may influence individuals' performances. By revitalizing the dialogue on the interplay of informal and formal social structures (McEvily et al. 2014), this article contributes to the network literature by extending the scope of core/periphery structures that have been used primarily to analyze either informal social networks or formal structures (Cattani and Ferriani 2008, Dahlander and Frederiksen 2012, Fonti and Maoret 2016, Hannan et al.1996).

Our results highlight that individuals positioned at the core of the informal intra-organizational knowledge-sharing network who simultaneously belonged to a core R&D laboratory had the highest innovative productivity, measured as the number of product improvements they were able to produce. However, we also observed that this greater ability to develop innovations was contingent on how these "core/core" individuals distributed their ties within the informal intra-organizational knowledge-sharing. In particular, core/core individuals with ties to the periphery of such networks tended to exhibit lower innovation productivity, while those who concentrated their knowledge-sharing ties on colleagues located in the core of the informal network achieved greater innovative productivity.

Theoretical implications: The effect of formal and informal structures on innovation

Our work responds theoretically to the recent call to "rediscover the missing link between formal organization and informal social structure" (McEvily et al. 2014, p. 299). Organizational theorists seldom investigate how formal and informal elements interact to define important organizational outcomes. Rather, prior literature on informal elements (social networks) and formal elements (organizational units) has developed in parallel, focusing only on a single distribution of ties among individuals or organizational groups. This literature has not been reconciled with the equally important role of formal structures as a predictor of individual and organizational performance (Burns and Stalker 1961, Krackhardt and Hanson 1993, McEvily et al. 2014).

Our findings are thus an initial, important step toward a more comprehensive examination of how organizational social structures affect innovation, which ultimately requires a precise identification of the inner workings of the specific social mechanisms that link formal and informal core positions to innovation productivity. At a baseline, our analyses reveal that the effects of core positions in the formal and informal structure largely operate in parallel. In fact, when controlling for each structure in our regression analyses, the magnitude of the effects of formal and informal core positions remain stable, hinting at the presence of distinct, non mutually-exclusive sets of mechanisms linking core positions and higher innovation productivity. This finding is important because it allows us to specify the nature of the relationship between formal and informal structures. Rather than being alterative or substitutive, the effects of these two dimensions are independently established and reinforce each other, increasing individuals' innovative productivity. This matters because the separate and joint effects of formal and informal dimensions should be theorized and tested as independent and not conflated or selectively ignored as has happened in the past (e.g., Ancona and Caldwell, 1992, Hansen 2002, Smith-Doerr et al. 2004, Tsai 2001).

We also offer a first insight into the nature of such mechanisms, which the literature has so far glossed over: in the words of Argyres and colleagues, "the organizational mechanisms through which R&D organizational structure affects innovation have been underexplored" (Argyres, Rios and Silverman, 2018). Our informants have qualitatively suggested that processes as the definition of the innovation strategy and goals, budgeting and staffing, monitoring and control, and interfacing with other functions are part of the key processes that belong to the formal core of our R&D division. In our setting, all these processes were carried out in two central laboratories, and our results show that being located there afforded material advantages to inventors and engineers that were precluded to those affiliated to peripheral laboratories.

Most importantly, our results show that formal and informal core positions do not simply co-exist and operate in parallel, but function according to what McEvily and colleagues (2014) call an *augmentative logic*, working together in an multiplicative way. This finding seems to point at the fact that formal and informal core positions enable individuals to leverage and mobilize not simply different, but *complementary* types of resources that facilitate implementation activities and greater innovative outcomes. For instance, individuals affiliated with core units, while mobilizing tangible resources (e.g., budget), might receive resistance from their peers within different units because they lack legitimacy and recognition. Conversely, though social support allows core individuals in the informal network to pursue their productive goals, they might encounter some resource constraints due to their affiliation to more peripheral units. Although each of these types of resources independently fosters individuals' innovation performances, their simultaneous, complimentary availability underlies the augmentative logic. Therefore, individuals affiliated to core units that are also core in the informal intra-organizational knowledge-sharing network reap greater benefits for achieving higher levels of innovative performance, taking advantage of the positive spillovers resulting from the combination of complementary tangible and intangible resources. Uncovering organizational complementarities is particularly important as they can generate competitive advantages for firms (Brynjolfsson and Milgrom 2013).

Our findings also suggest that such complementarity could be inter-temporal. In other words, our findings may point at how formal and informal positions impact different phases of the process "of converting the idea into a tangible outcome that can subsequently be diffused and adopted" (Perry-Smith and Mannucci 2017, p.56).

Positive impacts of different positions on different phases would generate a multiplicative effect like that which we found in our cross-sectional data. Since our dependent variable only measures the outcomes of the innovative process (and not different phases), future researchers should try to tease out how different structural positions interact with the whole innovation process, from idea generation to idea implementation.

Theoretical implications: Core-periphery structures

Our study also contributes to the social networks literature on the performance effects of core-periphery positions (Cattani et al. 2013, Cattani and Ferriani 2008). Previously, researchers have shown that individuals located at the interface of core and peripheries are able to resolve the trade-off between legitimacy and creativity, thus maximizing their ability to generate novel ideas (Cattani and Ferriani 2008). However, while the studies by Cattani and colleagues (2008, 2013) were conducted at the field level of analysis, our study extends the core-periphery framework, applying it to an intra-organizational context to study innovation. This extension matters for three reasons:

First, field-level network studies (e.g., Cattani and Ferriani 2008, Cattani et al. 2013), by nature of the empirical context examined, do not naturally lend themselves to distinguishing between formal and informal core-periphery structures. Arguably, in such contexts this distinction is minimal and inconsequential as with most project-based organizations, the formal structure overlaps with the internal division of labor and thus with the collaboration patterns among social actors. Moreover, both formal and informal components dissolve when the project is over, in stark contrast to the enduring social structures that emerge, diverge and ossify within organizations. Indeed, informal knowledge-sharing relationships often become misaligned with the respective formal structure (Krackhardt and Hanson 1993), making a distinct theorization of formal and informal at the intra-organizational level more salient than it could possibly be at the field level.

Second, the benefits of network peripheral positions hinge on the reasonable assumption that peripheral individuals have ties outside their professional knowledge-sharing networks, which increases the diversity, and thus the novelty, of their ideas (Perry-Smith and Shalley 2003). However, that strongly depends on the nature of the innovation considered. In our case, given the focus on predicting incremental instead of radical innovations, we did not find peripheral organizational members to have a distinct advantage because of their access to outside sources of knowledge. Instead, we find core positions to have a stronger impact on innovation productivity than peripheral ones (Dahlander and Frederiksen 2012), suggesting the importance of carefully identifying the benefits of peripheral positions within organizations with respect to the dependent variable studied.

Finally, and related to the previous point, our focus on incremental instead of radical innovation also matters (Dewar and Dutton 1986, Ettlie et al. 1984, Gatignon et al. 2002). Incremental innovations have often been disregarded by social networks researchers *in lieu* of novel idea generation (Burt 2004, Perry-Smith and Mannucci 2017), yet they absorb the majority of R&D investments in most companies (McEvily and Chakravarthy 2002) and have been proven to be extremely relevant for firms' financial performance (Christensen 1992). We believe our study could be a building block for future studies that focus on the implementation of incremental innovations, to refine our understanding of the many different ways in which organizations innovate.

Managerial implications

The results of this study also have practical implications for managers interested in improving their companies' technological and innovation performance. By overlaying two related core–peripheral structures, we give managers a tool to identify a small subgroup of individuals who constitute the organizational "engine," or core, in that they develop more innovations than anyone else, due to their legitimacy, recognition, support, status, and access to valuable knowledge and resources. It is crucial to isolate and identify this subgroup, especially when it comes to the demands of the wider organization. The visibility of these core/core individuals exposes them to requests from multiple organizational stakeholders, leaving them open to the risk of "spreading themselves too thin," which, according to our findings, could deplete the innovative productivity generated by their core positions in both the formal and informal dimensions, and create network patterns that are suboptimal for the organization as a whole. Core units should be encouraged to keep a focused system of network relationships gravitating around other central individuals, allocating time and effort for these relationships, particularly if the goal is to increase innovative productivity through the implementation of innovations. This is not to say that R&D managers should isolate their workforce in core networks, shielding them from connections with different parts of the network. Indeed, over time, this could result in the reduction rather than the promotion of innovation productivity. Instead, the message emerging from our findings is one of relative focus of network relationships (particularly for individuals located in core organizational structures) to counteract the tendency towards over dispersion of network time and effort.

Additionally, to increase innovation productivity, core individuals in the informal network that operate in peripheral organizational units should either be moved to core units or given more attention, resources and legitimacy through other mechanisms. We observe that such individuals could boost their high innovative productivity through affiliation with core formal units. Moreover, the structure of the informal network may change and evolve over time, which highlights the importance of continuously focusing network ties toward core parts of the network. As cores reconfigure in a network, for instance around new promising technologies, they have to be reinforced and protected to promote innovation productivity. Managers interested in boosting innovation productivity must identify and protect existing cores, while making sure that they don't stifle the reconfiguration of the informal structure.

Limitations and future avenues for research

While providing important contributions to theory and practice, this study has some limitations that must be acknowledged. First, we collected our data from a single R&D division of one company at a given time, and the participants in our sample had relatively short average tenures at the time of the survey. This begs the question of the generalizability of our findings to different empirical contexts in which the nature of knowledge is different (e.g., business units, service organizations, or smaller organizations), or in which individuals have had more time to structure their network and establish different connections. Additional research in different networks or to individuals with different characteristics (e.g. non-scientific settings) would help establish the external validity of our work. Second, endogeneity and reverse causality are common concerns in social network studies. Innovative individuals could be endogenously located at the organizational core, due to their innate characteristics. More innovative individuals may have idiosyncratic features (e.g., experience, expertise, etc.) that make them desirable for collaborations, which might in turn shape their position in the overall social structure. We tried to minimize such concerns in our empirical models, as all our analyses contain individual-level covariates as controls for individual experience, ability and knowledge. We also control for organizational tenure (proxy for experience), level of education, organizational job grade (proxies for knowledge and ability), and prior patenting experience (proxy for ability and expertise; Cross and Cummings 2004, Reagans and McEvily 2003, Tortoriello and Krackhardt 2010). In addition, we instrumented our informal core measure (Model 6 Table 2) to account for its potentially endogenous nature. However, the cross-sectional nature of our study does not allow us to conclusively eliminate the risk of endogeneity.

Overcoming this limitation would allow researchers to investigate how individuals successfully strategize in changing their network positions in each phase of the innovative process (Perry-Smith and Mannucci 2017). For example, individuals at the periphery of the informal social network, while favored in creative processes, might not be able to develop their ideas into tangible products because they lack the legitimacy, recognition and support in their social network required to pursue their productive endeavors. In addition, individuals affiliated to peripheral units do not have access to or control over the valuable resources necessary to develop ideas into innovation. Due to the cross-sectional nature of our data, we can only speculate how individuals at the periphery of the informal intra-organizational knowledge-sharing network and/or affiliated with peripheral units might position themselves over time in order to achieve greater innovation productivity. Individuals might be able to deliberately activate different ties not only within the same networks, but also in different networks (e.g., knowledge-sharing, friendship, advice, etc.) in each phase of the innovative process. Moreover, by showing how organizations are composed of multiple and non-overlapping social structures (i.e., informal intra-organizational knowledge-sharing ties and a formal organizational structure), it is possible that peripheral actors might leverage their affiliation to core units, or vice-versa, to develop their ideas into tangible products. A longitudinal analysis could well unveil how their potential, not only as providers of novel ideas, but also as leading players in implementation activities for the development of new products, is exploited in different stages of the innovation process, due to their positions in different social structures.

Finally, the combined benefits provided by formal/informal core-periphery positions might change substantially if a different type of innovation or different outcome variables altogether were being examined. For instance, predicting radical instead of incremental innovations might require a different combination of core/periphery positions across the formal and informal dimensions. Or, predicting other performance indicators could require the activation of mechanisms that are different to those we have documented in this study.

We hope that future research on core-periphery will extend the formal/informal analysis proposed here to different types of network ties and concepts, and to different types of formal arrangements that guide organizational functioning. This would extend the explanatory power of core-periphery models, and ultimately increase our understanding of how formal and informal mechanisms combine, explaining different types of outcome variables.

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Table 1. Descriptive statistics and bivariate correlation table.

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Innovation productivity	1.07	1.60															
2. Core position in informal knowledge-sharing network (coreness informal)	0.21	0.41	0.41														
3. Affiliation to a core organizational unit (coreness formal)	0.20	0.40	0.11	0.10													
4. Laboratory manager	0.06	0.23	0.27	0.26	-0.05												
5. Job grade	13.52	2.67	0.47	0.37	0.03	0.31											
6. Education level	2.95	0.49	0.04	-0.01	-0.01	-0.07	0.10										
7. Gender (1 = male)	0.90	0.30	0.06	0.08	-0.05	0.03	0.16	-0.06									
8. Seniority (log)	2.58	0.94	0.31	0.29	0.14	0.21	0.43	0.14	0.03								
9. Number of previous patents (log)	0.10	0.37	0.12	0.34	0.18	0.02	0.13	-0.06	0.02	0.23							
10. External scientific knowledge	4.56	1.33	0.14	0.11	0.20	-0.02	0.12	0.12	-0.04	-0.03	0.03						
11. External industrial knowledge	4.18	1.43	0.13	0.12	0.14	0.14	0.12	0.01	-0.06	-0.02	0.10	0.39					
12. Laboratory size (log)	3.07	0.62	0.06	0.01	0.50	-0.22	-0.07	-0.06	-0.06	0.08	0.04	0.23	0.01				
13. Network size	11.00	6.71	0.25	0.45	0.00	0.14	0.17	0.08	0.00	0.16	0.12	0.06	0.09	-0.05			
14. Network constraint	0.29	0.20	-0.23	-0.26	-0.05	-0.04	-0.22	0.08	-0.11	-0.15	-0.12	0.03	-0.03	-0.03	-0.04		
15. Network density	0.38	0.18	-0.29	-0.22	-0.14	-0.13	-0.17	-0.02	0.07	-0.30	-0.15	-0.09	-0.12	-0.19	-0.39	0.29	
16. Non-respondent	0.11	0.32	-0.02	-0.15	-0.01	-0.09	-0.01	-0.08	0.00	-0.02	-0.05	-0.04	-0.02	0.09	-0.58	-0.52	-0.08

Sample size n = 276. Correlations bigger than |0.095| are statistically significant at the 0.05 level.

Table 2. Results of OLS regression analysis of individual innovation productivity.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Core position in informal knowledge-sharing network (coreness informal)		.851*	.895*		.870*	1 .733*	.676*
		(2.222)	(2.324)		(2.280)	(2.256)	(1.783)
Affiliation to a core organizational unit (coreness formal)				.837***	.880***	.940*	.754***
				(4.156)	(4.427)	(2.119)	(3.585)
Coreness informal * Coreness formal							.867**
							(2.425)
Laboratory manager	.825	.617	.589	.769	.554		.550
	(1.264)	(0.922)	(0.816)	(1.145)	(0.8)		(0.795)
Job grade	.192***	.174***	.171**	.188***	.170***	.162***	.169***
	(3.841)	(3.688)	(3.708)	(3.814)	(3.653)	(3.573)	(3.676)
Education level	- .060	.009	.021	- .057	.013	.085	.012
	(-0.199)	(0.033)	(0.079)	(-0.191)	(0.050)	(0.403)	(0.045)
Gender (1 = male)	.143	.197	.170	.202	.261	.318	.226
	(0.512)	(0.698)	(0.720)	(0.751)	(0.961)	(1.097)	(0.796)
Seniority	.153	.095	.130	.162	.103		.096
	(1.164)	(0.758)	(1.061)	(1.239)	(0.821)		(0.797)
Number of previous patents	.131	- .035	- .124	.122	- .049		- .103
	(0.379)	(-0.095)	(-0.323)	(0.355)	(-0.135)		(-0.282)
External scientific knowledge	.029	.017	.013	.036	.024	.011	.027
	(0.402)	(0.248)	(0.186)	(0.5)	(0.354)	(0.146)	(0.416)
External industrial knowledge	.028	.017	- .001	.022	.010	- .006	.010
	(0.408)	(0.254)	(-0.010)	(0.322)	(0.150)	(-0.095)	(0.147)
Network size	.020	.001	.010	.028*	.009	- .010	.009
	(1.388)	(0.072)	(0.585)	(2.096)	(0.510)	(-0.384)	(0.479)
Network constraint	- .971**	- .815**	- .818*	- .851**	- .686**	- .484	- .713**
	(-2.691)	(-2.687)	(-2.567)	(-2.454)	(-2.408)	(-0.812)	(-2.459)
Network density	-1 .040*	-1 .214*	- .956*	- .994*	-1 .169*	-1 .411*	-1 .170*
	(-1.953)	(-2.297)	(-1.808)	(-1.865)	(-2.230)	(-2.306)	(-2.217)
Laboratory size	.119	.116		.107	.105	.053	.071
	(0.714)	(0.646)		(0.583)	(0.529)	(0.214)	(0.358)
Laboratory centrality	- .292*	- .269*		- .029	.008	.049	- .020
	(-1.952)	(-1.772)		(-0.247)	(0.054)	(0.154)	(-0.144)
Laboratory knowledge path lengths	7 .214*	6 .547		- .803	-1 .889	-3 .023	- .969
	(1.660)	(1.501)		(-0.252)	(-0.473)	(-0.342)	(-0.257)
Laboratory communication with other labs	.950*	.801		.605	.435	.201	.513
	(1.741)	(1.559)		(1.138)	(0.823)	(0.296)	(0.921)
Non-respondent	- .413	- .494*	- .360	- .277	- .354	- .442	- .383
	(-1.485)	(-1.650)	(-1.196)	(-1.051)	(-1.265)	(-0.990)	(-1.330)
Scientific laboratory random effects	Yes	Yes	No	Yes	Yes	Yes	Yes
Scientific laboratory fixed effects	No	No	Yes	No	No	No	No
Area of technological expertise fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coreness informal treated as endogenous	No	No	No	No	No	Yes	No
Constant	-8.305***	-6.923***	-0.720	-4.577*	-2.977	-1.490	-3.332
Number of observations	276	276	276	276	276	276	276
Number of scientific labs	16	16	16	16	16	16	16
R-squared (within)	0.428	0.448	0.463	0.432	0.453	0.430	0.460
R-squared (between)	0.400	0.388	0.124	0.444	0.427	0.424	0.434
R-squared (overall)	0.457	0.476	0.372	0.465	0.485	0.464	0.491
Robust standard errors clustered on scientific labs	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] t-scores are in parentheses.

[#] $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; one-tailed tests for hypothesized effects.

Table 3. Results of OLS regression analysis of individual innovation productivity.

	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
	Incremental innovation	Incremental innovation	Incremental innovation	Incremental innovation	Incremental innovation	Incremental innovation	Radical innovation
Core formal/core informal	2 .298***	2 .195***	1 .515***	2 .186***	2 .185***	2 .112***	.513***
	(4.928)	(4.668)	(4.206)	(4.263)	(3.806)	(3.875)	(3.120)
Core formal/peripheral informal	.754***	.717***		.650*	.894***	.775**	.041
	(3.585)	(3.270)		(2.047)	(3.846)	(3.027)	(0.316)
Peripheral formal/core informal	.676*	.659*	.670*	.685*	.539	.631*	.338***
	(1.783)	(1.847)	(1.808)	(1.787)	(1.267)	(1.721)	(3.685)
EI Index (core/periphery)		.402	.465	.227	.392	.304	
		(1.326)	(1.368)	(0.591)	(1.183)	(0.804)	
Core formal/core informal * EI Index		-2 .411***	-2 .394**	-2 .047***	-2 .214***	-2 .210**	
		(-3.631)	(-3.298)	(-3.881)	(-3.607)	(-2.844)	
Core formal/peripheral informal * EI Index				- .101			
				(-0.251)			
Peripheral formal/core informal * EI Index				.923			
				(0.820)			
Laboratory manager	.550	.552	.602	.581	.6	.619	.042
	(0.795)	(0.802)	(0.841)	(0.834)	(0.855)	(0.860)	(0.232)
Job grade	.169***	.164***	.164**	.163***	.158***	.151**	.014
	(3.676)	(3.632)	(3.619)	(3.516)	(3.748)	(2.393)	(0.936)
Education level	.012	.003	.012	.002	.048	.103	.026
	(0.045)	(0.013)	(0.050)	(0.009)	(0.209)	(0.388)	(0.347)
Gender (1 = male)	.226	.194	.092	.219	.179	.182	- .016
	(0.796)	(0.687)	(0.370)	(0.758)	(0.612)	(0.577)	(-0.167)
Seniority	.096	.068	.098	.087	.042	.089	.057
	(0.797)	(0.542)	(0.824)	(0.738)	(0.293)	(0.643)	(1.465)
Number of previous patents	- .103	- .090	- .163	- .132	- .057	- .040	.027
	(-0.282)	(-0.243)	(-0.411)	(-0.358)	(-0.151)	(-0.106)	(0.299)
External scientific knowledge	.027	.027	.018	.026	.023	.040	.023
	(0.416)	(0.414)	(0.288)	(0.402)	(0.368)	(0.586)	(1.196)
External industrial knowledge	.010	.003	- .009	.015	.008	.015	- .016
	(0.147)	(0.051)	(-0.148)	(0.245)	(0.123)	(0.229)	(-0.541)
Network size	.009	.009	.009	.011	.009	.010	.001
	(0.479)	(0.482)	(0.458)	(0.585)	(0.501)	(0.556)	(0.328)
Network constraint	- .713**	- .708*	- .822*	- .656*	- .668*	- .771**	.084
	(-2.459)	(-2.191)	(-2.349)	(-2.105)	(-2.075)	(-2.582)	(0.393)
Network density	-1 .170*	-1 .092*	- .901	-1 .035*	-1 .117*	-1 .141*	.243
	(-2.217)	(-2.003)	(-1.619)	(-1.920)	(-2.002)	(-1.966)	(1.430)
Laboratory size	.071	.049	- .305**	.070	- .008	.062	- .010
	(0.358)	(0.251)	(-3.148)	(0.352)	(-0.041)	(0.288)	(-0.117)
Laboratory centrality	- .020	- .026		- .052	- .103	- .010	.183
	(-0.144)	(-0.191)		(-0.376)	(-0.697)	(-0.056)	(1.373)
Laboratory knowledge path lengths	- .969	- .439		.252	1 .911	- .994	-4 .023
	(-0.257)	(-0.116)		(0.066)	(0.466)	(-0.196)	(-1.132)
Laboratory communication with other labs	.513	.569		.611	.624	.603	.508*
	(0.921)	(1.019)		(1.114)	(1.121)	(0.876)	(2.031)
Non-respondent	- .383	- .336	- .351	- .319	- .343		.060
	(-1.330)	(-1.087)	(-1.107)	(-1.049)	(-1.109)		(0.445)
Formal core team members					- .077*		
					(-1.787)		
Informal core team members					.091		
					(0.944)		
Scientific laboratory random effects	Yes	Yes	No	Yes	Yes	Yes	Yes
Scientific laboratory fixed effects	No	No	Yes	No	No	No	No
Area of technological expertise fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-3.332	-3.377	-0.501	-4.113	-4.365	-3.722	-1.129
Number of observations	276	276	276	276	276	245	276
Number of scientific labs	16	16	16	16	16	16	16
R-squared (within)	0.491	0.497	0.228	0.480	0.506	0.475	0.365
R-squared (between)	0.459	0.467	0.479	0.469	0.455	0.324	0.729
R-squared (overall)	0.486	0.494	0.420	0.495	0.477	0.448	0.268
Robust standard errors clustered on scientific labs	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] t-scores are in parentheses.

[#] $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; one-tailed tests for hypothesized effects.