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RESEARCH ARTICLE

Research network propagation: The impact of PhD students' temporary international mobility

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ABSTRACT

As the global mobility of researchers increases, many of whom are supported by national funding agencies' mobility schemes, there is growing interest in understanding the impact of this overseas mobility on knowledge production and networking. This study addresses a relatively understudied mobility—the temporary international mobility of PhD students in STEM fields—and its relation to the establishment of research collaborations between mobile PhD students and researchers at the host university and with other researchers overseas. First, we find that 55% of the participants established relevant international collaborations (i.e., with hosting supervisors and/or others at the hosting university), and we explore these collaboration patterns in detail by taking a novel research propagation approach. Second, we identify features of the visiting period that influence the formation of research collaborations abroad, such as the prestige of the host university, the duration of the international mobility period, the cultural distance, and the number of peer PhD students at the host university. Previous research collaborations between the home and host supervisors are also found to play a crucial role in research collaboration development. Age at the time of mobility is not found to be particularly relevant. We find that female PhD students are less able to benefit from collaborative research efforts than male students. These findings advance the knowledge of global research networks and provide important insights for research funding agencies aiming to promote international research mobility at the doctoral level.

1. INTRODUCTION

Scientific collaboration is increasing (Lee, Seo, et al., 2012) and is multilayered, as it encompasses the geographical (including local, national, and international, and diverse mixes of all of these) and the sectoral (within and between academic and nonacademic actors) and is influenced by culture, language, and the field of research (Shin, Lee, & Kim, 2013). Collaboration can occur for various reasons, but the increasingly complex challenges faced by researchers are a significant factor, as they cannot be solved by disciplinary thinking alone and require interdisciplinary problem-solving strategies (Yates, Woelert, et al., 2016). Collaboration in science is associated not only with issues of pragmatism and self-organization in the pursuit of complementarities of expertise, competence, and the sharing of special data and equipment but also with field positioning, socialization, specialization, knowledge cultures, path dependencies, and trust (see Melin, 2000). In addition, the increasing costs of scientific research can only be met through distributing the expenditure and effort, which can be effectively achieved through collaborations (Iglic, Doreian, & Ferligoj, 2017). Several studies have linked research collaborations with research productivity and impact (e.g., Abbasi, Altmann, & Hossain, 2011; Wagner, Whetsell, & Leydesdorff, 2017), but the identified benefits are relatively broad, as several of the potentially advantageous outcomes of collaboration are not easily measured (Leahey, 2016). The benefits are mainly associated with the generation of new ideas, but collaboration also develops human and technical expertise, absorptive capacity, and the transferability of knowledge to both organizations and individuals (Walsh, Lee, & Nagaoka, 2016). Thus, policymakers and research agencies have developed incentives for scientific collaborations to be established, and this development is closely associated with issues of mobility and migration (Patrício, Santos, et al., 2018).

Scientific collaboration has been extensively researched, as knowledge-exchange processes have become increasingly important in global, regional, and national systems of innovation. The research has mainly focused on collaboration-related determinants and dynamics among academics, institutions, teams, fields of research, and disciplinary spheres, and between academic and nonacademic organizations (e.g., Hall, Vogel, et al., 2018). Research collaboration has also been extensively studied in relation to migration and mobility because these phenomena are closely associated with the establishment of organized science and form part of the ethos of being an intellectual (Kim, 2017). Globalization processes, economic and geopolitical competition, fighting for talent, "brain-circulation," and other factors associated with a knowledge society have increased the importance of mobility and collaboration in terms of knowledge production, competitiveness, and career advancement (Jacob & Meek, 2013). Scientific mobility has in recent years diversified and extended in terms of countries of origin and destination, and has become the norm for academics and research students (Czaika & Orazbayev, 2018). The motivations for these various types of mobilities are not necessarily related to better economic rewards, and may include better research, education, and career opportunities, reputational gains, access to sophisticated scientific equipment, and working with prestigious colleagues (Fernández-Zubieta, Geuna, & Lawson, 2015). Most studies of research mobility have focused on the medium to long term, and short-term, temporary mobilities have been neglected (Teichler, 2015). Research collaborations and the migration and mobility flows of scientists and PhD students have been steadily increasing (e.g., Gureyev, Mazov, et al., 2020), but the conditions influencing the ability of PhD students to develop research collaborations during temporary international mobility has rarely been considered.

We focus on the temporary mobility of PhD students first because it occurs at a time when the students are being socialized to become researchers, and their abilities to conduct research independently are developing (Laudel & Glaser, 2008). Thus, this mobility can offer benefits in terms of research productivity and network formation, but also in terms of access to leading research teams and flows of knowledge (e.g., Aksnes, Rorstad, et al., 2013; Franzoni, Scellato, & Stephan, 2014; Tartari, Lorenzo, & Campbell, 2020). The expected benefits gained through mobility in this time of social and research skill development can continue after the period of temporary mobility, and can thus potentially minimize the identified financial, cultural, social, or family constraints, which can occur when mobility continues for longer periods or happens later in a career (Bauder, 2020; Patrício et al., 2018; Teichler, 2017). Second, this type of mobility tends to involve less expenditure for both the individual and for publicly funded mobility programs, as several types of fees (such as tuition fees) do not need to be covered, while other costs are minimized, such as those for accommodation if the period abroad is shorter. The effects of temporary mobility during doctoral education may be similar to doing PhDs abroad in terms of networking and exposure to new knowledge (Horta & Blasi, 2016). Thus, in this study, we address two research questions: (a) What characteristics of temporary mobility affect the establishment of research collaborations of PhD students with peers at a hosting institution during a period abroad? and (b) What are the determinants associated with international temporary mobility that affect the ability of PhD students to extend their research networks to include other researchers overseas?

The data used for this analysis were sourced from a survey administered to Chinese students doing PhDs in a science, technology, engineering, or mathematics (STEM) subject, and who participated in the 2014 "National Development High-level University Public-Sponsored Postgraduate Student Scheme" managed by the China Scholarship Council (CSC). We focus on the temporary mobility of PhD students funded by the Chinese government, as this is part of an effort to develop the rapidly growing research system (the number of full-time equivalent researchers increased from 1,210,840 in 2010 to 1,866,108 in 2018)[1]. The aim is for China to become more integrated and networked with the global research community and therefore contribute to its development (Horta & Shen, 2019). This type of mobility is concentrated in the fields of higher learning and STEM research, as these fields are regarded as critical for developing knowledge societies that have the potential to become innovative and creative engines and thus drive economic growth. China awards the second largest number of science and engineering doctoral degrees in the world after the United States, with 34,440 awarded in 2015, which represents 64% of all PhDs awarded in the country (NSB, 2020). The mobility considered in this study follows a logic of knowledge accumulation and learning. This is intended to create human and social capital and to stimulate a research system that can meet national and local challenges through combinations of national and global knowledge (Cao, Baas, et al., 2020). Our study is also associated with the desire of Chinese researchers to be exposed to new and different knowledge, societies, and cultures. Like most researchers worldwide, they are keen to develop networking opportunities (Yang, Volet, & Mansfield, 2018) and are driven by the complementary dynamics of competition and collaboration, which involves individuals, organizations, and countries in global science research (Santos & Horta, 2020). The international exposure resulting from this mobility may also create awareness and trigger change in terms of the institutional and cultural obstacles that science development can face, which for China involve an excessive focus on short-term thinking, funding rules, governmental micromanagement and bureaucracy, nonmeritocratic evaluation systems, and associated *guanxi* rationales (Han & Appelbaum, 2018). In addition, this government-sponsored mobility program has been implemented by a nation that is growing to prominence as a scientific superpower, and thus analyzing it can inform both Chinese policymakers and those from developing countries that are aiming to catch up. They are likely to require policies and programs related to talented mobility that can enable them to progress in a faster and more efficient way (Heitor, Horta, & Mendonça, 2014). Within this context, and bearing in mind the abovementioned knowledge gap, the analytical setting of this study is aimed at measuring scientific network propagation, based on the coauthorship of publications, which are then regressed relative to key factors known to influence research collaboration and relevant to the mobility of scientists (e.g., Jonkers & Cruz-Castro, 2013).

The remainder of this paper is organized as follows. The next section offers a brief literature review on issues pertaining to mobility and research collaboration and mobility during doctoral education. This is followed by a research design section that details the data, research collaboration dependent variables, explanatory variables, and descriptive statistics. The methodology section provides details of the models used in the analysis. The results section presents the main

[1] Source: OECD, Main Science and Technology Indicators (MSTI Database): https://stats.oecd.org/# (accessed on August 31, 2020).

findings, which are discussed in the conclusions section, and contributions to knowledge in the field and policy implications are outlined.

2. LITERATURE REVIEW

Both mobility and research collaborations are of critical importance for the future career opportunities and progression of doctoral students and early career researchers (Celis & Kim, 2018). Doctoral students are therefore motivated to be geographically and institutionally mobile because this mobility is expected to facilitate access not only to different types of learning and knowledge-sharing experiences that will boost their human and technical capital but also to increased possibilities for collaboration and integration with international research networks (Franzoni, Scellato, & Stephan, 2015). The literature suggests that this mobility follows the same scientific power patterns found in international collaborations. In global terms, PhD students tend to move toward the scientific powerhouses that occupy a central position in the world of science, in the same way that scientists try to form research collaborations with colleagues based at these powerhouses (Gui, Liu, & Du, 2019). Access to better human and technical capital (such as working with elite scientists, research funding, and the ability to work in well-equipped laboratories and infrastructures, which is key for most research conducted in STEM fields), and experiencing greater research autonomy and freedom (Azoulay, Ganguli, & Zivin, 2017) have led to this trend, but the prestige and signaling gained in national and international scientific systems (Horta, Cattaneo, & Meoli, 2018; Jacob & Meek, 2013) constitute another important factor.

Although the potential benefits of such mobility are known, the ability to accrue advantages from it is not straightforward, and some research suggests a darker side to mobility and an inability to capitalize on the potential benefits (Walsh, 2010). A lack of preparation or interest on the part of host institutions, or an exploitative interest, may lead to this, but it can also be related to issues pertaining to the unpreparedness of the students in making the most of this mobile learning experience (Netz & Jaksztat, 2017). In this context, the role of social-cultural capital and the doctoral student's capacity to overcome related shocks and barriers are viewed to be key, as is previous educational or social experience abroad (Elliot, Baumfield, et al., 2016). The adaptation of doctoral students to the different cultural and social environments and the flexibility to cope with it to their benefit can be an important influence on the ability to learn and to engage in collaborative research activities (Coey, 2018).

The nature of mobility has been changing for PhD students, and while the number of students doing doctorates abroad is increasing, so is the practice of sending PhD students to host institutions abroad so that they can conduct research in a completely different academic environment (Horta & Blasi, 2016). Research funding agencies in most countries in the world are interested in promoting the international mobility of PhD students, and increasingly so on a temporary basis, as they realize that this mobility is part of a reconfiguration process that has the potential to transform national scientific systems (with associated expectations of economic transformation), as the embodied scientific knowledge that international mobility represents is related to integrating global knowledge networks (Canibano, 2017). Research funding agencies and doctoral students themselves are increasingly emphasizing temporary international mobility rather than (or in parallel with) doing a PhD abroad (Canibano, Otamendi, & Solis, 2011). The rationale is that the temporary mobility of PhD students is expected to generate experiences similar to those that international PhD students have, in the sense that they will be able to acquire new knowledge while having the potential to act as knowledge brokers in transnational scientific networks between their sending and hosting country (Bilecen & Faist, 2015). This can be achieved with lower costs through temporary international mobility (and probably lower administrative barriers) compared with longer mobility periods or migration (see Orazbayev, 2017).

Personal factors also strongly influence the propensity to be mobile and the potential benefits that can be gained from mobility (Azoulay et al., 2017). Female PhD students have been found to be more vulnerable in situations of transnational academic mobility (Mahlck, 2018), and they are known to be traditionally less internationally mobile than men, in both long-term and short-term mobility spells, which makes them less integrated in international scientific networks (Jons, 2017). This is partly due to socialized gender roles: Female PhD students face a greater strain in dealing with work–family balance than their male peers, which places them at a disadvantage in terms of mobility opportunities and benefits (Schaer, Dahinden, & Toader, 2017). However, recent research shows that transnationally mobile women publish in better quality journals than those who are not mobile, underlying the importance of international mobility for women involved in science (Horta, Jung, & Santos, 2020). Studies have also shown that mobile women adapt better than men to newer research environments in the hosting institutions and are more likely to engage in research collaborations (Rhoten & Pfirman, 2007). This adaptation relates to the cultural dimension of the scientific and technical human capital model that Corley, Bozeman, et al. (2019) deem critical for intellectual capacity-building and future career development. This dimension includes not only gender but also disciplinary culture, ethnicity, and socioeconomic status. In this context, recent research has shown that social class matters in addition to gender in influencing mobility choices and in dealing with environments that demand previous experience of cosmopolitanism, which is not available to everyone (Netz & Jaksztat, 2017).

This study is based on a sample of Chinese PhD students. Chinese nationals currently represent the largest share of international students at all levels of education, and the flow of outbound Chinese nationals to pursue a PhD abroad or engage in temporary international mobility within the scope of their PhD studies continues to grow. This is in line with the rapid development of the Chinese scientific and higher education system (Shen, Wang, & Jin, 2016). In the past 50 years, Chinese nationals have been internationally mobile for both personal and national reasons. On the personal level, motives can be associated with the accumulation of symbolic and intellectual capital, which fosters human and technical capital that can be used both to integrate global scientific networks and to strengthen career opportunities in China and abroad (Leung, 2013). This has played a key role in shaping the development of the Chinese scientific system and the relationships that this system has with its global counterparts, particularly those in North America and Europe (Jonkers, 2010). At the national level, these personal motivations have been supported by policies fostering brain-circulation, reverse-brain-drain, and brain-gain, such as the 1000 Talents program, which is aimed at upgrading the research capabilities of Chinese universities and research institutions (Lu & Zhang, 2015). The major challenges for Chinese PhD students abroad and those who engage in international mobility during their doctoral studies are related to the social and cultural adaptation to completely different research and learning environments and societies, which are likely to influence the benefits gained from the international mobility experience (Ye & Edwards, 2015).

3. RESEARCH DESIGN

3.1. Sample and Data

This study relies on a comprehensive data set covering Chinese doctoral students in STEM fields with international mobility experiences sponsored by the Chinese Scholarship Council (CSC). In 2007, the CSC launched a publicly sponsored doctoral student mobility program. This program has two functions: first, to fund undergraduates or Master's graduates to pursue doctoral degrees outside mainland China, and second, to fund doctoral students from mainland China to go overseas for 6–24 months; these are referred to as visiting or exchange doctoral students. To receive CSC funding, students need to contact a foreign supervisor, obtain an invitation letter from the host institution, and submit it to the CSC along with a research proposal. The CSC organizes experts to review the research proposal and decides whether to grant funding based on criteria including the quality of the proposal, the ranking of the applicant's university, and the ranking of the host institution.

From 2007 to 2014, the CSC supported 41,824 graduate students to pursue PhD degrees or to study overseas for 6–24 months (Table 1). The data for this study are based on a survey of CSC grantees. In May 2014, using email addresses provided by the CSC, the research team sent online questionnaires to 16,798 doctoral students who had returned to China. The research team sent reminders every 7 days to respondents who did not fill out the questionnaire in the first wave. The implementation of the survey took 1 month in total. A response rate of 35.18% was achieved, as 5,910 questionnaires were returned. After comparing the sample with the population of returned students, their characteristics were found to be very similar in terms of gender, academic fields, host countries, and university types. Thus, the sample was regarded as representative. After a selection process, 5,506 valid questionnaires were obtained, of which 5,019 were from doctoral exchange students who mainly traveled to the United States, the United Kingdom, Germany, Japan, Australia, France, and other developed countries.

All of the PhD students in the sample were surveyed in China in May 2014 and provided sociodemographic information (age, gender, parents' education) and the STEM subfield of their doctoral degree, along with past educational experiences and previous international mobility. Details of supervisors and hosting institutions were also recorded (for details, see Jiang & Shen, 2019).

The information available from the survey was integrated with data related to the PhD students' scientific productivity. A comprehensive database assembled from Scopus including detailed information (at the paper level) on research networks was developed for both the authors (PhD students) and their coauthors (including supervisors at the home and hosting institutions) to identify publications resulting from collaborations established during the period abroad. Following the literature (e.g., Aman, 2020; Cattaneo, Malighetti, & Paleari, 2019; Forti, Franzoni, & Sobrero, 2013;

Table 1. CSC grantees, 2007–2014 (China Scholarship Council, 2016)

Year	For doctoral degrees	Exchange and visiting doctoral students	Total
2007	394	3,474	3,868
2008	2,000	2,692	4,692
2009	1,879	2,466	4,345
2010	2,387	2,458	4,845
2011	2,843	2,473	5,316
2012	2,726	3,330	6,056
2013	2,276	3,586	5,862
2014	2,226	4,614	6,840
Total	16,731	25,093	41,824

Gaule & Piacentini, 2013), matching errors in the bibliometric data set were minimized using a disambiguation algorithm to retrieve authors' Scopus numerical identifiers. A specific ID was associated with a doctoral student if the following criteria were met: (a) The last and the first name of the doctoral student corresponded to that reported in the survey; (b) the last and the first name of one coauthor corresponded to the name of the doctoral student's home supervisor reported in the survey; (c) the university and departmental (if any) affiliation name was correct; and (d) the subject area of the majority of indexed products corresponded to the specific author ID.

By applying our disambiguation algorithm, we were able to match 1,564 PhD students. We then examined in detail the propagation of their international research networks that resulted from their doctoral visiting experience. The data consisted of 30,029 papers (published no later than 2017) and 63,407 unique coauthors.

3.2. Quantification of Research Network Propagation

In this section, we present the identification strategy used to identify the international research collaborations PhD students established as a direct consequence of their visiting period abroad. An effective assessment of temporary mobility experiences relies on the accurate identification of these research collaborations. Thus, after proposing the research network propagation procedure and providing examples for clarification, the second part of the paper (Sections 4 and 5) examines the features of the visiting period (CSC program) to assess what encourages the formation and development of research collaborations, with the aim of providing valuable insights to funding agencies and institutions involved in designing such programs.

A network perspective was taken when identifying the international research collaborations related to the visiting period abroad, (e.g., Dehdarirad & Nasini, 2017). To fully capture the benefits in terms of research network development over time, the complete history of research collaborations was considered and not solely those during the author's time abroad (or a few years later to account for publication lag). A network propagation approach was taken, in which the collaborations were categorized as first or second stage based on whether they were initiated during the period abroad and with authors affiliated with the hosting university (first stage), or were established with authors who were not affiliated with the hosting university but who had previously coauthored with at least one first-stage coauthor (second stage). Second-stage collaborations represent the expansion of the scientific collaboration network resulting from the consolidation of the first stage collaboration. Figure 1 illustrates the key research network elements and related terminology for clarification.

The identification process can be generalized in five main steps:

1. Let AU be the set of authors. For each author i, $i \in AU$, determine the set of coauthors $COAU_i$.
2. For each author–coauthor pair ij, $i \in AU$, $j \in COAU_i$, determine the set of coauthored papers (Pap_{ij}) and compute the first collaboration date as follows:
   $Firstcol_{ij} = \{\min(date_p), p \in pap_{ij}\}$, where $date_p$ is the publication date of paper p.
3. Identify author i's first-stage coauthors (j) based on the following conditions:

   (a) $j \in COAU_i$,
   (b) $Firstcol_{ij} \in \{VisitingTime_i, VisitingTime_i + k\}$
   (c) $AffId_{j,Firstcolij} = VisitingAffId_i$

   Author j is identified as a first-stage coauthor for author i if: (a) She is a coauthor of author i; (b) the first coauthored paper is dated between the visiting period and the

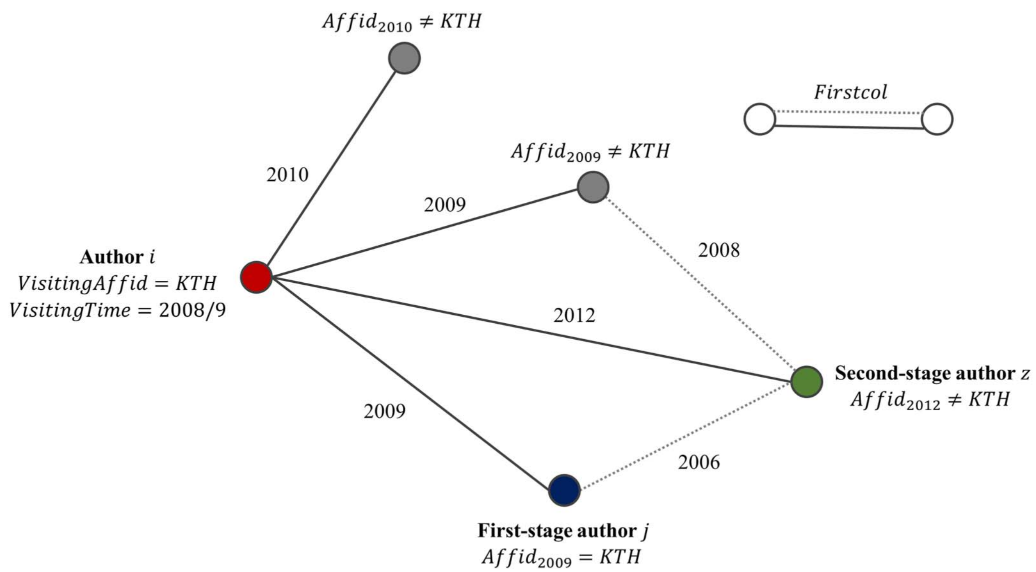

Figure 1. Example of a network of research collaborations. Author *j* (blue dot) is a first-stage coauthor for author *i* (red dot) as she was affiliated (*Affid*) with author *i*'s hosting university (KTH—The Royal Institute of Technology, Sweden), and the two collaborated on the first paper (2009) during the time author *i* spent abroad. Author *z* (green dot) is identified as a second-stage coauthor, as she coauthored a paper with both authors *i* and *j* (in 2012), and she previously collaborated with first-stage coauthor *j* (2006) before any of author *i*'s other coauthors. Grey dots represent general coauthors who are neither first-stage nor second-stage.

considered publication lag (*k*) taken as 3 years[2]; and (c) at the time of the first collaboration, author *j* was affiliated to the hosting institution.

4. Identify author *i*'s second-stage coauthors (*z*) based on the following conditions:

   (a) $z \in COAU_i$,
   (b) $\exists j \in 1stage_i \mid Firstcol_{jz} = \min(Firstcol_{zx}),\ x \in COAU_i$,
   (c) $Firstcol_{iz} = \min(date_p),\ p \in Pap_{ij} \cap Pap_{iz}$,
   (d) $Affid_{z,Firstcoliz} \neq VisitingAffid_i$

   A given coauthor *z* is considered to be a second-stage coauthor for author *i* if: (a) She is a coauthor of author *i*; (b) there is a first-stage coauthor *j* who has collaborated with *z* before any other coauthor *x*; (c) the three of them—author *i*, first-stage coauthor *j* and *x*—have collaborated together (i.e., $P_{ij} \cap P_{iz} \neq \{\emptyset\}$), and that was the first collaboration between author *i* and *z*; and (d) *x* was not affiliated to the hosting university (to avoid overlapping and misclassification as first-stage coauthors).

5. Identify research products realized with first- and second-stage coauthors. In particular, we consider three different quantifications at the first and second stages:
   - *Active collaboration*: a dummy variable equal to 1 if the author has published at least one paper with first-stage and second-stage coauthors, respectively.
   - *Number of papers*: the numbers of papers coauthored with first-stage authors and second-stage authors, respectively.

[2] Publishing in scholarly peer-reviewed journals usually entails long delays from submission to publication because of publications' preparation time and delays resulting from the scholarly review process (Aksnes, 2003; Björk & Solomon, 2013). It is likely that a paper initiated during the visiting period would be published some years later and this delay also differs across areas and academic journals.

Table 2. Real data demonstrating scientific network propagation based on the cumulative number of papers published by one researcher

Year	No. papers	No. papers – first-stage	No. papers – second-stage
2006	1	0	0
2008*	3	2	0
2010	9	5	1
2012	14	7	2
2014	15	7	2
2016	22	7	2

* Visiting period abroad between 2008 and 2009 at The Royal Institute of Technology (KTH) in Sweden.

- *SJR weighted number of papers*: the number of papers weighted by the journal SJR[3].

To avoid overlapping and double counting, second-stage research products were calculated as the net of those that also involved first-stage coauthors.

To better demonstrate the data available and the identification procedure, Table 2 and Figure 2 represent the evolution of the research collaboration network for an author in our data set who spent a period abroad between 2008 and 2009 at the Royal Institute of Technology (KTH) in Sweden. Figure 2 extends the basic one-to-one relationship and clarifies the evolution of collaboration patterns over time and across different types of authors. Twenty-two papers were published by the author in 11 years from 2006 to 2017. The size of a node is proportional to the number of cumulative coauthored papers, as is the thickness of the edges. In 2008, the author published two papers with a first-stage coauthor and three second-stage coauthors (see the green nodes in Figure 2). In subsequent years, the author strengthened his collaboration with the visiting institution by collaborating with other first-stage authors (up to nine in 2012) and publishing one paper each in 2009 and 2010 with previously met second-stage coauthors.

3.3. Determinants of Individual International Collaborations

In this section, we examine the contextual factors and the individual characteristics that may affect PhD students' research network propagation once enrolled in the CSC program.

3.3.1. Contextual factors

3.3.1.1. University prestige The international standing of a university is measured using the Academic Ranking of World Universities (ARWU), a metric frequently used in the literature because of its superiority as a measure of university research orientation (Taylor & Braddock, 2007). This is regarded as a more objective indicator of research outputs than the more subjective alternative international rankings based on peer review and reputational indicators (Saisana, d'Hombres, & Saltelli, 2011). The literature suggests that spending a visiting period in research-oriented universities may increase the probability of doctoral students engaging in research collaborations (Azoulay et al., 2017). In these contexts, research is a priority that contributes to attracting standout faculty and dedicated resources to maintain the universities'

[3] The SCImago Journal Rank (SJR) indicator is a measure of the scientific influence of scholarly journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where the citations come from.

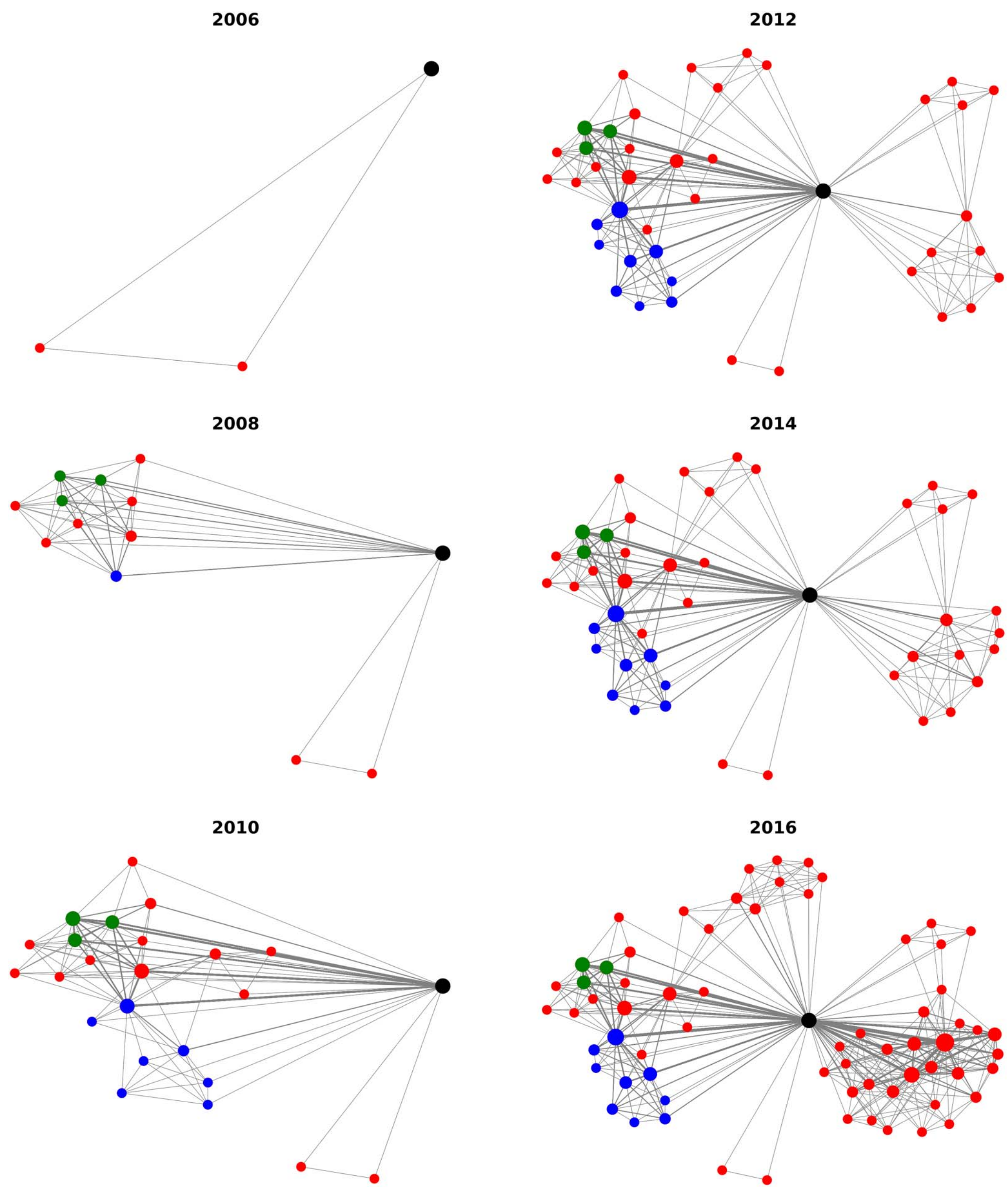

Figure 2. Representation of collaborations undertaken by an author in our data set who spent a period abroad between 2008 and 2009 at the Royal Institute of Technology (KTH) in Sweden. Red nodes indicate general coauthors, while blue and green nodes represent first-stage and second-stage coauthors, respectively.

elite status (Jacob & Meek, 2013). In our analysis, a dummy variable equal to 1 for universities included in the first 50 positions of the yearly ARWU classification is included to measure university prestige, because it has been reported that the top 50 universities in a ranking define the common features of a world-class university (see Shehatta & Mahmood, 2016).

3.3.1.2. Visiting duration This is the number of years elapsed between the start of the visiting program at a cross-border university and the return to China to complete the doctoral program. Students are assumed to form more international collaborations when they have more time in which to do so, and this is particularly crucial when addressing higher quality collaborations (Patrício et al., 2018). A longer stay is expected to lead to the emergence of stronger local networks and personal relationships and the possibility of targeting more complex and challenging projects (Baruffaldi & Landoni, 2012). However, the duration of international mobility may reduce the positive effects, particularly when it is contextualized as part of a doctoral program that is based at a Chinese university. After a long period, a mobile PhD student may feel pressed to return to China to finish their program and graduate.

3.3.1.3. PhD students' "peer crowdedness" Research-oriented doctoral programs aim at maintaining and boosting their research standing by developing research collaboration networks and welcoming visiting PhD students from other institutions. This situation is in theory a win-win for the visiting PhD students and for the hosting PhD supervisor and his or her students. A previous study found that more than 60% of Chinese exchange doctoral students in a STEM field published papers with their host supervisors (Shen, 2018). However, if the hosting university overemphasizes this practice, one supervisor may be supervising several PhD students from his or her own university in addition to those visiting. This can lead to overwork situations, which may result in lower-quality supervision for a PhD student experiencing temporary international mobility at that university (Green & Bowden, 2015). However, larger groups of students at the host institution have the potential to foster greater exchange of information and research collaboration (Horta & Lacy, 2011).

3.3.1.4. Cultural similarity The propensity to collaborate across international borders has been acknowledged to vary globally. The social traits, historical ties, and ethnic specificities of different countries all influence their cultural proximity and affect the willingness of researchers to collaborate internationally (Wagner & Leydesdorff, 2005). Thus, PhD students moving to countries that are more culturally distant from China may find it more difficult to implement collaborations, as they are hindered by very different methods of establishing social interrelationships (Ye & Edwards, 2015). In this study, the impact of moving to a different culture is evaluated by measuring the extent to which Chinese cultural traits are different from those of the host country across the following Hofstede's indicators:

- *Power distance*: Perceived power gap between members of an institution.
- *Individualism*: Perceived degree of an individual's independence from collective actions.
- *Uncertainty avoidance*: Perceived degree of tolerance of the individual for uncertainty and ambiguity.

These indicators are entered into our analyses in differences with respect to the baseline value for China. The larger the difference, either positive or negative, the less alike the two countries are in terms of Hofstede's cultural dimensions. In detail:

$$Cultural\ \ difference = ABSvalue\left(Index_{China} - Index_{hosting\ country}\right)$$

$$Index = \{power\ distance, individualism, uncertainty\ avoidance\}$$

3.3.2. Individual factors

Individual dimensions (e.g., age, gender, age at departure) are included as additional explanatory factors in the model to assess their effect on the ability of students to engage in international research collaborations. These are detailed in Table 3.

Table 3. Description of variables

Variable	Description
Age at departure	Age of the researcher at the time of departure.
Gender	Dummy variable equal to 1 if the researcher is male, and 0 otherwise.
Past educational experience abroad	Dummy variable equal to 1 for students who have experienced education abroad before entering the visiting doctoral program, and 0 otherwise.
Home supervisor network	Dummy variable equal to 1 if the home supervisor has coauthored a research article with the hosting supervisor before the start of the visiting doctoral program, and 0 otherwise.
Student's research autonomy	Dummy variable equal to 1 if the PhD student has published without the home supervisor before the program, and 0 otherwise.
Years from visiting to graduation	The years elapsed between the year of PhD graduation and the end of the visiting period.
Subfields	
• *Medicine*	Dummy variable equal to 1 if the doctoral student was enrolled in a PhD program in Medicine, and 0 otherwise.
• *Engineering*	Dummy variable equal to 1 if the doctoral student was enrolled in a PhD program in Engineering, and 0 otherwise.
• *Basic Science*	Dummy variable equal to 1 if the doctoral student was enrolled in a PhD program in Basic Science, and 0 otherwise.

3.4. Descriptive Analysis

This section reports a set of descriptive statistics related to our sample. Table 4 presents the top five destinations by country for Chinese doctoral students involved in the CSC program. A large proportion moved to native English-speaking countries, which are also advanced countries in terms of science positioning worldwide, such as the United States (55.44% of the total population of mobile PhDs), the United Kingdom (7.10%), and Australia (7.05%). At an institutional level, students opt to deepen their STEM studies at a doctoral level by moving to technical-oriented universities, such as the Georgia Institute of Technology in the United States (2.44%) or the Karlsruhe Institute of Technology in Germany (0.33%). Others consider prestigious universities such as UC Berkeley (1.22%), which are known to provide powerful signals in the academic labor market.

Table 5 presents the descriptive statistics for the PhD students' research network propagation. Up to 55% of visiting doctoral students were engaged in a research collaboration with authors affiliated with the hosting university, while 4% of them also collaborated with second-stage authors who were not affiliated with the hosting university but who had previously coauthored with at least one first-stage coauthor. This evidence suggests that the CSC program contributes to boosting the international research networking of Chinese early-career researchers. The international breadth of the program appears to consolidate previous contacts with authors from the hosting university and to enable doctoral students to leverage the privileged setting and explore deeper cross-border collaborations over time. The quality of papers implemented through an

Table 4. CSC-funded doctoral students' top five destinations by country

Country	University	No. students	% students
United States		867	55.44
	Georgia Institute of Technology	38	2.44
	Purdue University	25	1.61
	University of Illinois at Urbana-Champaign	20	1.28
	UC Berkeley	19	1.22
	Ohio State University	19	1.22
	(Other universities: 189)		
United Kingdom		111	7.10
	University of Cambridge	13	0.83
	University of Bristol	11	0.72
	University of Southampton	7	0.44
	University of Oxford	5	0.33
	University of Nottingham	5	0.33
	(Other universities: 36)		
Canada		111	7.10
	The University of British Columbia	16	1.05
	University of Toronto	15	0.94
	University of Alberta	14	0.89
	University of Waterloo	12	0.78
	McGill University	8	0.50
	(Other universities: 22)		
Australia		95	6.05
	University of Technology Sydney	16	1.05
	University of Queensland	16	1.00
	Monash University	9	0.55
	University of Western Australia	8	0.50
	University of Melbourne	6	0.39
	(Other universities: 22)		
Germany		63	4.05
	Karlsruhe Institute of Technology	5	0.33
	Technische Universität Munich	5	0.33

Table 4. *(continued)*

Country	University	No. students	% students
	Universitats Klinikum Aachen	5	0.33
	Ludwig-Maximilians-Universität Munich	4	0.28
	Technische Universität Berlin	3	0.22
	(Other universities: 32)		

international collaboration is higher compared to the average doctoral students' research productivity. On average, the PhD students published papers with an SJR impact factor of 0.62, which increased to 1.42 and 1.18 for papers published with a first- and a second-stage collaboration, respectively.

Table 6 presents the descriptive statistics for the factors influencing the network propagation dynamics. Notably, 68% of universities where students spent their visiting research period (on average 1.5 years) are ranked in the top 50 of the ARWU ranking. Visiting PhD students may benefit from the chance to collaborate within groups of an average of 6 peers, but some may have been in groups of more than 20 students, which may have been detrimental to their learning experience. The hosting countries were found to be different in terms of individualism when compared to China, but relatively similar in terms of the way people deal with uncertainty. According to Hofstede's cultural dimension theory, the Chinese population in general can be characterized as follows: a high power distance, inequalities among people are accepted and hierarchical power relations are polarized, a relatively low level of individualism, which is to the detriment of a high degree of interdependence among members of a group (thus a collectivist society), and low uncertainty avoidance, meaning that Chinese people can be considered pragmatic, adaptable,

Table 5. Collaboration network variables

	Variable	Count	Mean	Std. dev.	25%	50%	75%
Total	nr. (*% of PhDs*)	1564 (*100%*)					
	No. papers		19.2	20.3	7.0	13.0	25.0
	SJR		11.9	22.8	1.7	4.9	13.4
	SJR per paper		0.62	1.12	0.24	0.38	0.54
First-stage	nr. (*% of PhDs*)	860 (*55%*)					
	No. papers		6.4	12.2	2.0	3.0	6.0
	SJR		9.1	22.7	1.3	3.2	8.1
	SJR per paper		1.42	1.86	0.65	1.07	1.35
Second-stage	nr. (*% of PhDs*)	64 (*4%*)					
	No. papers		3.3	3.1	1.0	2.0	4.0
	SJR		3.9	4.6	0.6	2.6	5.5
	SJR per paper		1.18	1.48	0.60	1.30	1.38

Table 6. Determinants of research network propagation

Variable	Mean
University prestige	68.0%
Visit duration	1.4
PhD peers' crowdedness	5.9
Cultural differences	
Power distance: diff	40.3
Individualism: diff	63.4
Uncertainty avoidance: diff	19.8
Female	33.5%
Age at departure	30.8
Past educational experience abroad	50.6%
Home supervisor network	9.3%
Student's research autonomy	7.5%
Years from visiting to graduation	1.1
Subfields	
Engineering	64.7%
Medicine	9.4%
Basic Science	25.9%

and entrepreneurial[4]. Women accounted for a third of the mobile population of Chinese doctoral students, and the average age at the time of departure was 31 years. Half of the students already had experience abroad before the mobility period. In terms of collaborations, only 9% were able to benefit from strong connections that the home supervisor had already established at the hosting university (at least one coauthored Scopus-indexed article), and 7.5% had published a paper without the home institution supervisor before their overseas visit, signaling research autonomy. The majority of students (65%) were doing their PhD in engineering disciplines and took on average 1.1 years to graduate after the visiting period.

4. METHODOLOGY

Our analysis examined whether the CSC program generates positive externalities that help expand the research networks of PhD students who experience temporary international mobility. However, as all of the PhD students in the sample were mobile, to address potential selectivity bias, data were collected from a random sample of 1,200 nonmobile students in 2013 who did not take part in the program in 2014. Information about each student's characteristics was obtained and combined with the matching data on the internationally mobile PhD students. Following previous studies (e.g., Higgins & Gulati, 2003), a selectivity instrument was created as a control in our regression analysis based on a two-step Heckman procedure (Heckman, 1979), as the ability

[4] See https://www.hofstede-insights.com/country-comparison/china/.

to establish connections abroad was observable only for a part of our sample. In the first step, the likelihood that a doctoral student would participate in the international program was predicted (through a probit regression; see the Appendix). The predicted values were then used to create the selectivity instrument (the Mills ratio), which was included in the models that evaluate the factors influencing the establishment of international collaborations (Hamilton & Nickerson, 2003; Higgins & Gulati, 2003; Van de Ven & van Praag, 1981). This provided a better understanding of how temporary mobility under the CSC program was associated with the establishment of international research collaborations by PhD students. In the second stage, the following three analyses were conducted: (a) the likelihood that at least one international collaboration was established (the probit regression); (b) the count of the international collaborations (Poisson regression); and (c) the quality of the established international collaborations (Tobit regression based on the weighted sum of the Scimago impact factor of the journals in which the doctoral students published). These models were first used to establish the broad determinants of international collaborations, without distinguishing between first- and second-stage collaborations. The focus then turned to second-stage collaborations, and a Probit model was used to identify the features that influence the probability of establishing stronger international research links.

5. RESULTS

We conducted regression analyses to explore how contextual and individual factors can affect PhD students' research collaborations with peers at a hosting institution after a mobility period abroad. Table 7 reports the regression results for (a) the likelihood of opening a cross-border collaboration, whether a first- or second-stage collaboration (Model 1); (b) the number of such collaborations (Model 2); (c) the quality of these international collaborations (Model 3); and (d) the likelihood of opening a second-stage cross-border collaboration (Model 4).

Four variables are found to be significant. First is the prestige of the hosting university, which positively influences the probability of international collaboration with researchers at the hosting university and influences the intensity of collaborations (i.e., the number of coauthored papers). Visiting a prestigious university increases the probability of establishing an international collaboration by 7 percentage points (pp) (Model 1, Table 7) and predicts 0.2 more I stage collaborations (Model 2, Table 7). This also affects the chance of international collaboration with researchers who are not affiliated to the hosting university but who had previously coauthored with at least one first-stage coauthor (i.e., second-stage collaboration), although it does not appear to affect publication in high-quality journals. These findings suggest that PhD students visiting the most prestigious universities are better able to engage in first- and second-stage collaborations than those visiting less prestigious universities. The visitors are likely to benefit from prestigious universities' high levels of human and technical capital, and these universities also act as gatekeepers and facilitators of national and international collaboration dynamics (Jacob & Meek, 2013). The inability of visiting PhD students to produce high-quality papers compared to their peers at less prestigious universities may be explained by a multitude of factors, including the fact that top scholars in these universities may try to implement a risk-minimizing strategy when collaborating with visiting Chinese PhD students due to supervisory style differences, and assumed responsibilities regarding the supervision of visiting PhD students (see Ingleby & Chung, 2009).

The second variable is the duration of the visiting period, which has a positive impact on most dependent variables, indicating that for its benefits to be realized, temporary international mobility must be for a reasonable amount of time. The literature focusing on visiting doctoral programs has reported that an appropriate time window is required to enable PhD students to

Table 7. Determinants of the explanatory variables

Variable	(1) First-stage & second-stage (0/1)	(2) Count of collaborations	(3) SJR Weighted collaborations	(4) Second-stage (0/1)
ARWU top 50	0.186***	0.060**	0.611	0.216**
	(0.072)	(0.030)	(1.591)	(0.102)
Visit duration	0.537**	1.383***	18.370***	−0.369***
	−0.230	(0.113)	(5.464)	(0.121)
Visit duration (squared)	−0.093	−0.243***	−3.406**	0.143***
	(0.068)	(0.033)	(1.641)	(0.031)
No. of peer students at destination	0.004	0.016***	0.298**	−0.000
	(0.007)	(0.003)	(0.146)	(0.011)
Cultural difference				
Power distance: diff	−0.020***	−0.016***	−0.393***	−0.002
	(0.005)	(0.002)	(0.104)	(0.007)
Individualism: diff	0.003	0.000	0.095	0.009**
	(0.003)	(0.001)	(0.066)	(0.005)
Uncertainty avoidance: diff	−0.016***	−0.015***	−0.250***	−0.012
	(0.004)	(0.002)	(0.085)	(0.007)
Years from visiting to graduation	−0.068	−0.231***	−2.724**	0.168***
	(0.048)	(0.020)	(1.062)	(0.046)
Female	−0.049	−0.345***	−2.616*	−0.521***
	(0.071)	(0.031)	(1.570)	(0.092)
Mills ratio	0.040	−0.291**	−8.804	0.714
	(0.331)	(0.133)	(7.255)	(0.733)
Age at departure	−0.014	−0.023***	−0.340	−0.042***
	(0.019)	(0.008)	(0.414)	(0.015)
Past international experience	0.095	0.200***	1.522	0.248
	(0.067)	(0.028)	(1.469)	(0.169)
Home supervisor network	0.813***	0.948***	18.549***	0.552***
	(0.129)	(0.034)	(2.338)	(0.166)
Student's research autonomy	0.218	0.563***	6.234**	0.436
	(0.143)	(0.048)	(3.031)	(0.426)

Table 7. *(continued)*

Variable	(1) First-stage & second-stage (0/1)	(2) Count of collaborations	(3) SJR Weighted collaborations	(4) Second-stage (0/1)
Subfields				
Engineering	0.272***	0.030	−1.853	0.078
	(0.078)	(0.031)	(1.716)	(0.079)
Medicine	−0.323**	−0.264***	−7.475**	−0.016
	(0.129)	(0.059)	(2.982)	(0.096)
Constant	0.734	1.806***	8.500	−1.986***
	(0.750)	(0.307)	(16.518)	(0.643)
Observations	1,564	1,564	1,564	1,564

Note: ***, **, * Significant at the 1%, 5%, and 10% levels, respectively.

adapt to a new culture and often language, and to a home life abroad, before they are able to start working effectively. Only after they have adapted can they start developing working relationships and actively participate in the life of the hosting university (Mill, Johnson, et al., 2014). In detail, our findings show that increasing the visiting period by 1 year improves the probability of establishing a first-stage cross-border collaboration by 21 pp (Model 1, Table 7). Model 2 further suggests that this time horizon would predict four more first-stage collaborations and a boost in the cumulative SJR indicator equal to 18 (Model 3, Table 7). However, our results also show that when the duration of the visiting becomes too long, there are declining marginal gains (an inverted U-shaped effect) in terms of the ability to engage in new collaborations and publish in high-impact journals. Longer visiting experiences may help ensure research collaborations with researchers other than their supervisors (second-stage collaborations), however, the curvilinear results (a U-shaped effect) suggest that either the PhD students manage to establish a second-stage collaboration in a short time period or they require a much longer time to embark on this type of collaboration.

The third finding is that visiting PhD students' productivity and performance benefit from joining hosting supervisors who manage larger numbers of PhD students. An increase of one supervised PhD student predicts 0.1 more first-stage collaborations (Model 2, Table 7) and an increase in the cumulative SJR indicator of 0.3 (Model 4, Table 7). This may be related to peer-to-peer interactions that complement the supervision of the hosting supervisor through both academic and emotional support in informal groups (Janson & Howard, 2004), which is acknowledged to transfer both practical skills and tacit knowledge (Leshem, 2007). A larger research-oriented group does not, however, influence the establishment of first- and second-stage collaborations, although it is a determinant of the number of collaborations and the average quality of connections.

The fourth finding concerns the important role of social and cultural similarities and differences, which are a part of international mobility and important for the personal development of both those who are mobile and those who host them. The results show that mobile Chinese PhD students face greater issues in establishing research collaborations in societies where uncertainty avoidance and power distance are different from Chinese culture. Considering that most of the mobile Chinese PhD students in the sample moved to English-speaking countries with almost opposite power distance and uncertainty avoidance, the findings are not surprising; they probably reflect the longer time that the students required to adapt to different societies and cultures and the greater range of obstacles that they must overcome before and probably during collaborations (see Ye & Edwards, 2015). This is not the case for individualism, possibly because of the positive effects that they may encounter through interacting with greater numbers of peers at the hosting institution, some of whom may be Chinese nationals (considering the Chinese diaspora of students doing PhDs abroad; Shen et al., 2016), and because the typical adaptive, pragmatic, and entrepreneurial characteristics of Chinese people help them to overcome barriers and drive them to engage in increasingly autonomous research collaborations.

The findings for other variables are also relevant. Existing links between the home supervisor and the hosting supervisor before the PhD student's international visit takes place represent an important variable that has been previously identified. Having a home supervisor who has previous research links with the hosting supervisor has a positive effect on all of the variables considered, including the PhD student being able to publish in high-impact journals. This is the only variable that positively affects all of the dependent variables, which underlines the important role that previous existing links play in fostering the success of visiting research periods abroad (as argued by Patrício et al., 2018). This effect is likely to be due to the trust that has already been built between supervisors, thus helping to establish a trusting relationship between the visiting PhD student and the hosting supervisor. An existing relationship between supervisors may also create incentives for the hosting supervisor to pay more attention to the research activities of the visiting PhD student than if no previous relational rapport exists. In this context, it should be considered that the hosting supervisor has his or her own PhD students based at the hosting university, and these are likely to take priority in terms of supervisory time and resources. In addition, when supervisors have a previous research relationship or the visiting PhD student is doing research on a topic that follows or is closely related to research that the supervisors collaborated on, the PhD student may then be able to expand his or her network (possibly with other researchers associated with a project supervised in common).

Women are less likely to set up more collaborations, but also higher quality collaborations and second-stage collaborations, indicating they are less likely to internationally extend their collaborations than their male peers. These findings are aligned with the literature suggesting that female PhD students are not able to take as many benefits from international mobility as their male counterparts (Jons, 2017; Mahlck, 2018). The visits we investigated were conducted in the context of STEM fields, in which women are a minority, which may enhance this effect. The finding does not validate claims by previous researchers that mobile women adapt better than men to new research environments nor that they are prone to be more engaged in collaborative activities (as argued by Rhoten & Pfirman, 2007). In addition, the ability of PhD students to publish independently without the supervisor before the mobility period positively influences the number of collaborations and the ability to publish research from these collaborations in high-impact journals. This is an expected finding because it underlines that a degree of scientific maturity on the part of the student is a competitive advantage over other students engaging in similar mobility experiences for research purposes. The relatively low influence that past international experience has on most dependent variables, except on the ability to augment the number of collaborations, is an unexpected finding. The finding concerning time from the visit to graduation is to the best of our knowledge novel. The longer this time is, the fewer the collaborations and publications in high-impact journals. This may be because during this time PhD students typically focus on writing up their theses and finishing their PhDs, which is labor intensive and produces a sense of an end of a cycle (McAlpine, Paulson, et al., 2012). The positive and significant result concerning second-stage collaborations points to a transition from the conclusion of the PhD (end-of-cycle) to the engagement with new collaborators and the establishment of a new postdoctoral cycle. Finally, although age during the mobility period does not appear to have much of an effect, the longer time horizon of younger doctoral students appears to motivate them to implement second-stage collaborations.

6. CONCLUSIONS

During a period of temporary international mobility, 55% of the mobile PhD students established first-stage international collaborations (i.e., with hosting supervisors and/or others at the hosting university), and 4% of these were able to establish second-stage collaborations (i.e., with researchers abroad outside the hosting university). Although the value of temporary international mobility for early career researchers during their doctoral studies has been recognized (Canibano et al., 2011), our study identifies specific characteristics that encourage the development of collaborations for PhD students from STEM fields while on temporary mobility abroad. When designing international mobility programs for PhD students, research funding agencies should consider previous research collaborations between supervisors at the home and host university, the prestige of the host university, the duration of the mobility period (in terms of their adaptation to social and cultural environments that are distant from the culture and society of origin), and the number of peer PhD students supervised by the hosting supervisor at the host institution. In this study, the focus is on the impact of cultural and social distance on research collaborations, but the mobility experience also encourages other externalities, which may potentially encourage the cultural adaptability and integration that are key to developing the global talent that countries require to foster their scientific and socioeconomic progress (see Corley et al., 2019).

Some studies dispute the benefits of mobility in general. Bernela and Milard (2016), for example, found little explanatory power for geographical mobility in terms of collaborations based on a career analysis of two prolific and established chemists. Our study mainly identifies the conditions of temporary mobility that are associated with the creation and development of research networks based on coauthorship. The effects observed may simply be a reflection of a spatial translation of existing ties, as in many cases the mobilities (and destinations for those mobilities) of PhD students and early career researchers are defined, shaped, and developed by supervisors or senior scholars. Melin (2004) found that contacts made during postdocs abroad often led to collaborations and copublications (countering the findings of Bernela & Milard, 2016), and also revealed that postdoctoral mobility is often reliant on the advice, contacts, and networks of senior colleagues. Our study acknowledges the important positive and significant effect of the home network supervisor network in first-stage, second-stage, and number of collaborations, and in publishing in higher impact journals. However, only 9.3% of the PhD students that went abroad had a supervisor at the home university who had collaborated previously with an academic based at the hosting university, suggesting that for most of the mobile PhD students, network formation during the time away was not associated with a spatial translation of existing collaborations, but rather with their integration into a new environment, and their agency and effort during the mobility period.

The extent of the research propagation can also be considered as providing mixed signals in terms of policy implications. Of the PhD students in the study, 55% were able to publish in collaboration with scholars affiliated to the hosting university and 4% with authors who were not affiliated with the hosting university but who had previously coauthored with at least one first-stage coauthor. This suggests both positive and negative aspects. In terms of negative outcomes, 45% of the mobile PhD students did not manage to publish collaboratively at all, but the argument for the positive effects is more persuasive. First, the findings are based on successful and formalized collaborations, which are measured through coauthorships on research endeavors that result in publication (Katz & Martin, 1997). However, informal collaborations may have also been established, and externalities in terms of learning new theories, methods, and exposition to different cultural and knowledge environments may also have been pursued and achieved. Second, the analysis is focused on STEM field PhD students from China working in different social and cultural settings and within a process of learning and socialization, and who had probably not yet developed the proficiency to publish, even in collaboration, and even if they wished to. In this context, it is relevant that only between 75% to 90% of students doing PhDs in US universities in STEM fields are able to publish before concluding their PhDs (50% to 68% of these publications were coauthored with their supervisors; Pinheiro, Melkers, & Youtie, 2014). Third, the average visit period lasts 1.4 years, which is a relatively short time in which to develop collaborations with scholars at a hosting university. In addition, only 9.3% of those engaged in temporary mobility had supervisors in contact with peers at the hosting institution. This is possibly due to two reasons. First, academics at the host universities are typically busy and have their own PhD students, whom they are likely to prioritize in collaboration, supervision, and coauthorship. Second, the network between supervisors in China and international supervisors is not yet sufficiently consolidated to foster supervisory linkages.

The finding that temporary mobility in prominent universities positively influences all kinds of networking, including the ability to engage in second-stage collaborations but not the ability to publish in higher impact journals, is of interest. Students' motivations to spend time at these universities may be more closely related to signaling purposes in terms of social capital than to making use of the superior human and material resources required to develop more ambitious and frontier research. Network visibility signaling may be more important than the more traditional scientific signaling (Dalen & Henkens, 2005). Network visibility signaling has been increasingly recognized as a motivation and rationale for those engaged in international mobility due to the cumulative self-reinforcement of social capital, which in the long run is expected to enhance international scientific standing, although sometimes at the expense of national social capital for early-career researchers (Bauder, 2020). Qualitative analyses of Chinese scholar mobilities suggest that this motivation for international mobility is particularly risky for early career researchers (Leung, 2013). In addition, academics at top universities may also be extremely selective in their collaborations and may want only to collaborate with promising PhD students, who may well be their own, rather than investing in more ambitious and quality-driven research with temporarily visiting PhD students.

Finally, the study offers a new way to explore scientific network propagation. Our approach is novel because it not only allows identification of the scientific collaborations that are established with authors affiliated to the hosting university during the period abroad but also captures the full-scale network benefits that arise from the PhD student's visit. Unlike other contributions aimed at developing specific measures of research collaborations or evaluating their determinants and impact (e.g., Abramo, D'Angelo, & Murgia, 2017; Guan, Yan, & Zhang, 2017; Wang, 2016), our methodology takes a more integrated perspective to explain the evolution of the scientific profile of a researcher over time by tracking the network expansion that arises from the cross-border research experience she undertook during her doctoral studies. Given the complexity of research collaborations (Katz & Martin, 1997), our network analysis considers the most explicit product of scientific collaborations (coauthorship) to identify such interactions, depicting as collaborators the scientists who directly contributed to the publication of an article (He, Ding, & Ni, 2011). While this restricts the plethora of research collaborations, it considers the most important channel of scientific transfer and development among individuals and systems (Sauer, 1988). Thus, our overall approach can be considered as prudential when exploring the propagation of visiting PhD students' research networks. A PhD student could indeed have set up other collaborations during the visit, beyond those identified by our procedure (Section 3.2). We tentatively ignore these dynamics, underestimating the number of research collaborations established by doctoral students and not introducing potential bias, thus opening an interesting avenue for future investigation in the area of scientific research network development.

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AUTHOR CONTRIBUTIONS

Hugo Horta: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing—original draft, Writing—review & editing. Sebastian Birolini: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing—original draft, Writing—review & editing. Mattia Cattaneo: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing. Wenqin Shen: Data curation, Funding acquisition, Project administration, Resources, Writing—original draft, Writing—review & editing. Stefano Paleari: Supervision, Writing—original draft, Validation.

COMPETING INTERESTS

The authors have no competing interests.

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DATA AVAILABILITY

The data used in this manuscript cannot be made available to third parties as it was obtained in the scope of a publicly funded project (project number: 18JYC024), which constrained accessibility to others outside the project. Authors collaborating in the manuscript signed agreements restraining them from sharing the micro-data.

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APPENDIX

First step of Heckman procedure to predict the likelihood that a doctoral student will participate in the international program.

Variable	Probability of being internationally mobile
Female	–0.028
	(0.051)
Age at departure	0.907***
	(0.093)
Age at departure – square	–0.014***
	(0.001)
Married	0.150***
	(0.054)
No. peer students at home	0.042***
	(0.006)
College score (baseline: 10%)	
10–25%	–0.126**
	(0.056)
25–50%	–0.368***
	(0.075)
50%	–0.522***
	(0.133)
Mother education (baseline: College)	
Graduate	0.120
	(0.302)
High	–0.099
	(0.077)
Middle	–0.193**
	(0.079)
Primary	–0.278***
	(0.076)
Constant	–13.223***
	(1.474)
Observations	4,071