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Turning heterogeneity into improved research outputs in international R&D teams

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Abstract

The heterogeneity that characterises international research and development (R&D) teams often brings with it a wide spectrum of knowledge and information resources potentially relevant for the operation of the team. This study provides an insight into the effects that heterogeneity of knowledge available within and created by international R&D teams may have on their research outputs. The study looks at a context where a positive relationship exists and high levels of knowledge sharing take place between team members, referred to as knowledge orchestration, as a prerequisite for successful outputs in international research. The research involved 93 members of R&D teams working – either directly or indirectly, on the domain of industrial mortars. Within that domain, research participants are focused on the search for innovative solutions to improving the energy efficiency of buildings and the production of renewable energy. Partial Least Squares (PLS) using the SmartPLS allowed for the analysis of the data collected from practitioners. The results show that knowledge orchestration has a significant mediation effect between the heterogeneity of knowledge created by international R&D and their outputs.

Keywords:
International R&D team, Heterogeneity of knowledge, International research outputs, Knowledge orchestration.

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1. Introduction

International organisations are, by nature, knowledge-intensive organisations (Ringel-Bickelmaier & Ringel, 2010). In an environment driven by the application of information technologies in all areas of socio-economic development, it is knowledge creation and reuse within the organisation which leads to innovation (Khedhaouria & Jamal, 2015) and to sustainable business performance (Inkinen, 2016). Notably different from local enterprises, international organisations have no choice but to encourage a collaborative approach to knowledge creation, planning, capture and diffusion between individuals and teams (Hume & Hume, 2016). Although such efforts do not always lead to a cultural change –as argued by Corfield and Paton (2016), they often lead the workforce to effectively engaging with knowledge management processes, developing reasoning skills and gaining a higher-level perspective of the importance of knowledge for the organisation (Little & Deokar, 2016).

Such a knowledge-driven complexity or structural uncertainty that dominates the context of organisations cannot be governed unless through the implementation of learning processes (Manlio Del Giudice, Carayannis, & Della Peruta, 2012). Investments in R&D teams therefore represent a way for firms to search for innovations that may improve performance (Alessandri & Pattit, 2014). Many international organisations have excellent R&D teams, often working in specialised and increasingly more geographically dispersed centres (Rodgers, Khan, Tarba, Nurgabdeshov, & Ahammad, 2017). However, businesses in general and international organisations in particular frequently fail to take advantage of other sources of research and development, such as those under the umbrella of governments (Cheng, Johansen, & Hu, 2015). Business opportunities are therefore missed due to a failure to address the demands of local, national and international businesses with the outcomes of the work of international R&D teams.

Scholars and practitioners acknowledge that R&D teams often lack the practical tools to fight against the heterogeneity of knowledge and its fragmentation (Felin & Hesterly, 2007). In this context, the concept of knowledge heterogeneity has been understood and defined in different ways. For example, drawing upon the interpretation of the concept by Atanasova and Senn (2011), Zhang and Li (2016) have described knowledge heterogeneity as the diversity of knowledge and skills that the R&D group represents, with a potentially immediate benefit to stimulate creativity. However, similar to the negative consequences that information overload –as a side effect of access and availability, may bring to individuals' productivity (Melnic & Botez, 2014; Werquim, 2010), knowledge heterogeneity within the team may have unintended side effects. While there are research groups that look for and apply new and diverse ideas (Tsai, 2018), others feel they just need more time for applying existing routines and practices to improve their daily operation (Zhang & Li, 2016). The combination of individuals and groups with a different appetite for the adoption of new knowledge within the same team may have negative consequences for productivity.

On these bases, it seems feasible to assume that the heterogeneity of knowledge can have a dual effect on business performance: by allowing the emergence of multiple, potentially effective interpretations of the same reality it may lead to deterioration of the working environment and uncertainty in some team members about the value of the information being used by the team. This means that under stressful circumstances (e.g. last-minute deadlines, budget cuts or unexpected/undesired mergers, acquisitions and takeovers), knowledge heterogeneity created by international R&D teams could be counterproductive as it leads to lack of coordination among otherwise homogenous groups, and to the widening of the range of potentially irrelevant options available (Zhang & Li, 2016). All of this may be translated into decisions that neither respond to the requirements of changes and contingencies nor bring any innovative ideas into the team (Amabile, 1998; Corfield & Paton, 2016). As Mukherjee, Gaur, Gaur and Schmid (2013) point out, knowledge heterogeneity in newly formed R&D alliances may generate contradictory effects by generating misunderstandings and a lack of common language within the organisation. The goal of knowledge orchestration in this context can be interpreted as supporting research collaboration with R&D team members worldwide by fostering personal interaction with technology tools such as data mining or big data analytics (Felin & Hesterly, 2007).

In this study, knowledge orchestration refers to the relationship and high levels of knowledge sharing between R&D team members (Nissen, Evald, & Clarke, 2014). Knowledge orchestration is therefore considered as the basis for knowledge creation (Nissen et al., 2014; Tan, 2016; Patel & Ragsdell, 2011), driving the emergence of new patents, the dissemination of research results and the emergence of new R&D projects, as well as reducing the risk of redundancy of research efforts (Nissen et al., 2014).

The analysis in this section points to heterogeneity of knowledge as a pre-requisite for the positive orchestration of knowledge that can help management counteract the negative effects of diversity, where needed. As Pineyro et al. (2013) noted, when a heterogeneous group with different points of view have to look for consensus, the presence of tools such as orchestration can help team members reach agreement. In this context of diversity of viewpoints, knowledge orchestration could also be a possible solution for network actors to appropriately mobilise and coordinate knowledge without sacrificing the agility and autonomy of the R&D team in decision making (Dhanaraj & Parkhe, 2006; Heikkinen &Tahtinen, 2006). Despite the evidence supporting these views, some studies have suggested that "the heterogeneity of knowledge" is a negative factor for workplace adjustments (Felin & Hesterly, 2007; Nissen et al., 2014).

To contribute to the understanding of the challenges in this context and particularly the circumstances where knowledge orchestration leads to improved research outputs, this study addresses the following two questions: (1) does the presence of heterogeneity of knowledge result in an increase in research outputs?, and (2) does the presence of knowledge orchestration tools enhance research outputs? Since the relationship between the "heterogeneity of knowledge created by international R&D team" and its "research outputs" has not been sufficiently studied (Molleman & Slomp, 1999), this research adds to the existing body of knowledge by studying the link between knowledge heterogeneity and research outputs though knowledge orchestration in international R&D teams. The following section reviews the relevant literature and proposes a conceptual model.

2. Conceptual framework

2.1 Knowledge orchestration

The definition of the concept of knowledge orchestration has evolved significantly over the years. Drawing upon a reading of Dhanaraj and Parkhe (2006), Yoo, Henfridsson and Lyytinen (2010) argue that coordination is needed for the intersecting organisations to acquire, distribute and use knowledge without sacrificing innovation, inventiveness, novelty, or newness. The concept of boundary objects (BOs) was introduced as an enabler of such a coordination, and described as those elements that allow for the accomplishment of coordination between multiple stakeholders (Star and Griesemer, 1989). Discussion of

BOs leads to the assumption of the presence of environmental elements and/or information and communication technologies (ICTs), shared for an anchoring of the influence and direction between network participants, and to fit the knowledge needs of each of them (Carlile, 2002; Griesemer, 2015; Nicolini, Mengis, & Swan, 2012). As a consequence, it has been argued that in their search for efficient knowledge exchange mechanisms, research teams need to foster those BOs that facilitate effective cooperation among agents across networks (Holdt Christensen & Pedersen, 2018; Jordão & Novas, 2017; Liu & Lai, 2011).

Although every organisation could apply a different approach to operationalising knowledge orchestration, several authors have already tried to find BOs that may help explain high degrees of coordination and effectiveness of network participants. For example, Lanza, Simone and Bruno (2016) quantified knowledge orchestration by measuring the presence of co-specialised employees. The results of their study suggest that by influencing the effectiveness of new and upgraded routines, old bureaucratic routines have a negative effect on performance. On a separate study, Liu and Lai (2011) measured BOs by studying analyst journals and analyst user communication recordings. Their findings point to the presence of different sub-groups and leaders within the organisation as a requirement for mutual adjustments (Connell & Voola, 2007; Suppiah & Sandhu, 2011), which affect those potential opportunities offered by bilateral partnerships when connecting organisations and their teams (Carayannis, Del Giudice, & Rosaria Della Peruta, 2014; Wenger, 2000a). In this regard, Cegarra-Navarro and Rodrigo-Moya (2005) propose to use inquiry-based activities, team-working, critical thinking and problem-solving skills as a way to search for solutions and to accomplish outcomes that go beyond limited vision of each of the parties concerned.

This study suggests that knowledge orchestration could be measured by operationalising virtual tools. Virtual tools were described by Laudon and Laudon (1996) as those appliances used for data and information management, and also to acquire, distribute and use knowledge at any time and in any place. We understand virtual tools as ICTs that allow for the improvement of intra- and inter-organisational communication and collaboration, the improvement of operations, the enhancement of productivity and team work, and the growth of the firm. Having access to virtual tools will engage members of the team in learning activities, thus creating and capturing knowledge via Internet-based tools (Bresciani, Ferraris, Giudice, & Del Giudice, 2016), and other mobile technologies (Del Giudice, Scuotto, Garcia-Perez, & Petruzzelli, 2018; Wang et al., 2003).

2.2 Heterogeneity of knowledge

We live in a heterogeneous world where, fortunately, there are more varieties of colours than just black and white. Bonifacio, Bouquet and Cuel (2002) describe “heterogeneity” as a dynamic and multifaceted process in which organisational members are mobilised by the free flow of information and ideas to have equal access to a diverse array of information (Cassiman & Golovko, 2011; Miller & Friesen, 1983). If we extrapolate these ideas to the business context, then it could be argued that heterogeneity of knowledge refers to those significant information asymmetries that exist among segments of stakeholders, enterprises and workers (Felin & Hesterly, 2007; Tsai, 2018). Cegarra-Navarro and Rodrigo-Moya (2005) provide interesting insights into the relationships between diverse thinking and team work by suggesting that a heterogeneous team is an imperative if management seeks to improve performance.

A heterogeneous R&D team is one in which members come from a diverse set of backgrounds or have a diverse orientation. International R&D groups formed by people from different cultural backgrounds may serve as a source of both variety of knowledge, know-how and understanding (Gronum et al., 2012; Yang & Wang, 2017). When not effectively managed, such a diversity often leads to discrepancy, inconsistencies and misunderstanding (Pelled et al., 1999; Tsai, 2018). Under these circumstances, it is important to understand which factors support and accelerate the efficiency of international R&D groups and which, on the other hand, lead to negative issues caused by the heterogeneity of knowledge. Athreye, Batsakis and Singh (2016) analysed knowledge sourcing in foreign-based R&D subsidiaries and found that competitive advantages will be more solid when there are several and different sources of knowledge.

2.3 Linking heterogeneity of knowledge with research outputs through knowledge orchestration

The analysis in this section leads us to argue that all information asymmetries generated via social and formal relationships are not necessarily negative for business performance and innovation. This is in line with the arguments made by authors such as Del Giudice & Maggioni, (2014) Gronum, Verreynne and Kastelle (2012), who have pointed out that by including different types and sources of information in the team, knowledge conversion could be enhanced, with an consequent positive effect on innovation. Along the same lines, Yang and Wang (2017) argue that when the information is compiled from different stakeholders and interest groups, each with their own aspirations and expectations, the results are richer and more cohesive. This in turn facilitates the process of meeting the information needs of users and teams (Manlio Del Giudice & Maggioni, 2014). Hirunyawipada and Paswan (2013) assert that the diverse and heterogeneous expertise of R&D members improve creativity in solutions.

Paradoxically, team members may also use or disclose their knowledge to generate common, ordinary outcomes. In this case, a highly specialised team may be found to be using its existing knowledge in a traditional way and therefore lack novelty in its outcomes. Furthermore, it has been found that information asymmetries between managers and employees may provide managerial solutions for authoritarian and repressive organisations (Cegarra-Navarro, Eldridge, & Wensley, 2014).

This study adheres to the stream of thoughts reflected in previous studies which have found heterogeneous knowledge to be a triggering factor of improving business performances, as highlighted by Santoro, Bresciani and Papa (2018). We therefore assume that by increasing the diversity of the sources of information, better cooperation between different users is achieved. This leads to a circumstance where the information needs of various agents or interest groups can be simultaneously addressed (Echajari & Thomas, 2015; Rodan, 2002). Based on this argument, this paper proposes the following hypothesis:

Hypothesis 1: Heterogeneity of knowledge has a positive effect on research outputs.

It is widely acknowledged that the right visual conditions (lighting, projection angle etc.) often lead to better visibility. In fact, “black” can be correctly identified as the visual impression experienced by a person when no light can reach the eye. By extrapolating these ideas to stressful situations in the business environment such as last-minute deadlines, budget cuts or unexpected/undesired mergers, acquisitions and takeovers, then it could be argued that not only may heterogeneity cause difficulties for knowledge conversion, but it may also cause intercommunication troubles, choice disagreement or even arguments (Pelled, Eisenhardt, & Xin, 1999; Tsai, 2018). As Knoppen, Sáenz and Johnston (2011) noted, different ways of implementing the learning processes may cause difficulties when applying new knowledge onto the innovation process. In addition, the heterogeneous and unverified information obtained from social media and other structures can become part of the problem (Sánchez-Casado, Cegarra-Navarro, & Tomaseti-Solano, 2015), leading to valuable time and resources being wastes if employees do not have access to the necessary tools for knowledge discovery and management (Little & Deokar, 2016). These tools are not limited to information technologies (Wang, Liu, Desai, Danilevsky, & Han, 2015), so long as they help team members to learn from mistakes and from one another while collaborating to pursue an improved team performance (Khedhaouria & Jamal, 2015).

These considerations led to an understanding that, in some situations, heterogeneity of knowledge may cause divisions and challenges when attempting to develop clear interpretations of reality which, in turn, may lead to a lack of a common language in the team. This means that, while useful in some cases, in certain circumstances heterogeneity should be controlled to stop it from interfering with the spontaneity and open-ended nature of free flow of information and ideas (Knoppen et al., 2011). As Huang, Lin, Wu, and Yu (2015) pointed out, the excess of autonomy in a research group can cause a loss of the overall vision of the company and lack of focus on its objectives. In other words, although high heterogeneity of knowledge derived from R&D autonomy improves working conditions for inventiveness, if not managed it may hinder the effect of innovation on the overall results of the company (Teirlinck, 2017). In this vein, Xiao, Zhang and Basadur (2016) suggest that only if knowledge is equitably distributed among members of a group, are equitable and efficient decisions achieved. When a greater control is needed, knowledge orchestration –often in the form of tools for knowledge discovery and management, offers an excellent opportunity to overcome some low-light situations and thus to discern all colour varieties in sight. In fact, since knowledge orchestration is a process that explicitly addresses the fragmentation of knowledge (Junni, Sarala, Tarba, Liu, & Cooper, 2015), this process can be used to broaden the vision pf management and hence that of the organisation (Coombs, Hislop, Holland, Bosley, & Manful, 2013).

Based on above arguments the following hypothesis is proposed:

Hypothesis 2. Heterogeneity of knowledge has a positive relationship with knowledge orchestration.

As previously discussed, knowledge orchestration can be operationalised through material objects and epistemic objects, supported in some cases by technological virtual tools (Ransbotham & Kane, 2011). According to Ferraris, Santoro and Dezi (2017), organisations should make offer their employees tools that facilitate the integration and homogenisation of both scattered and heterogeneous knowledge resources. Such tools could be used to empower employees to make their own decisions on how to deal with unwanted information and compensate for the lack of a common language, when necessary. As suggested by Dhanaraj and Parkhe (2006) “orchestration” is thus a set of objects required when people need to co-ordinate different activities and interact with the rest of the world. Through orchestration, team members can understand the common goals of the different working groups, as well as how their individual/team innovations contribute to the overall objective of the organisation (Gully, Incalcaterra, Joshi, & Beaubien, 2002; Montoya, 2016). Further, orchestration allows individuals to reflect upon routines, procedures, protocols and mental models of their own teams (Wenger, 2000b).

Orchestration of the knowledge resources is thus conceived as the main means of developing and disseminating innovations (Johnston & Paladino, 2007). This is because it facilitates the creation of sustainable competitive advantage through the utilisation of knowledge and collaboration (Rohde & Sundaram, 2011). In addition, knowledge resources are used to reduce the complexity of the innovation process. As such orchestrating knowledge becomes a significant driver for positive research results (Du Plessis, 2007; von Zedtwitz, Gassmann, & Boutellier, 2004). Orchestration of the knowledge could be considered similar to the role that absorptive capacity plays in knowledge management: both of these can help acquire, assimilate, transform and exploit knowledge from unverified sources and outside of the team working (Hu, Wen, & Yan, 2015; Inkinen, 2016; Mariano & Walter, 2015). Therefore, a new hypothesis explaining the incidence of orchestration of the knowledge in research outputs is proposed:

Hypothesis 3. Knowledge orchestration mediates the relationship between heterogeneity of knowledge and research outputs.

The relationships between the proposed hypotheses are shown in Figure 1. It should be noted that, as the model shows, this study also investigates whether a positive indirect effect exists between heterogeneity of knowledge and research outputs through knowledge orchestration.

Insert Figure 1 about here.

3. Methodology

3.1 Data collection

In order to verify its hypotheses, this research has studied the relevant concepts in the context of the multinational company Saint-Gobain Weber (https://www.saint-gobain.com/en/weber). Saint-Gobain Weber is a truly global organisation, with a presence in over 67 countries and its central headquarters in Paris, France. The decision to engage with Saint-Gobain Weber was based on our belief that knowledge is the key to their competitiveness. This is based upon Saint-Gobain's views of its technological know-how as their competitive edge, stated in the company website (Weber, 2011). In fact, the technology value of the company manifests itself as innovations in sustainable products and the quality of its products. These innovations guarantee extremely high levels of efficiency in both building and distribution of construction products (Sánchez, 2011). The company employs about 179,000 employees of over 100 nationalities, with around 25% of them working for the construction products division. According to the information recently released by the company[1] the company turnover in 2018 was €41,774 million. In addition, the company's 2018 sales increased by 4.4% like-for-like,

[1] Title of relevant press release and link to it https://www.saint-gobain.com/en/press/press-releases

with a positive 3.0% price impact. Since Saint-Gobain Weber is investing heavily in research for its competitiveness, this was an ideal organisation to engage in this research in order to achieve the aim and scope of the study.

The survey elaboration process started with a contact to a panel of top management executives in order to ensure the coherence of the questions from the management perspective. The idea was to have, from the start of their engagement, a closer contact with the company in order to ensure that any information generated by the research was of relevance for the organisation, and thus maximise their engagement. The fact that one of the authors was an employee of Saint-Gobain Weber enabled the research team to achieve this aim.

Data were collected between July and August of 2018 in the form of a survey. Although the questionnaire was sent to participants in electronic format, 20% of responses were collected in paper. The rest was received via email. The sample can be described as follows: 40% of participants hold top managerial positions, 33% of them are considered as middle management, and the rest head of departments and their staff members. At the time of the survey, more than 40% participants had been employed by Saint-Gobain Weber longer than 15 years, and 60% had an age between 36 and 50 years. All participants had staff under their supervision.

From a sample of 200 R&D teams, the total number of participants came from 93 teams representing more than 10 countries, with a response rate of 46.5%. The factor of error was 7.45% for p=q=50% and a reliability level of 95.5%. Considering that this survey involved senior management, the response rate achieved was higher than the average rate of 15 to 25 percent suggested by Menon, Bharadwaj, and Howell (1996). A plausible explanation for this response rate may be attributed to the fact that respondents received the survey from a colleague as opposed to an external person or a survey company.

3.2 Measures

Three statistical tests were conducted to avoid the presence of response bias (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Firstly, a factor analysis of all the variables to ensure the absence of response bias showed four factors with eigenvalues greater than 1.0 with an explained variance of 75.41%. Secondly, we proceeded to compare the first and last answers (1= early and 2= late) in terms of heterogeneity of knowledge, knowledge orchestration and research outputs, the independent sample t-test revealed no significant difference between the first and last answers ($p=0.664$, $p=0.538$, and $p=0.911$, respectively). Finally, we conducted the Harman's single factor test (Podsakoff et al., 2003). The results showed that the fit was considerably worse for the one-dimensional model than for the measurement model, while the one-factor model generated a Satorra-Bentler $\chi^2_{(27)}$= 92.46; χ^2/d.f=3.42, the measurement model yielded a Satorra-Bentler $\chi^2_{(24)}$= 27.80; χ^2/d.f=1.15). All these results suggest no substantial common method bias (Armstrong & Overton, 1977).

The interviews with managers and key employees within Weber provided an insight into the heterogeneity of knowledge, knowledge orchestration and international research indicators. Several items were modified, and a first draft of the questionnaire was tested. All items of the final version of the questionnaire are available in appendix 1. A sevenpoint Likert type scale (1 = “totally disagree”, 7 = “totally agree”) was used. The questionnaire constructs were as follows:

- The measures for the heterogeneity construct consisted of 3 items, adapted from Mohammed and Dumville's (2001) work. These items not only describe the way team members have access to different knowledge in terms of content (Rodan & Galunic, 2004), but also the heterogeneity among the actors (Sammarra & Biggiero, 2008).
- The research reported in this paper points to knowledge orchestration as being a mechanism for coordinating the knowledge fragmentation and heterogeneity (Dhanaraj & Parkhe, 2006; Nätti, Hurmelinna-Laukkanen, & Johnston, 2014). This construct was measured by the three indicators. The underlying assumption being made by these indicators is that research groups that have access to virtual tools are more likely to be able to understand and adopt new ideas if these can improve their relationship with virtual members.
- In this study, three items measured international research outcomes and assessed the team's quality and capacity for researching and implementing strategic goal and initiatives capable of revitalising the international networks (Hitt, Tihanyi, Miller, & Connelly, 2006; Zahra, Korri, & Yu, 2005).
- This study considers the number of people under supervision and the level and hierarchy in the organisation as control variables to verify whether the hypothesised relationships still hold even after controlling for these variables. Such incorporation is justified by the fact that behaviour control is determined by such variables (Ouchi, 1978).

3.3 Data Analysis

The model shown in Figure 1 was tested using the SmartPLS software version 3.2.8 Build 1058. The main reason to use PLS-SEM is that latent variable scores are well determined by PLS-SEM (Cepeda-Carrion et al., 2019). In addition, since the model shown in Figure 1 is built with the purpose of testing causal hypotheses, confirmation is necessary via both fit indices and global model verification (Henseler, 2018). Taking these issues into account, PLS-SEM is considered an appropriate software tool for the analysis since it provides fit indexes and also allows for researchers to operationalise models with small or reduced sample size (Henseler, Ringle, & Sarstedt, 2016; Henseler, 2018; Henseler, Hubona, & Ray, 2016).

Given that there is a high level of correlation between indicators, heterogeneity of knowledge (HK), research outputs (RO) and knowledge orchestration (KO) were specified as a composite reflective construct mode ‘A’ (Dijkstra & Henseler, 2015; Henseler et al., 2016a). In addition, since the model does not include multidimensional constructs, the measurement and the structural models can be estimated and evaluated simultaneously (Benitez, Henseler, & Roldán, 2016). As shown in Table 1, the fit statistics for the model indicate a reasonable data fit. The standardised root mean square residual (SRMR) value of the measurement model was 0.067 and all discrepancies were below the 95%-quantile of the bootstrap discrepancies (HI_{95}), which suggests very good measurement model fit (Henseler, Hubona, & Ray, 2016b).

Insert Table 1 about here

The results provided in Table 2 show the validity of the composite constructs. With regard to the HK, RO, KO and the control variable constructs, the scale composite reliability (SCR) and the average variance extracted (AVE) are above the common standards of 0.8 and 0.5 respectively (Dijkstra & Henseler, 2015; Henseler, Ringle, & Sarstedt, 2016). In addition, all factor loadings from all constructs are statistically significant, with the lowest value for the item measuring "RO1" being "0.732". The generated variance inflation factors (VIFs) for all the study variables ranged from 1.450 to 3.078 showing that multicollinearity was not present.

Insert Table 2 about here

The constructs correlation matrix, the Cronbach's Alpha, means and standard deviations are presented in Table 3. As shown in Table 3, the Cronbach's Alpha are above the common standards of 0.7. Discriminant validity was determined by comparing that each construct related more strongly to its own measures than to others' (Fornell & Larcker, 1981). In addition, all HTMT are below the value of 0.90, thereby providing evidence of discriminant validity (Henseler et al., 2016a).

Insert Table 3 about here

4. Results

As shown in Table 4, the path coefficients between heterogeneity of knowledge, international research outputs and knowledge orchestration are statistically significant (p values lower than 0.05). For those path coefficients, the intervals determined through the use of bootstrapping (5,000 resamples) do not contain the zero value (Hair, Ringle, & Sarstedt, 2013; Hayes & Scharkow, 2013). Also, it is important to note that control variables such as hierarchical level and supervisory angle are not statistically significant in relation to international research outputs.

The results also demonstrate that the structural model has satisfactory predictive relevance for the international research outputs (Q^2 = 0.201) because that value is higher than 0 (Shmueli, Ray, Velasquez Estrada, & Chatla, 2016). In addition, the proposed model explains the 20.1 percent of the variance in the international research outputs (R^2). Based on Preacher and Hayes (2008), a post-hoc indirect effect analysis was also carried out to tests the indirect effect of heterogeneity of knowledge on international research outputs by way of knowledge orchestration (*HK→KO→RO*). As Table 4 shows, the indirect effect of heterogeneity of knowledge is 0.18 (i.e. 0.402*0.449), which is statistically significant as the interval determined through bootstrapping does not contain the zero value. Consequently, from the above analysis, hypotheses 1, 2 and 3 found support.

Insert Table 4 about here

5. Discussion

This research brings several theoretical contributions to the domain of international R&D, particularly for scholars and practitioners working to address its knowledge-related challenges and their effects on team operation and outputs. Firstly, the study proposes that a reliable relationship and high levels of knowledge sharing between international R&D team members, that is, knowledge orchestration, facilitates the collection of information and knowledge from different sources to support innovation. While the subjects of international R&D and collective cost and time efficiency have been treated from different perspectives (e.g. Gully, Incalcaterra, Joshi, & Beaubien, 2002), this study pioneers the efforts to successfully link international R&D performance with knowledge orchestration. In doing so, this study establishes the importance and opens new avenues for future research into the factors that define a successful degree of knowledge orchestration in different contexts and their implication for R&D and multi-national teams.

A second contribution to the existing body of knowledge on the subject is derived from the study of the correlation between specific information and communication technologies and knowledge creation, with the impact that this may have on innovation and performance. This study proposes that the use of knowledge orchestration, specifically virtual tools, facilitate interaction between team members. Similarly, the research suggests that individuals' participation in different tasks may lead to a deeper understanding of existing knowledge and to the generation of new knowledge. While the use for technologies for knowledge sharing has been studied from different theoretical standpoints –see for example Dhanaraj & Parkhe (2006), the context of international R&D teams has received limited attention, particularly when it comes to achieving goals related to both knowledge orchestration and heterogeneity of knowledge (Molleman & Slomp, 1999). This study therefore highlights the need for international R&D groups to adopt virtual tools that will have the effect of mobilising and coordinating knowledge without sacrificing flexibility and independence in the process of achieving international goals. Furthermore, this finding highlights that specific virtual tools can help to counteract heterogeneity within an international R&D team when this becomes a necessity for knowledge-related decision making.

Thirdly, and as an unintended consequence of points one and two above, the research raises awareness of the meaning and upmost importance of the decentralised nature of knowledge and competencies in international R&D teams and functions. By focusing on the relationship between international team performance driven by R&D outputs, the use of information and communication technologies, and the careful management of knowledge and its orchestration, this research has confirmed some of the main interdependencies influencing the management of global R&D, as defined by Von Zedtwitz et al. (2004). This will not only have the potential to inform the future agenda of R&D management theory but also its practical implications. For example, our research supports the value of virtually integrating R&D units into global networks through the use of technology, or the decentralisation of R&D processes and the management of knowledge interfaces between virtual innovation teams.

Finally, the research has shown that –different to what other studies (e.g. Pelled et al., 1999; Tsai, 2018) had found, the presence of both heterogeneity of knowledge and knowledge orchestration within an international R&D team may indeed result in an increase in the quality and quantity of its outputs. This finding summarises the core argument driving this research and therefore paves the way for its empirical lessons. Regarding the first hypothesis, the results obtained support a positive and significant relationship between heterogeneity of knowledge and international research outputs. These findings are in accordance with the research conducted by authors such as El

Louadi (2008), who asserts that knowledge heterogeneity within groups could be a means to optimize the arrangement of individuals across units.

With regard to the testing of the second hypothesis, the results support the proposition that, the more heterogeneity exists among the members of R&D groups, the more important knowledge orchestration becomes. A possible explanation for these results may relate to the fact that too much heterogeneity within the R&D group may well overcomplicate and, in doing so, limit the interaction between participants. In this vein, prior research has found an association between the heterogeneity (and fragmentation) of knowledge and the evidence of difficulties in agreeing, of the presence of conflict, and difficulty in achieving coordination among different stakeholders (Pelled et al., 1999; Tsai, 2018). In order to overcome this issue, knowledge orchestration may be made to have a significant impact on fragmentation, as it facilitates the integration and coordination of emergent trends, and these insights can then be fed back into the company's strategy development process.

In terms of the third hypothesis, the results support the argument that knowledge orchestration has a significant mediating effect. A possible explanation for these findings may relate to the fact that virtual tools mediate between parties involved and ensure the right processes are in place to guarantee access to the information, texts, graphics, links or any other contents members of R&D groups require (Dhanaraj & Parkhe, 2006; Nätti et al., 2014). These results are especially important since a R&D group that has access to timely and reliable data may mitigate the impact of misunderstandings and improve the process of achieving international goals (Hitt et al., 2006; Zahra et al., 2005).

The association between control variables, such as hierarchical level and supervisory angle and international research outputs is insignificant (path coeff.=-0.013, p-value>0.1). A possible explanation for these findings may relate to the fact that for Weber R&D teams to grow and prosper in a turbulent context such as the buildings and the production of renewable energy during the period that we have examined, it is necessary for them to implement practices such as self-organising, self-control and self-regulation.

Practical implications

In the current economic and globalised environment, it is crucial for R&D teams to have an important and differentiating role in order to boost the internationalisation of their business and outcomes (Miller & Friesen, 1983). Effective management of R&D teams becomes an imperative for innovation in products, techniques and technologies that serve to expand the reach of the business (Cassiman & Golovko, 2011). Increasingly, R&D teams are geographically distributed, with members located in or coming from different parts of the world, which generates a heterogeneous knowledge base. Managers are faced with the challenge of managing international R&D teams to maximise their research outputs.

The first contribution of this study is to offer a practical example of how to implement a knowledge orchestration strategy, which has the potential to lead to a better performance in international R&D teams. This would help organisations achieve a higher level of research outputs from their international teams. Managers will learn from our research that the relationship between research outputs and heterogeneity of knowledge is a positive one, and that they can manage the way international teams are created and established. This could become a turning point in the way managers focus their recruitment strategies during the formation of international teams. Instead of selecting members who fit a specific profile in order to avoid heterogeneity of knowledge, this study shows that heterogeneity could become an opportunity and we therefore encourage management to capitalise on it.

Our second contribution is derived from the positive relationship between heterogeneity, the need for knowledge orchestration and the need for the use of virtual tools. Virtual tools may lead to a better performance in international R&D teams. In the current business context, this research becomes key for management to gain a better understanding of the dynamics of international R&D teams, helping organisations achieve a sustained competitive advantage.

Limitations and future research

Previous sections have highlighted a number of areas for future research, mostly derived from the decentralised nature of knowledge and competencies in international R&D teams and functions. These have included, for example, the study of virtual integration of R&D units, or the decentralisation of R&D processes. In additions to these, the conduct of this research in collaboration with a large multinational organisation from one specific business sector opens further opportunities for future studies. For example, there is value in replicating the analysis in organisations from other sectors, such as technological or food industries, to better understand the generalisability of our findings.

Future research could also seek to eliminate the subjectivity in the answers with more objective indicators. For example, empirically obtained key performance indicators could be used, in order to evaluate more objectively the results obtained by international R&D teams. The inclusion of other moderating variables could also open new avenues for future researches, since there are many variables that may have an influence in the management of international R&D teams.

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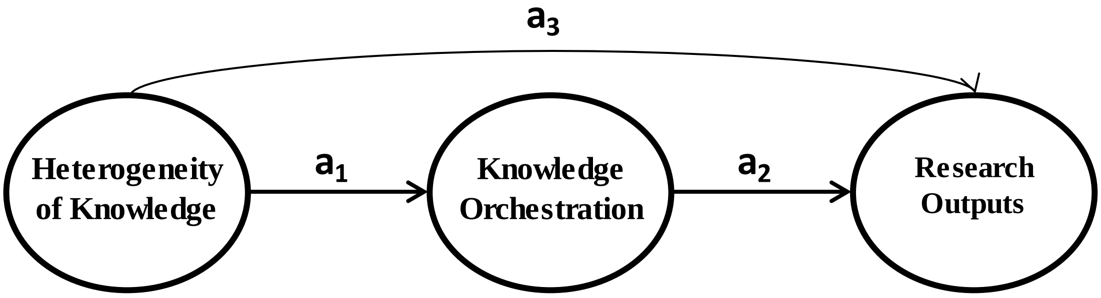
Appendix: Questionnaire items

Heterogeneity of knowledge: with respect to your organisation, indicate the extent to which you agree or disagree (1= strongly disagree and 7= strongly agree):
HK1: There are working groups formed by people of different backgrounds HK2: There are working groups formed by people with different points of view about the quality of the products HK3: There are working groups formed by people with different points of view about the commercial name or the design of the product
Knowledge orchestration: with respect to your organisation, indicate the extent to which you agree or disagree (1= strongly disagree and 7= strongly agree):
KO1: There are virtual tools for communication between geographically distributed teams. KO2: There are virtual tools that enable work in a remote way. KO3: There are virtual tools that enable work flexibility and family conciliation. KO4: There are virtual tools that enable the internationalization of the strategy
Research outputs: with respect to your organisation, indicate the extent to which you agree or disagree (1= strongly disagree and 7= strongly agree):
RO1: There are patents generated internationally. RO2: The innovations of some countries are shared internationally to other countries. RO3: R&D (improvement) projects are implemented internationally. RO4: International collaboration activities are integrated into the strategic plan
Control variables:
CV1: Number of people under supervision 1. 0 2. 1-5 3. 6-10 4. 11-14 people 5. More than 14 people CV2: Level of hierarchy 1. Staff 2. Middle Management 3. Head of Department 4. Top Management 5. Other

Notes:
HK= Heterogeneity of knowledge; RO= International research outputs; KO= Knowledge orchestration; Control variables= CV

Figure 1: Theoretical model



$H1=a_3$
$H2=a_1$
$H3=a_1*a_2$

TABLE 1
Results of the Confirmatory Composite Analysis

Overall saturated model fit evaluation	Value	Hi_{95}	Hi_{99}
SRMR	0.067	0.080	0.097
d_{ULS}	0.297	0.421	0.624
d_G	0,164	0,202	0.227

Note:
Global goodness of fit and bootstrap-based 95% and 99% quantiles (saturated model)
SRMR→ Standardized Root Mean Square Residual; d_{ULS}→ Unweighted Least Squares Discrepancy; d_G→ Geodesic Discrepancy

TABLE 2

Construct summary, confirmatory factor analysis and scale reliability

Construct	**VIF**	**Weight**	**loading**	**Reliability (SCR[a]., AVE[b])**
Heterogeneity of knowledge **(HK)**				
HK1	1.501	0.419	0.822	AVE=0.719
HK3	2.058	0.411	0.877	SCR=0.884
HK4	1.949	0.351	0.842	
Knowledge orchestration **(KO)**				
KO1	3.078	0.297	0.893	AVE=0.811
KO2	2.919	0.269	0.879	SCR=0.928
KO3	3.009	0.281	0.884	
KO4	3.128	0.281	0.890	
Research outputs **(RO)**				
RO1	1.450	0.278	0.732	AVE=0.721
RO2	2.283	0.320	0.867	SCR=0.885
RO2	1.760	0.281	0.778	
RO3	1.746	0.281	0.829	
Control variable **(CV)**				
CV1	2.122	0.330	0.864	AVE=0.863
CV2	2.122	0.734	0.974	SCR=0.927

Notes:
The fit statistics for the measurement model were:
[a] Scale Composite Reliability (SCR) of $p_c = (\Sigma\lambda_i)^2 \text{ var }(\xi) / [(\Sigma\lambda_i)^2 \text{ var }(\xi) + \Sigma\, \theta_{ii}]$ (Bagozzi and Yi, 1988).
[b]Average variance extracted (AVE) of $p_c = (\sum\lambda i2 \text{ var }(\xi))/[\sum\lambda i2 \text{ var }(\xi) + \sum\theta ii]$ (Fornell and Larcker, 1981).

TABLE 3
Descriptive statistics

	Mean	S.D	HTMT	CA	Inter-correlations 1	2	3	4
1. Heterogeneity of knowledge	5.294	1.110	0.513	0.804	***0.847***			
2. Knowledge orchestration	5.412	1.163	0.641	0.883	0.538	***0.900***		
3. Research outputs	5.663	0.883	0.513	0.807	0.410	0.399	***0.849***	
4. Control variable	3.522	1.231	0.280	0.842	-0.149	-0.245	-0.103	***0.827***

Note:
Mean = the average score for all of the items included in this measure; S.D. = Standard Deviation; HTMT= Heterotrait-Monotrait Ratio; CA = Cronbach's Alpha. The bold numbers on the diagonal are the square root of the Average Variance Extracted. Off-diagonal elements are correlations among constructs.

TABLE 4
Construct effects on endogenous variables

Hypotheses	Path Coef.	Confidence intervals		Supported
		$5\%CI_{li}$	$95\%CI_{hi}$	
H1: HK → KO	a_1=0.402**	0.12	0.65	Yes
H2: KO → RO	a_2=0.449**	0.17	0.69	Yes
H3: HK → RO	a_3=0.237*	0.00	0.46	Yes
H0: CV → RO	a_c=-0.013	-0.17	0.12	No

Indirect effects though	Point estimate	Percentile bootstrap 95% confidence interval		
		Lower	Upper	Sig
HK→KO→RO= $a_1 \times a_2$	0.180*	0.03	0.38	0.04

Notes:
[(based on t(4999), one-tailed test); **p < 0.01; *p < 0.05 (based on t(4999), one-tailed test). t(0.05, 4999) = 1.645; t(0.01, 4999) = 2.327]
HK= Heterogeneity of knowledge; KO= Knowledge orchestration; RO= International research outputs; Control variables= CV
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