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The making of homophilic networks in international research collaborations: A global perspective from Chilean and Korean engineering

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ABSTRACT

As globalization has expedited mobility of faculty across nations, faculty hiring is taking place at an international level. Institutions and governments often perceive hiring faculty who were trained in different countries as a strategy for reaching the status of world-class universities. The major assumption behind this hiring strategy is that faculty who are educated in prestigious universities in foreign countries will bring cutting edge knowledge and networks that will lead to future research collaborations. Yet, a dearth of research empirically investigated the assumption that institutions that train future foreign faculty and those that hire faculty with foreign degrees will have greater presence in the international networks of research collaboration. Filling this hole, this study examines this assumption from an international perspective, using the case of industrial engineering departments at selective research universities in Chile and Korea. Based on the unique data that document faculty hiring (degree attainment institutions) and research collaboration (co-authorship), and institutional prestige (global ranking positions), we analyzed the relationship between faculty hiring network and research collaboration network, as well as their association with institutional prestige. The results provide strong evidence of the positive relationships between doctoral training and future research collaboration, and the strong presence of institutions with global prestige. These relationships result in homophilic networks that suggest a concern about a reduced diversity in theoretical perspective and research methods within the disciplinary field.

1. Introduction

Hiring faculty who are foreigners or attained degree from other nations has been an important strategy among governments and institutions for being at the forefront of knowledge production and reaching the status of "World-Class Universities" (WCU) (Altbach and Salmi, 2011). Moreover, attracting faculty trained in prestigious foreign institutions—primarily in English-speaking countries—is considered as an effective mechanism for increasing the scientific and technical human capital of a nation or institution (Bozeman et al., 2001), particularly in regions with emerging higher education systems (Franzoni et al., 2015). The major assumption behind these hiring strategies is that these faculty will bring cutting-edge knowledge and networks that will lead to future research collaborations (Shin and Harman, 2009). Although one's training/education in graduate program is an important mechanism for future collaboration (Bozeman and Corley, 2004; Melin, 2000), the connection between the hiring and collaboration networks in international context has not been explored at the organizational level.

Meanwhile, these strategies may have some unintended consequences. Previous research has shown that the dynamics of doctoral training and faculty hiring create a "caste system," in which prestigious institutions hire faculty trained at other prestigious institutions, while the graduates of prestigious institutions also dominate the job market at lower-tier institutions (Bedeian et al., 2010; Burris, 2004; Crane, 1965). Thus, scientists from prestigious institutions train the next generation of leading scientists, who will continue leading the elite institutions (Crane, 1965). These dynamics might reduce diversity in theoretical perspective and research methods within disciplinary networks (e.g., Bedeian et al., 2010; Burris, 2004). This type of homogeneous networks is known as *homophily* in the social network literature (McPherson et al., 2001). In the context of research collaboration, these homophilic networks may even result in a stage in which scientists cannot think "out-of-the-box": new problems cannot be addressed by the current scientific paradigm (Kuhn, 2015). We believe that understanding the network structure of the training-hiring and collaboration is the first step to consider the meaning of hiring across countries. In particular, the current study aims to explore the relationship between network structure of faculty training and hiring as

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well as that of research collaboration from an international perspectives, exploring the features of the two networks in terms of the diversity and prestige of the institutions.

In particular, we focus on the faculty-hiring and research collaboration networks that have occurred in Chile and Korea. We examine two representative countries in Latin America and East Asia that have taken important faculty-hiring and research collaboration strategies aiming at improving the global recognition of their national universities (Altbach and Knight, 2007). Both countries have aggressive policies of sending students to pursue higher education abroad to increase their human capital (Altbach and Salmi, 2011; Moon and Kim, 2001) and of supporting international collaboration as a key mechanism for advancing scientific research (CONICYT, 2011; Shin, 2012). Thus, the cases of Chile and Korea are particularly useful for investigating the institutional networks that are created as faculty are trained at and hired by universities and collaborate with each other across nations. In this investigation, we study the following research questions: how does the training-hiring network correspond to research collaboration network? How is institutional prestige related to those networks?

1.1. Research policy and faculty hiring context in Chile and Korea

In both Chile and Korea, where the centralized national system guides science policy and higher education, the link between national policies on scientific activities and universities' faculty personnel criteria is strong (Kim and Cummings, 2011). For the last decade, the countries have been implementing science policies for "catching up in the global brain race" (Wildavsky, 2010). For example, Brain Korea 21 policy aims to build globally competitive research universities through research funds and program and to upgrade the research infrastructure and graduate-level training of the universities (MoE, 2005). The allocation of the funding was based on measurements including the number of international publication and other forms of outputs such as patent. Furthermore, some funding programs required research collaboration at the international level. In Chile, the National Commission for Scientific and Technological Research implemented Becas Chile, an ambitious scholarship program for training doctoral students abroad (CONICYT, 2012) and a specific line for funding international research liaisons with other countries, such as the U.S., France, and Finland (CONICYT, 2011). In the Korean context, the Ministry of Education and Ministry of Science and ICT are providing the Global Research Network Program and Global Research Lab Program, respectively. Those programs solicit collaborations between Korean researchers with foreign researchers, which will result in publications in international journals (e.g., those indexed in the Web of Science, SCOPUS) (Kang et al., 2016).

Researchers pointed to the migration of students and faculty as the main mechanism of developing international collaborations. The assumption is that the social ties that students gain during their graduate-degree training abroad will lead to future collaborations even after they return to work in their countries of origin (Adams et al., 2005; Freeman and Huang, 2014). From this perspective, faculty hiring across nations has been an important strategy for improving the quality of higher education and reaching WCU status (Salmi, 2011). Particularly, hiring "foreign-born" faculty have been a popular practice in East Asia and Latin America, where the desire for WCU status is strong (Altbach and Salmi, 2011; Byun et al., 2013; Inane and Tuncer, 2011; Rhee, 2011). For example, the Korean and Chinese governments created special funding for public universities to attract foreign-born star scientists (Shin, 2012) and rising scholars (Li et al., 2015). In 2016, Chilean universities had about 2,800 foreign-born faculty, which represented a 60% increase from 2008 (Ministry of Education, 2016); Similarly, the number of foreign faculty has observed a dramatic increase from 424 in 1990, 1313 in 2000, and to 5,719 in 2016 in Korea (Korean Educational Statistics Service, 2016); at 4-year institutions, about 50% of the newly hired faculty are foreign degree holders (Korean Educational Development Institute, 2012). Another path is hiring "returnees" who attained their graduate studies abroad. A main strategy is funding scholarships for doctoral education abroad, sometimes with the commitment to return to the country once one finishes his or her program of study. For example, Chile has adopted this approach intensely: between 2008 and 2016, the Chilean government funded about 3,000 students to receive doctorate degrees abroad, which is about half of the number of PhD holders living in the country in 2006 (Chiappa and Muñoz, 2015). The Korean government also offers scholarship programs for graduate degrees, particularly in science and technology (e.g., the Presidential Science Scholarship (Korea Student Aid Foundation, 2016)). Between 2011 and 2017, the number of PhD that was received by Koreans from foreign institutions reached to 40,713, 58% of which was conferred by U.S. institutions. In the field of Engineering, 63.54% of the foreign degree was conferred by U.S. institutions, followed by Japanese, British, and German institutions (24.32%, 3.87%, and 3.23%, respectively) (Korea National Research Foundation, 2016).

In response to governmental policies that promote international collaboration and knowledge production in the global circuit of knowledge, institutions have adapted new criteria for selecting new faculty members. Over the last decade, Chilean research universities have engaged in an intense search for new faculty trained in internationally well-known institutions to increase their potential productivity. This behavior is continuously reinforced as the number of publications weights in from applications to research grants to program accreditation (Celis and Véliz, 2017). Moreover, since the publications that count in the national systems are those in journal indexed in Web of Science or Scopus, English become the facto language for Chilean scholars. These incentives have also produced key changes in the preferences for those students who decided to study abroad. If in 2009 Spain was the main destiny for students granted with Becas Chile (120 students), the national scholarship for doctoral programs, in 2012, felt to the third place far behind the U.S. (first preference with 99 students) and UK (85 students) (CONICYT, 2012). Since then, the U.S. and U.K. have remained as the first destinations for doctoral students who studied abroad (CONICYT, 2017a). The preference for English speaking countries is more pronounce in science and engineering than in other fields. According to Becas Chile, in the area of engineering and technology, in the period 2008–2014, the top three destinations for doctoral students were the U.S. (72), U.K. (33), and Australia (24) (CONICYT, 2017a).

Similalry in Korea, academics with doctoral degrees from advanced higher education systems are preferred in hiring at academic institutions. This trend is attributable to two factors. Similar to the Chilean case, research productivity has been a major factor for hiring decision (Kim and Lee, 2006), as government policies evaluate research performance of an academic unit based on the publications in international journals recognized by databases such as SCI, SCOPUS and Web of Science (Kang et al., 2016). In addition, English has become a medium of instruction. As new faculty members are expected to conduct classes entirely in English, the selection process embraced this by including presentation in English in the interview process (Byon and Kim, 2011). In the Korean context, PhD degrees attained from Western countries, particularly "American PhDs" have been predominantly preferred in the academic job market (Shin, 2012). The global hegemony of American universities let the U.S. PhDs function as global cultural capital (Kim, 2016), and therefore, the U.S. PhDs are expected to perform better in publishing articles in high-profile international journals and teaching in English (Kwon, 2009). Institutions also expect that selective American elite private institutions help the school boost the "global image" to students and general public (Kim, 2016). In fact, U.S. PhDs come in with more international publications prior to their employment, whereas among the non-U.S. PhDs, publications in Korean journals were higher (Lee and Park, 2015).

The dominence of American PhD is particularly high at prestigious universities (Lee and Park, 2015) and top science and engineering programs: For example, at Seoul National University, U.S. PhDs take up

about 47.7% of all faculty members, followed by Korean and Germany (41.8% and 2.9%, respectively). At its college of engineering, 78% of the faculty attained their degrees outside of Korea, which is higher than the overall average (Seoul National University diversity council, 2017).

Despite the significant investment in those policies and the massive and global flow of faculty among universities and nations, no empirical study has explored the connection and dynamics between faculty-hiring and research collaboration networks at the institutional level. In particular, we seek to explore the relationship between these two networks and their degrees of diversity. Thus, this study brings a new perspective to the analysis of faculty hiring and research collaboration at the global level, and its implications for the global presence and prestige of higher education institutions.

2. Literature review

2.1. Research collaboration across borders and faculty publications

In many countries, individual faculty member's reward for academic life and the status of employing institutions are highly dependent upon their research performance (Teodorescu, 2000). Often, faculty productivity is quantified as the number of publications, number of articles cited, and research funding they procure. Tenure and promotion requirements are based on those measures, and the pressure to publish in the "top-tier" journals has been significantly increased (Adams and Thornton, 1986; Petry and Kerr, 1982; Peterson, 2001). Research collaboration has normally been seen as a way to produce output of greater quality or greater quantities than could be achieved individually (Campion and Shrum, 2004; Hudson, 1996). Previous studies found that faculty who reported to have had at least one collaborative research project tend to have a higher number of publications (Godin and Gingras, 2000; Melin, 2000). Lee and Bozeman (2005) argued that collaboration is a strong predictor of publication count, but when they divide the credit by the number of co-authors, collaboration and publication productivity are not significantly related.

Researchers have investigated how participants' characteristics mediate the relationship between collaboration and research productivity. Pravdic and Oluic-Vukovic (1986) showed that increased productivity is dependent on the frequency of collaboration among co-authors. Also, conducting research with scientists who have a higher (lower) number of publications increases (decreases) productivity. Pointing out the increasing number of foreign-born researchers in the U.S., Freeman and Huang (2014) analyzed the pattern and impact of collaboration among foreign scientists working in the U.S. Based on the science publication records during 1985–2008, they found that when foreign scientists work only with their respective ethnic groups, the number of publications and citation scores decreased. This negative impact of homogeneous networks might be due to the fact that foreign scientists with no previous publication records often lack social ties to engage in research teams with diverse ethnic compositions. Collaboration might also hold different value and practice across academic fields. Some studies found that collaboration is particularly important for fields in which trans-disciplinary research is emphasized. Particularly, the field of engineering and science has been reported to have a more active collaboration than other disciplines (Bordons and Gomez, 2000; Castells, 2000; Lee and Bozeman, 2005; Porter and Rafols 2009).

In addition, collaborative works at the international level tend to have more impact on faculty research. Analyzing citation data of major science journals, Narin and Whitlow (1990) and Adams (2012) found that internationally co-authored papers are cited up to twice as frequently, compared to domestically co-authored papers or those written by individual authors (Van Raan 1998). Moreover, faculty members who have high degrees of commitment to international activities tend to have high productivity (Altbach and Lewis 1996). Studying French and Italian academic physicists active during 2004–2005, Lissoni et al. (2010) found that engaging in international projects that consist of multiple co-authors predicted an additional 5.5 articles per year, and the average impact factor of the journals increased by 3.54–9.09 points depending on the seniority of the faculty members' positions.

While research on the process of collaboration building is scarce, a number of studies have attempted to understand the source of collaborative relationships. Among various types of social ties, researchers focused on the links established during doctoral training. As the concept of "invisible college" captures, many researchers tend to collaborate only with other graduates who attended the same school (Katz and Martin, 1997; Landry et al., 1996; Luukonen et al., 1992). For instance, Melin (2000) found that collaborations often started from past collaboration or supervisor-student relationship. Scellato et al. (2012) and Ynalvez and Shrum (2009) examined how this applies to the development of international collaboration when individual faculty members migrate. According to Scellato et al. (2012), individuals who received PhDs in countries other than the one in which they currently work (i.e., foreign-born faculty or foreign-degree holders (returnees)) tend to have a higher incidence of international co-authorship than non-mobile scientists. Such researchers also collaborate with diverse nationalities and publish in high-impact journals, controlling for the researchers' background, characteristics of the researcher's scientific field, and country of residence.

2.2. Institutional effects of faculty doctoral training and research collaboration

Some researchers emphasized that the increments related to collaborations ought to be considered from a much broader view (Lee and Bozeman, 2005; Wagner and Leydesdorff, 2005). The benefits of collaboration exceed the sheer sum of gains in individual productivity, as an individual's collaboration practice provides opportunities for other members in the organization. For academic departments, the quality of research and teaching would be improved as faculty work and share ideas across institutions and borders (Rynes 2011). In the study of collaboration strategies in the field of science and engineering, Bozeman and Corley (2004) found that mentoring junior colleagues, graduate students, and post-doctorates has been an important motivation for collaboration. They also found that faculty pursuing this "mentor strategy" are likely to be tenured. Ynalvez and Shrum (2009) explained that the mode of work and mentoring style may also influence future international collaboration. Collaboration also benefits academic departments by enhancing their prestige and reputation. Jones et al., (2008) found that researchers in departments with a higher level of "academic excellence" tend to have a higher propensity to collaborate, as they are considered to be competent to potential partners. Based on the positive connection between collaboration and departmental reputation, some institutions consider academic collaboration as a way of "broadening institutional base" (Jaffe and Jones, 2015; Wuchty et al., 2007).

Some studies show that the relationship between academic collaboration and departmental reputation to be stronger for international collaborations than for domestic collaborations. Adams et al. (2005) analyzed a panel data of 110 U.S. universities during 1981–1999 to examine the organizational factors that are related to collaboration patterns in scientific research. The study found that being ranked in the top 20 PhD programs in the National Research Council's 1993 Survey of Doctoral Programs deterred domestic collaborations and reduced team size (number of co-authors per paper), while it had positive impact on international collaboration. Another interesting finding noted that placement of former graduate students in scientifically emerging countries is a key determinant of institutional collaborations, especially collaborations with firms and foreign scientific institutions. Furthermore, bibliometric studies showed that international collaboration networks take the form of a "small world," which means that faculty, through co-authorships, have access to multiple researchers who are potential collaborators (Newman, 2010a). Such faculty collaboration

then allows institutions to become closer to other institutions with whom their faculty collaborate. However, a dearth of empirical research addresses the connection between faculty hiring and research collaboration that occur across nations. The current study explore how the network to which faculty members have access from their educational background is related to their collaboration patterns. This will provide significant implications for faculty hiring and research collaboration strategies. We speculate that globally prestigious institutions will have a central presence in this "small world" network of faculty collaborations. If this assumption holds and there is a significant relationship between faculty-hiring and collaboration networks, we will observe a type of homophilic network occurring at a global scale.

2.3. Faculty hiring and international collaboration in Chile and Korea

Few studies have provided useful perspectives for investigating faculty hiring and research collaboration in Chile and Korea. In a comparative study, Teodorescu (2000) found that engagement in international networks is the single most important factor for predicting full-time faculty's publication productivity in Latin America (Mexico, Chile, and Brazil) and Asia (Korea and Hong Kong). According to Teodorescu (2000), for Chilean faculty, the quality of graduate education had a significant positive relationship with the number of publications.

Meanwhile, Johnsrud's (1993) qualitative study of faculty members at three Korean institutions showed that faculty who did their doctoral studies abroad were mostly graduates of U.S. institutions. Also, he concluded that the ties that they forged abroad were weak and most of them terminated, except for the science and engineering faculty, where some collaboration persisted through time. Still, studies often assume that foreign degrees lead to more international collaboration, and compare the academic productivity of researchers based on the country where they were trained. For example, Shin (2012) found that foreign-degree holders in Korean universities, particularly those who hold U.S. PhDs, have more publications in internationally competitive journals than their Korean counterparts; interestingly, European degree holders had a lower level of productivity outcomes, compared to Korean degree holders. On the other hand, Jeong et al. (2011) finding was somewhat contradictory. Focusing on a public science research institute in Korea, they found no significant relationship between foreign-degree attainment and international collaboration. Yet, again, the setting was at a public research institute, which might be a very different entity compared to academic units in higher education institutions.

In this study we focus on the co-authorship network of faculty in the top five industrial engineering departments in Chile and Korea. As a proxy for collaboration, we used co-authorship since authorship well reflects the contribution of individuals to the realized publication outcomes (Adams 2012). Co-authorship captures the social interaction structures, information about cooperation patterns among authors, and the status and locations of authors in the broader scientific community (Mali et al., 2012; Wagner and Leydesdorff, 2005). Regarding the selected discipline, industrial engineering represents a field that requires a high level of interdisciplinarity, where migration of researchers and collaborative work is active and valued (Bordons and Gomez, 2000; Castells, 2000; Lee and Bozeman, 2005). Furthermore, industrial engineering is a discipline in which a fair comparison between Chile and Korea is possible: unlike other engineering fields, wherein Korean universities outsize Chilean institutions, industrial engineering is one of the largest engineering fields in Chile, and the size is equivalent to its mass in Korea. Finally, we used international rankings as a proxy for international prestige, as rankings are strongly associated with the idea of WCU status and worldwide influence (Hazelkorn, 2011).

3. Conceptual framework

Hiring of an individual may be seen as a strategy for improving an organization's performance by adding capabilities that the newly hired member brings. While traditional economic theories focus on human capital (i.e., individuals' knowledge and productivity), some researchers argued that the social capital that individuals bring should also be considered (McLean, 2009; Zelizer, 2010). Bozeman et al. (2001) and Bozeman and Rogers (2002) argued that scientific and technical human capital is the sum of technical knowledge that individuals gain from formal education or training, as well as their social relations and network ties. Both dimensions are important for science-driven discovery, as well as organizational solidarity and culture (Lacetera et al., 2004).

Lin (1999) further specified three mechanisms of social capital by which it affects the hiring organization. First, the structure of social capital, particularly the size and prestige of the network, are important for organizations (embeddedness). Having networks with prestigious organizations, as well as having diverse connections, can enhance the future prestige and/or reputation of hiring firms (Burt 1992; Flap 1995), which may influence the firms' access to resources. Second, social capital also means the opportunities that will be accessible through ties that would otherwise not be available (accessibility). Cutting-edge knowledge, expensive facilities, and highly productive individuals will be available through networks. Individual faculty members function as "bridges" to any type of resource that their organization of origin has. Finally, these assets will result in tangible forms of "action" returns (use). The reputation and access to additional resources will enhance measurable performance for all members in the organizations.

In the context of higher education, individual faculty members accumulate scientific knowledge, as well as their social connections throughout the advanced-degree training process. The quality of technical knowledge, as well as social ties, will vary depending on where they received their education. For example, the prestige or reputation of a graduate program will determine the gains from PhD training differently. Faculty who are educated in foreign countries might have different experience and value compared to their counterparts who have not been exposed to any international experiences. By hiring candidates who are graduates of highly prestigious universities, institutions expect to gain better reputations for the quality of education and research that they provide (Burris, 2004).

The social capital that individual faculty members bring will be significantly valued in the global higher education system where measurable performance is considered important. The notion of WCU status often relies on the international publications that departments or institutions produce (Hazelkorn 2011). Given resource and time constraints, generating co-authored academic papers based on research collaborations is one of the most effective and efficient ways to improve publication performance. As a result of enhanced reputation, as well as access to resources throughout the collaborations, the hiring department will be able to produce more publications in internationally recognized and indexed journals.

In sum, hiring decisions consider the scientific knowledge as well as the social reputation and ties that individual faculty members have gained from their advanced-degree training. Furthermore, this social capital leads to future research collaborations between the hiring institution and the training institution, often materialized in the form of co-authored academic publications. In this study, we explore the link between faculty hiring and international co-authorship in Chilean and Korean higher education institutions, in the field of industrial engineering, and how this link relate to the global prestige of institutions that trained their faculty (at the doctoral level) and collaborate with them (through co-autorship).

4. Methods

We selected the top five engineering schools in research universities in each country: the University of Chile (UCH), the Pontifical Catholic University of Chile (PUC), Federico Santa María University (UTFSM),

the University of Concepción (UdeC), and the University of Santiago (USACH) from Chile; and Seoul National University (SNU), Korea Advanced Institute of Science and Technology (KAIST), the Pohang University of Science and Technology (POSTECH), Yonsei University (Yonsei), and Korea University (KU) from Korea. The selection of the five institutions considered the following factors. First, the selection was based on their research performance, including the number of internationally indexed articles produced by the institutions (CONICYT, 2017a,b; Jungang Ilbo, 2017). Governmental supports for WCUs often go to those top programs that have resources and research outputs that are included in the selection criteria. Also, the choice of ten institutions considers the selectivity of their undergraduate engineering students (DEMRE, 2017; Uway, 2017), which is an important mechanism for institutions in the two countries to attain faculty members who attained PhDs in prestigious foreign institutions after graduating from the top undergraduate programs (inbreeding). Thus, this sample of institutions showcase the patterns in hiring and collaboration networks partially motivated by the governmental and institutional strategies to earn global status in scientific research in both countries, by bringing people from top programs. In the case of Chile, the size of the department and the research outputs of UdeC and USACH are far behind of those at UCH and PUC. Thus, adding a sixth university to the sample will have a minimum effect in the research trends we studied. In Chile, only few institutions have the chances and opportunities to aspire to the WCU status. In the Korean context, the stratification in higher education happened in a way that makes the distinction between the "SKY (SNU, KU and Yonsei)" plus the two science and technology universities and the next tier universities to be stable. This resulted in a different composition of student and faculty (Kim, 2008), which are essential to the research activities.

We collected data from industrial engineering departments at these ten institutions and recorded information about their full-time faculty listed on the departmental webpages. In total, our sample consisted of 176 faculty: 104 Chilean and 72 Korean professors. We created the faculty-hiring networks by connecting institutions where these 176 faculty are currently employed to institutions where same group of faculty obtained their PhD degrees (training institutions). This type of network is called a membership network (Breiger, 1974), which ties groups that share individuals (i.e., a university represents a node in this network). For instance, if there is a faculty at SNU who did his or her PhD at University of California-Berkeley (Berkeley), then we created a link between SNU and Berkeley in the faculty-hiring network. We did not register information about institutions where a faculty did a postdoctoral fellowship or work previously to current institution. For each institution in the network, we identified then the following attributes: country, region (North America, Asia, Europe, Latin America, Africa and Middle East, and Oceania), type (public or private), and ranking position according to the 2013 Academic Ranking of World Universities (ARWU), and the ARWU ranking for engineering programs. We used ARWU because it is considered one of the first publications of global rankings and most comprehensive international ranking systems that focuses on research-related factors (Salmi, 2011).

The data for the collaboration networks was derived from Scopus, a bibliographic database, in July 2013. Although Scopus has a wider coverage of peer-reviewed articles than other databases, it is not all-inclusive, and the retrieval of data might include errors in the names of authors or institutions (Falagas et al., 2008). In order to account for this issue, we entered faculty queries one by one and checked institutional names for duplicates or misspellings. For each faculty member, we identified his or her co-author lists from papers published after 1996. For each co-author, we then collected his or her affiliation at the time when the paper was published, and constructed the collaboration networks. These networks connect institutions where Chilean and Korean faculty work to the institutions with which their co-authors were affiliated. For instance, University A is connected to University B if a faculty member at University A co-authored a paper with an individual from University B. We limited the collaboration networks to the ties generated from the ten selected institutions (ego institutions). This means that these collaboration networks do not include ties between two institutions that are not among the ten selected Chilean and Korean universities. In other words, any single tie in the network has at least one of the ten selected ego institutions as a node. Finally, we assigned values to each tie between the ego and the partner institution (alter institution), corresponding to the number of faculty members at an ego institution who co-authored a paper with a faculty member from an alter institution. For example, if ego University A has three faculty members who published a paper with one or more faculty members from alter University B, then the tie between A and B has a value of 3. On the other hand, if one faculty member at ego University A has three papers published with one or more faculty members from alter University B, the tie between A and B has a value of 1. As a result, the strength of the link between two institutions increases as the number of faculty at the ego institution who collaborate with the partner institution does.

We used social network analysis to describe the faculty hiring and collaboration networks of the ten universities. Using UCINET and NetDraw, graphic representations and centrality measures were produced. In this study, we used node degree, eigenvector centrality, and betweenness centrality. Node degree is simply the number of ties attached to a single node. Weighted node degree is computed considering the values of each tie, which we computed for the collaboration network as described above. Eigenvector centrality is an attribute of each node, and accounts for the importance (i.e., number of ties) of those with whom the node is connected (Borgatti and Everett, 1997). Thus, in the networks of this study, instead of awarding institutions a point for each partner, eigenvector centrality gives each institution a score proportional to the sum of the scores of its partners (Newman, 2010b). Eigenvector centrality may also be unweighted or weighted. We computed normalized eigenvector measures, where the closeness to 1 indicates high centrality. Given the way we constructed the networks, with the eigenvector centrality we assign more influence to institutions that are connected to institutions with the highest numbers of ties than to those who are not connected with them. Finally, betweenness centrality is a measure of the extent to which a node lies on paths between other nodes (Newman, 2010b). In this study, we interpreted betweenness centrality as the ability of an institution to reach or collaborate with others, who are not necessarily current partners.

After describing the structure of the two networks, we conducted *t*-tests for exploring the relationship between the faculty-hiring network and the collaboration network. First, we conducted *t*-tests to estimate the mean differences in the collaboration network centrality measures (dependent variables: node degree, eigenvector centrality, and betweenness centrality) between the PhD training (institutions that appear in the hiring network) and non-training institutions (institutions that do not appear in the hiring network) (independent variable); then, we employed another set of independent variables that capture an institution's international ranking positions: i. ranked or not-ranked on ARWU; ii. top 25 versus top 26–200, conditional on being ranked. Using this measure, we estimated if there are significant differences in the collaboration centerality measures by ranking positions of the institutions. Since ego institutions are, due to the study design, included in the faculty-hiring and the collaboration networks, we excluded them when we conduct the *t*-tests. In other words, the *t*-tests focused on the partner institutions and their simultaneous influence on the Chilean and Korean systems.

In addition to the measures and tests conducted, we also interview two faculty in each country to discuss our findings. Also, the first author partially participated in a campus visit of a candidate for a faculty position at one of the industrial engineering department in Chile. The additional information informed our interpretation of the results and discussion. In order to keep us updated in terms of hiring trends in the studied departments, we have collected information to replicate the

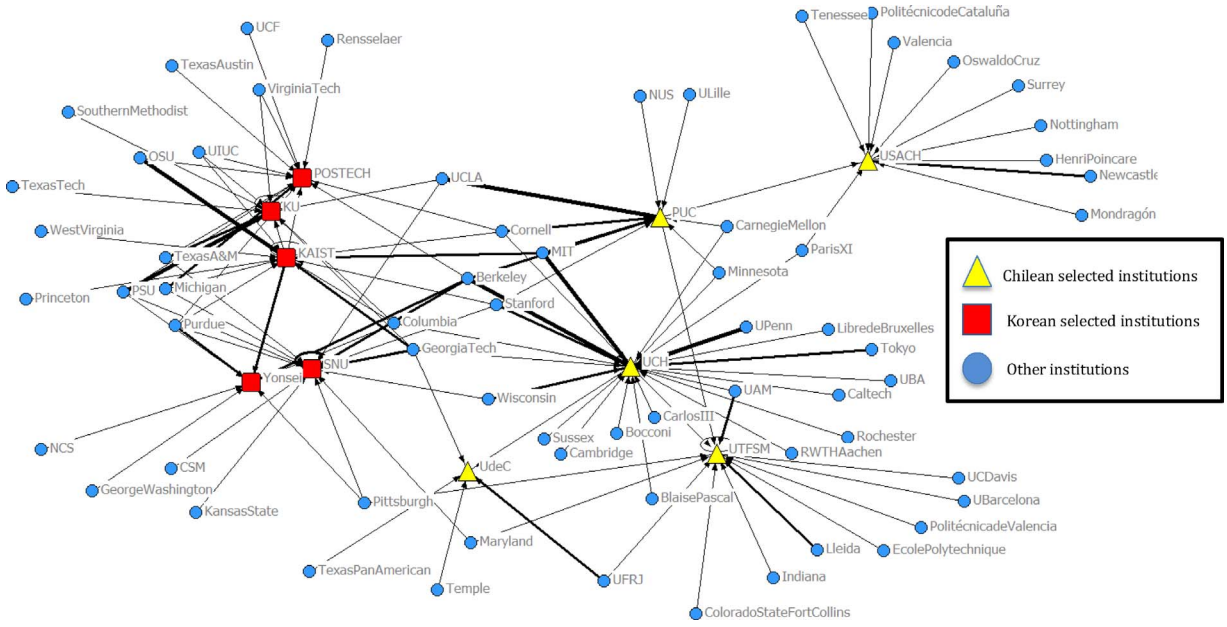

Fig. 1. PhD Network of Industrial Engineering Faculty Hiring.

faculty-hiring network with the ten selected institutions in October-November 2017. We did not finds significant differences those reported in this study.

5. Results

The faculty-hiring networks had 75 nodes (universities), of which only 5 nodes were Chilean (7%) and 5 nodes were Korean (7%). This indicates that both countries predominantly hire faculty who earned their PhD abroad (See Fig. 1). In few cases, they also hired faculty trained among the five selected institutions in each country, which also confirms the criteria of only five institutions was appropriate for the context of Chile and Korea. The U.S. institutions dominated the network: 105 among 152 faculty members (69%) received their doctoral education in the U.S., followed by European institutions. However, all European institutions were only tied to Chilean universities: 21 out of 80 faculty members (26%) obtained their PhDs in Europe. Table 1 shows the node degree for each of the ten ego institutions and the top PhD training institutions for each case. Schools such as the Massachusetts Institute of Technology (MIT), the University of California-Berkeley (Berkeley), Cornell University, Stanford University, Columbia University, the University of California-Los Angeles (UCLA), Georgia Institute of Technology (Georgia Tech), the University of Wisconsin, the University of Maryland, and the University of Pittsburgh trained faculty who were hired by institutions in both countries. Fig. 1 locates them at the center of the network. Berkeley, for instance, has alumni in two Chilean institutions (PUC and UCH) and in three Korean ones (POSTECH, SNU, and Yonsei). To the left side of Fig. 1, we can see the predominance of a group of four U.S. institutions in the Korean context: Purdue University, Texas A&M University, PSU, and University of Michigan (Michigan). There is no such a group or even a single European or U.S. institution with such a link to the selected Chilean industrial engineering departments.

Table 2 summarizes the collaboration network of the ten selected industrial engineering departments. In total, there were 3,324 institutions with 10,420 ties among them. On average, our ten selected universities were connected to 524 other institutions. KU was the institution tied with the largest number of nodes in our sample (791); UdeC had the lowest number (74). Table 3 presents the top 25 institutions according to their node degree, weighted and unweighted. The unweighted node degree column lists 37 institutions that were connected to 7 or 8 ego institutions out of the 10 in our sample. This means these 37 institutions were remarkably central in this view of the global network since their research collaborations were well represented in Chile

Table 1
Faculty-Hiring Network.

Institution (Ego Nodes)	Total Faculty	Faculty with PhD Info	Node Degree	Top PhD training Institutions
Chilean institutions:				
Pontifical Catholic University of Chile	17	14	11	UCLA (3), Cornell (2), MIT (2), Berkeley (2)
University of Chile	36	32	25	UPenn (3), MIT (3), Berkeley (3)
University of Concepción	11	6	5	UFRJ (2)
University of Santiago	18	12	11	Newcastle (2)
UTFSM	22	16	13	Lleida (2)
Total Chile	**104**	**80**	**52**[a]	**MIT (5), Berkeley (5)**
Korean institutions:				
KAIST	16	16	14	OSU (3), MIT (2), Georgia Tech (2), Yonsei (2)
Korea University	14	14	10	PSU[b] (3), Texas A&M (2)
POSTECH	14	14	13	Michigan (2)
Seoul National University	17	17	13	Berkeley (2), Georgia Tech (2)
Yonsei University	11	11	8	KAIST (2), Purdue (2), Berkeley (2)
Total Korea	**72**	**72**	**33**[a]	**PSU[b] (6), Berkeley (5), Georgia Tech (5), Purdue (5)**

[a] The total node degree by country represents the unique nodes that are connected to the five selected institutions in each country.
[b] PSU stands for Pennsylvania State University.

Table 2
Collaboration Network of Ten Selective Engineering Industrial Departments.

Institution (ego nodes)	Total Faculty	Faculty with Co-author Information[a]	Node Degree	Weighted Node Degree
Chilean institutions				
Pontifical Catholic University of Chile	16	15	375	503
University of Chile	36	24	764	1238
University of Concepción	16	5	74	76
University of Santiago	18	9	110	160
UTFSM	20	12	440	492
Total Chile	106	65	1470[b]	2469
Korean institutions				
KAIST	15	15	773	1508
Korea University	14	14	791	1510
POSTECH	14	14	734	1146
Seoul National University	17	13	546	1014
Yonsei University	11	11	628	1300
Total Korea	71	67	2161[b]	6758

[a] This column represents all faculty with co-authorship information found in Scopus.
[b] The total node degree by country represents the unique nodes that are connected to the five selected institutions in each country.

Table 3
Top 25 Central Partner Institutions in the Collaboration Network[b] – Degree Centrality.

	Node Degree (Unweighted)[b]			Node Degree (Weighted)	
1	Stanford	8	1	MIT	64
1	UC SanDiego	8	2	Hanyang U	57
1	UC Berkeley	8	2	Samsung	57
1	U of Texas at Austin	8	4	Pusan National U	56
1	U of Michigan	8	5	Kyung Hee U	53
1	Princeton	8	5	Sungkyunkwan U	53
1	Georgia Tech	8	5	UC Berkeley	53
1	U of Minnesota Twin Cities	8	8	Kyungpook National U	51
1	UPenn	8	9	Georgia Tech	51
1	U of Maryland	8	10	Elec. & Telec. Research Institute – Korea	46
1	Rutgers	8	10	Konkuk U	46
1	Imperial College London	8	10	Chungnam National U	46
1	UCLA	8	10	LG	46
1	PSU	8	14	Inha U	45
1	Harvard	8	15	Harvard	44
1	Purdue	8	16	Chonnam National U	43
17	Carnegie Mellon	7	16	Chung-Ang U	43
17	KIST	7	16	Ewha Womans U	43
17	U of Wisconsin	7	19	Chonbuk National U	42
17	Ohio State U	7	19	U of Michigan	42
17	U of Pittsburgh	7	19	Ajou U	42
17	IBM	7	22	KIST	41
17	CNRS	7	22	The Catholic U of Korea	41
17	Columbia	7	22	Inje U	41
17	SUNY Stony Brook	7	25	Gwangju Inst. of Science and Tech.	39
17	U of Colorado at Boulder	7			
17	MIT	7			
17	Cambridge	7			
17	National U of Singapore	7			
17	Northwestern	7			
17	U of Washington Seattle	7			
17	Cornell	7			
17	Johns Hopkins	7			
17	U of Southern California	7			
17	UBC	7			
17	North Carolina State U	7			
17	Wayne State U	7			

[a] This table excludes the ego nodes from the list.
[b] This column lists more than 25 nodes, since many institutions are tied in the last place.

Table 4
Twenty-five Most Central Institutions in the Collaboration Network – Eigenvector Centrality.

	Name of Institution	Eigenvector Centrality
1	KAIST	0.371
2	KU	0.363
3	POSTECH	0.352
4	Yonsei	0.338
5	SNU	0.301
6	Samsung	0.11
7	Hanyang U	0.108
8	Pusan National U	0.107
9	Sungkyunkwan U	0.101
10	Kyung Hee U	0.1
11	Kyungpook National U	0.098
12	Konkuk U	0.088
13	LG	0.088
14	UCH	0.087
15	Inha U	0.087
16	Chungnam National U	0.086
17	Elec. & Telec. Research Institute – Korea	0.086
18	Ewha Woman's U	0.083
19	Chonnam National U	0.083
20	Chung-Ang U	0.082
21	Ajou U	0.081
22	Georgia Tech	0.08
23	Chonbuk National U	0.08
24	Inje U	0.079
25	MIT	0.078

and Korea. The majority of these institutions were U.S. universities (81%). The weighted node degree list was highly dominated by Korean institutions (80%). This is explained by the high number of publications and co-authors in Korean institutions, compared to those produced in Chilean institutions. Of note, Korean companies, such as Samsung and LG, also comprised a high node centrality.

Table 4 exhibits the top 25 institutions according to their eigenvector centrality. Korean institutions dominated this list (88%). This result shows the strength of the Korean research institutions compared to Chilean ones. The institutions in this list are those that are well connected to research hub, which gives them potential access to ideas, resources, and future collaboration. According to this list, UCH, MIT, and Georgia Tech are institutions that are well established in the knowledge production with East Asian and Latin American partners. Table 5 presents the top 25 institutions according to their betweenness centrality. Notably, UCH was ranked at the top of the betweenness list although it is the fifth institution with the largest number of ties. In terms of the betweenness scale, U.S. institutions were highly influential. There were only two European institutions at the top: Imperial College of London (UK) and CNRS (France). In general, the foreign institutions (non-Chilean or non-Korean) with the highest centrality measures were MIT, Berkeley, Georgia Tech, Harvard, and Michigan.

Comparing the faculty-hiring and the collaboration networks, we found strong relationships between the two. First, a marked influence of U.S. institutions was reflected in both networks. Institutions such as MIT, Georgia Tech, and the University of Maryland were highly central in both networks. In general, top-ranked institutions were also highly central in both networks. In total, 60 of the 65 PhD training institutions (excluding the ego institutions) in the faculty-hiring networks were also part of the collaboration networks. Comparing the unweighted node degree means between the training and non-training institutions in the collaboration networks, we found that the mean of the PhD training universities is 4.5 nodes (from a minimum of 1 and maximum of 10) against a mean of 1.5 nodes for the non-training institutions ($t(3{,}312) = 19.5213$, $n = 3{,}314$, $p < 0.001$). We conducted more restricted *t*-tests by reducing the comparison sample to those institutions with a node degree greater than 3, which includes 33 PhD training institutions and 253 other non-PhD training institutions. The mean

Table 5
Twenty-five Most Central Institutions in the Collaboration Network – Betweenness Centrality.

	Name of Institution	Betweenness Centrality
1	UCH	1,809,717
2	KAIST	1,351,078
3	KU	1,336,752
4	POSTECH	1,276,656
5	UTFSM	1,027,201
6	Yonsei	940,266
7	SNU	815,830
8	PUC	701,818
9	USACH	237,223
10	UdeC	107,938
11	UC San Diego	23,147
11	Imperial College London	23,147
13	CNRS	22,125
14	U of Maryland	19,156
14	UC Berkeley	19,156
14	UPenn	19,156
14	UCLA	19,156
14	U of Minnesota Twin Cities	19,156
14	Princeton	19,156
14	Harvard	19,156
14	PSU	19,156
14	Rutgers	19,156
23	U of Texas at Austin	18,441
24	U of Michigan	18,360
24	Purdue	18,360

difference was still statistically significant, with means of 6.7 versus 4.9 nodes, respectively ($t(284) = -10.2007$, $n = 286$, $p < 0.001$). Within this subsample, there were also significant mean differences in eigenvector and betweenness centralities, with the PhD training institutions taking a more central position than those non-training institutions in the collaboration network. In general, the collaboration network among Korean institutions had a higher level of density than the density observed among the Chilean ones. In particular, the top five Korean selected engineering schools had a high frequency of collaboration with industry, governmental research offices, and less prestigious Korean institutions.

Finally, we conducted *t*-tests comparing centrality means between institutions grouped by institutional ranking, excluding the ego institutions. Among the 200 institutions listed in the 2013 ARWU engineering field ranking, there were 167 that appeared in the collaboration networks. Their unweighted node degree was significantly larger than for the unranked institutions, with 4 versus 1.4 nodes, respectively ($t(3312)$, $n = 3{,}314$, $p < 0.001$). Significant differences were also found when the sample was restricted to those with an unweighted node degree greater than 3. Within this subsample of 286 institutions, 68 were ranked in ARWU. The ranked institutions had a greater unweighted node degree centrality than unranked institutions (5.9 nodes versus 4.7, respectively) ($t(284) = -8.6182$, $n = 286$, $p < 0.001$). There were also significant mean differences in eigenvector and betweenness centralities within this subsample, with the ranked institutions having a more central position than those unranked institutions in the collaboration networks. When we focused only on those ranked institutions and compared the mean unweighted node degree centrality between the top 25 and the rest, the average centrality of the top 25 institutions was 7 nodes, whereas the mean of the unranked institutions was 3.5 ($t(165) = -8.5954$, $n = 167$, $p < 0.001$). For the weighted node degree means, the difference was 24.5 versus 7.3, respectively ($t(165) = -7.8671$, $n = 167$, $p < 0.001$). There were also significant mean differences in eigenvector and betweenness centralities between the top 25 and the rest of the institutions. Similar differences were found when we used the top 50 as a threshold. Finally, when analyzing the relationship between the faculty-hiring and the collaboration network for each individual ego institution, UCH stood out as having the most diverse faculty body according to the faculty-hiring network (in terms of the number and the nationality of the PhD training institutions). The institution also marked the top of both the node degree (unweighted) and the betweenness centrality lists.

6. Discussion

We only looked at one slice of the global research collaboration network of a single discipline, from the perspective of a handful of selective universities in two countries, Chile and Korea. Yet, this exploration contributes to the examination of collaboration patterns and training-hiring institutional relationships. As discussed in the introduction, Chile and Korea are countries with a strong commitment to positioning their higher education institutions as WCUs. Given their international engagement, we assumed that exploring their networks would allow us to observe more general global patterns that involve institutions with a wide global reach. From this microscopic or partial approach to understanding the global phenomenon of international training, hiring, and collaboration, we found strong evidence of the relationships between doctoral training and future research collaboration, and between these two and prestige, all at a global scale.

Again, we did not analyze the effect of foreign doctoral training at the individual level. Rather, we studied the aggregated effect at the institutional level. Our results showed that hiring faculty with foreign training, "returnees" or foreign faculty, is a mechanism for accessing a larger network and resources available in other countries. Social capital theory indicates that new faculty not only bring new knowledge and capacity for producing further research outcomes, but also bring valuable networks that will position the institution in the stratum of global higher education through international research collaborations. Our results suggest that the effects of these networks are stronger if faculty received training in advanced and mature higher education systems, mostly in prestigious institutions in English-speaking countries. Chilean and Korean institutions collaborate on research with the institutions from which they hire faculty. Since these selective institutions in Chile and Korea hire significant numbers of faculty from foreign countries, especially from the U.S., they acquire access to numerous prestigious institutions around the world. Both countries have implemented policies that put a premium on publication in international indexed journals (Celis and Véliz, 2017; Kang et al., 2016). Thus, the potential production of publication becomes the key dimension to assess future candidates. Training in prestige institutions in English speaking countries are considered a signal for that potential. Moreover, as PhDs from developed higher education systems dominate the faculty at the universities, particularly those top programs, the faculty hiring committees, according to our data, are also mostly trained in institutions with these characteristics and engaged in collaboration with prestigious universities. This might strengthen the cycle of hiring and collaborating with particular, prestigious U.S. institutions in the field of engineering in the two countries over time.

We also sought to understand network patterns on the global scale, for countries other than Chile and Korea. Our results indicate that by educating international doctoral students, institutions secure a strategic role in the international collaboration network. Institutions that are central in the faculty-training network are also central in the research collaboration networks. Their centrality makes these schools nodes with greater social capital in the network. In addition, it is the institutions that are prestigious—ranked in the global rankings—who are central in faculty-training and research collaboration networks. This might suggest that institutions that have greater social capital (including prestige) will accumulate more capital over time as they attract more talent to their school and opportunities to collaborate (*Matthew effect*). However, the causality is still unclear: it is possible that training more international students and establishing international collaboration would help institutions accumulate their social capital and prestige; or there is a feedback loop that perpetuates the relationship among

hiring, collaboration, and prestige. When prestige is measured and visualized by rankings, this trend might be more distinctive. Unpacking the antecedents and consequences of international training, hiring, and research collaboration while considering an institution's prestige (or global ranking systems) would be an area that future research should address.

We observed what Lin (1999) called the embeddedness of the network. Size and position within the network matter, and they give the most central nodes access to talents around the globe, which translates into research productivity. According to our results, the U.S. is clearly the most influential country in the network. U.S. institutions trained the largest number of faculty in Chile and Korea, and have the largest number of co-authors. The cross-sectional nature of our data prevents us from making causal claims. We are not able to specify whether the doctoral training produces future international collaborations, or a high presence of international collaborations translate into a greater enrollment of international doctoral students. However, using the notion of embeddedness, we point out that the current network structures crystallize positions over time, which generates a type of caste system (Burris, 2004) and homophilic networks (McPherson et al., 2001) of research collaboration, which brings potential barriers to a more diverse set of international collaborations. Thus, our results echo the concerns about the homogenization of perspectives and methods, used by the dominant science community, for addressing disciplinary, multidisciplinary, and key world problems (e.g., Bedeian et al., 2010; Burris, 2004). This study provides an analysis on the global scale of this phenomenon. To put it in modern terms, how much "thinking out of the box" will come from the scientific elite at engineering schools if everyone is trained in the same handful of prestigious institutions and collaborates with others who are similar to themselves? Future research is needed to examine how what is learned during doctoral training is conserved or transformed as faculty move across nations and collaborate internationally.

Certainly, the ego Chilean and Korean institutions also trained PhD students who are hired by other institutions or by the same institutions, in the respective country or abroad. We speculate that the observed high level of collaboration in Korea is in part due to the effect of faculty hiring patterns dominated for the five ego institutions. To some extent, this pattern would replicate the global structure at the national level. In this scenario, selective schools at the domestic level, the ego institutions in our study, would act as bridges or brokers (Burt, 1992; Lin, 1999) between the global and local levels. In Chile, the scale of doctoral education is still small. It would be interesting to observe the evolution of the Chilean system, focusing on whether it would create an internal/external dynamic exhibited in Korea (Kwon et al., 2012).

7. Conclusion

This study constructs and analyzes the hiring faculty networks and the research collaboration networks of five selected industrial engineering departments in Chile and Korea. The results show that those universities that educate doctoral students, who are then hired by Chilean and Korean institutions, are central in the global research collaboration network of the ten selected institutions; highly ranked institutions will have a higher centrality in the research collaboration network than those universities with lower rankings or unranked institutions.

This study also demonstrates that selecting partial or egocentric views of international liaisons in higher education is a valid strategy for understanding the global dimension of faculty work, international research collaboration, international comparative analyses, and interactions between the national and global levels. Certainly, a larger scale study (e.g., more countries, institutions, and disciplines) may confirm the patterns detected in this research and find other key patterns in the network, such as a core/periphery structure. A longitudinal approach will contribute to understanding the causal mechanisms that are in place in these international networks. In terms of social capital theory, our study suggests that individuals bring not only knowledge capacity, but also access to foreign talent and resources. However, this social capital interacts with the embeddedness of the network structures of the country and is field specific. Our results marked the dominance of a small group of U.S. institutions. At some level, this may undermine institutional diversity and their capacity to produce diverse forms of knowledge.

Finally, this study provides a practical implication that the strategy of hiring faculty who are returnees or foreign born might be effective for increasing an institution's global centrality. Having the global picture in mind, policy makers may consider how to use both the training of international doctoral students and the migration of faculty in order to foster global knowledge production and transfer through international or national collaborations.

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