SOCIAL CAPITAL AND RESEARCH PRODUCTIVITY OF FOREIGN-BORN SCIENTISTS IN THE UNITED STATES

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SOCIAL CAPITAL AND RESEARCH PRODUCTIVITY OF FOREIGN-BORN SCIENTISTS IN THE UNITED STATES

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LIST OF ABBREVIATIONS

GLM	Generalized linear model estimation
GMM	Generalized method of moments estimation
IV	Instrumental variable estimation
NSF	The National Science Foundation
NSOPF	National Study of Postsecondary Faculty
OLS	Ordinary least squares estimation
SDR	Survey of Doctorate Recipients
STEM	Science, Technology, Engineering, and Mathematics (disciplines)
STHC	Scientific and Technical Human Capital (model)
UK	The United Kingdom of Great Britain and Northern Ireland
US, USA	The United States of America

SUMMARY

The dissertation fills several gaps in our understanding of professional social capital and the performance of foreign-born scientists. The study is motivated by the paradox that foreign-born faculty are able to maintain higher research productivity than their US-born counterparts despite reporting difficulties with social relationships. It addresses the question of whether or not the professional social capital of foreign-born faculty differs from that of US-born faculty, and if so, do such differences impact the research productivity of foreign-born scientists?

The dissertation is based on the scientific and technical human capital model (Bozeman et al., 2001) and extends it using knowledge from the immigration literature pertaining to the differential social capital of immigrants and related productivity implications. Using *Netwise II* survey[1] data on 760 foreign-born and 963 US-born scientists, this analysis focuses on comparing the professional network sizes, relational properties, and geographic locations of the social capital of both populations.

The dissertation finds that the professional social capital of foreign-born scientists is restricted and resembles unique attributes previously found among lower-skilled immigrants. They have smaller professional networks than do

[1]The project is funded by the NSF grant “NETWISE II: Empirical Research: Breaking through the Reputational Ceiling: Professional Networks as a Determinant of Advancement, Mobility, and Career Outcomes for Women and Minorities in STEM” (NSF Grant # DRL-0910191).

domestic faculty but mitigate the lack of ties by maintaining relationships with individuals who provide resources necessary for research activities. Further, foreign-born scientists who arrive in the US during later career stages have more developed foreign networks and use them to substitute for the difficulty of accessing domestic support. On the contrast, US-educated foreigners have insufficiently developed both domestic and foreign professional social capital, thus indicating their inefficient integration into US academia. However, unique attributes of foreign-born scientists social capital, namely, more intensive use of ties and better developed international social capital, mitigate the negative productivity impact of having smaller professional networks.

1. INTRODUCTION

The purpose of the dissertation is to address the paradox of how foreign-born faculty in science, technology, engineering, and mathematics, or STEM, fields attain consistently high rates of research productivity (Corley & Sabharwal, 2007; Stephan & Levin, 2001b) despite social capital theory suggesting that this should not be the case. Social capital theory associates the productivity of an individual with the extent of social relationships and benefits received from them (Adler & Kwon, 2002; Bourdieu, 1986; N. Lin, 2001). The research productivity of scientists is also associated with professional relationships (Bozeman & Corley, 2004; Katz & Martin, 1997; Melin, 2000). Such association, however, appears not to apply to the productivity of foreign-born scientists, as they constantly report difficulties establishing professional relationships (Collins, 2008; Foote, Li, Monk, & Theobald, 2008; Skachkova, 2007).

Despite the high number of foreign-born faculty in the scientific workforce of the US (National Science Foundation, 2016b) and the apparent social capital paradox, very few studies have addressed the social relationships of foreign-born faculty . Thus, the purpose of this research is to fill the gaps in our understanding of social relationships and the performance of foreign-born scientists. It extends the scientific and technical human capital framework of research productivity (Bozeman, Dietz, & Gaughan, 2001) by exploring the unique characteristics of the social relationships of foreign-born scientists. This information is drawn from the immigration literature suggesting that the social ties of immigrants often differ from those of the native community (Portes, 1995) in the number of relationships they form, the characteristics of peers with whom they form relationships, and the types and amounts of resources that they receive (Light, Sabagh, Bozorgmehr, & Der-Martirosian, 1994; Nee & Sanders, 2001).

I explore potential differences between foreign- and US-born scientists by asking the following research question: **In academic science, does the professional social capital of foreign-born faculty differ from that of US-born faculty?**

If the answer to the prior question is affirmative, the scientific and technical human capital model (Bozeman et al., 2001) and evidence from the immigration literature (Nee & Sanders, 2001; Ryan, Sales, Tilki, & Siara, 2008), suggest such differences could impact the productivity of scientists. The potential impact is addressed by the second research question: **Do observed social capital differences, if any, impact the research productivity of foreign-born scientists?**

The first chapter provides a review of the foreign-born scientific workforce and their productivity to clarify and contextualize the focus of the dissertation. It begins with a review of unique features of the research productivity of foreign-born faculty and existing explanations for why they are more productive than their US-born counterparts. It continues by summarizing the current extent of research on the social relationships of foreign-born faculty, and then, to underscore the importance of this issue, it presents a review of the US academic workforce and the growth in the number of foreign-born faculty.

1.1. Higher research productivity of foreign-born scientists

Prior research has found that foreign-born academic scientists in the US have higher research productivity than their US-born colleagues. In 2004, the National Survey of Postsecondary Faculty reported that while foreign-born scientists produce significantly more refereed articles, an average of 5.56 annually, US-born scientists produce an average of 3.81 (National Center for Education Statistics, 2006). The same survey also found that foreigners have higher productivity of other research outputs such as textbooks, conferences presentations, and patents. Their stronger research performance is further confirmed in the Survey of Doctorate Recipients published by the National Science Foundation (NSF) and smaller-scale studies on academic faculty (Corley & Sabharwal, 2007; Kim, Wolf-Wendel, & Twombly, 2011; Lee, 2004; Webber, 2012). The studies demonstrate broader aspects of foreigners' productivity, such as being as likely or slightly more likely to receive governmental research grants, more often being named as inventors, having applied for and received patents, and having a greater probability of turning patents into commercial products (Corley & Sabharwal, 2007; Kerr, 2013; Lee, 2004).

Not only do foreign-born scientists exhibit higher research productivity, but they are also disproportionally represented among the exceptional scientists in the US. For example, at a higher rate than their overall share in the US academic society, foreigners are represented among the members of the National Academy of Sciences. More than half of the 250 most-cited authors are foreign-born, comprising a significant proportion of owners of extensively cited patents and scientists with successful, commercially launched spinoffs (Stephan & Levin, 2001b).

Studies have provided several explanations for the higher research productivity of foreign-born scientists, including the research focus of their academic activities, demographic, professional, and institutional differences, and greater human capital. First, the higher publication productivity of foreign-born scientists often results from the research focus of their academic activities. Foreign-born faculty spend more hours on research activities than US-born faculty (Corley & Sabharwal, 2007; Sabharwal, 2011) and fewer hours teaching and advising (Mamiseishvili, 2011b; Mamiseishvili & Rosser, 2009; Webber, 2012). According to NSF data, about 90% of foreign-born scientists report research as their primary or secondary activity, and only 35% report teaching. Moreover, two-thirds of these scientists are supported by research grants or contracts (National Science Foundation, 2016b). Worth to mention that even foreign-born female faculty are more likely to engage in research activities while US-born women scientists are more extensively involved in teaching and service activities (Mamiseishvili, 2009).

One reason why foreigners select research over teaching stems from cultural differences that render teaching more difficult than research (Foote et al., 2008). Foreign-born scientists often find it difficult to adjust to American academic standards, the grading system, and the classroom culture, especially if they have not experienced the American classroom as undergraduate student (Collins, 2008). Foreigners also feel as if their teaching is undervalued by students because of students' inherent prejudices, the foreign professor's pronunciation, style of teaching, use of uncommon narratives or concepts, and lack of conforming to the usual stereotypes (Alberts, 2008; Skachkova, 2007). Foreign-born scientists also spend less time on service because they are, to a lesser degree, represented among managerial, higher academic, or authority positions (Corley & Sabharwal, 2007). Moreover, a higher percentage of foreigners occupy post-doctoral positions, and thus, they are more likely to work solely on research because of the nature of post-doctoral positions (Corley & Sabharwal, 2007).

Another set of explanations for the higher research productivity of foreign-born scientists relates to various demographic and professional differences. For example, a higher proportion of them are male (Corley & Sabharwal, 2007), they are younger than US-born scientists, they occupy lower academic ranks, and they are not yet tenured (Z. Lin, Pearce, & Wang, 2008; Mamiseishvili & Rosser, 2009). Prior research associates being male, earlier career stage and lower ranks with higher focus on research rather than other academic activities leading to higher research productivity (Stephan & Levin, 1992). Further, foreigners more likely to be employed in research-oriented institutions, especially on larger, internationalized campuses, and in bigger cities, and working in such institutions is positively correlated with research productivity (Corley & Sabharwal, 2007; Kim et al., 2011; Mamiseishvili, 2011a). Finally, a higher proportion of foreign-born faculty are engaged in disciplines characterized by higher publication output, such as STEM disciplines, rather than those that are not, such as social sciences (Kim et al., 2011).

Although research activities, gender, age, academic rank and tenure, institutional settings, and disciplines account for some of the differences between the productivity of foreign and US-born scientists, they do not paint the entire picture of the discrepancy. After controlling for these factors, studies have still found that foreigners are more productive in research than their US-born colleagues (Kim et al., 2011; Mamiseishvili & Rosser, 2009). Another explanations for these productivity differences are associated with levels of effort and amount of human capital. Foreign-born scientists report that because of pressure of immigration procedures or unfamiliarity with the tenure and promotion processes, they have to expend more effort in their research than US-born colleagues (Collins, 2008; Kim et al., 2011). They work harder because of the "glass ceiling" and discrimination, undervaluation of their skills and results, and feelings of social and professional isolation (Collins, 2008). Foreign-born scientists in the US and other developed countries have expressed concern that different expectations exist regarding performance and quality of research. They receive closer scrutiny and to earn the same recognition, feel constant pressure to devote more effort into research activities than local scholars (Ackers & Gill, 2008; Kwankam, 2010; Skachkova, 2007).

Another contributor to higher productivity among foreign-born scientists is their stronger foundation of human capital, attributed to efforts of the American scientific community to recruit the “best and brightest” from the global talent pool (Matthews, 2010). Therefore, foreign-born scientists have typically received a higher level of training and possess stronger skills than native-born scientists in comparable positions (National Science Foundation, 2016a); they also report having received better undergraduate education than their US-born colleagues (Kim et al., 2011). Economists explain that U.S. academic institutions can afford employing highly productive foreigners because their salaries are usually lower than those of the US-born labor with similar skills and capacity. At the same time, the US-born population with similar potential, often crowded out of academia by foreigners, tend to find more lucrative employment opportunities (Regets, 2001). Moreover, the comparatively stronger skill sets of immigrant scientists are not unique to the US. For example, Eastern European scientists in Germany and the United Kingdom also report that their skills are sometimes stronger than those of local colleagues in similar jobs, and they often believe that their skills are above the level required in their positions (Ackers & Gill, 2008). Finally, immigration studies generally emphasize the high productivity of migrants because they represent a very selective population characterized by exceptionally strong achievement motivation (Rogler, 1994).

1.2. Limited research on the social capital of foreign-born scientists

The higher research productivity of foreign-born scientists presents an interesting paradox: maintaining higher productivity while possessing lower social capital. Foreign-born scientists, who often report having difficulty establishing professional ties, and social capital theory suggests they would have more limited access to resources (Bourdieu, 1986; N. Lin, 2001), would be expected to have lower productivity. The importance of possessing social capital is also evident in science. It is through social connections that scientists acquire and share knowledge, competencies, skills, methods, and techniques required for conducting their research (Bozeman & Corley, 2004; Katz & Martin, 1997; Melin, 2000). Relationships help researchers access funding, data, and equipment required for their professional activities (Melin, 2000). In addition to establishing that social connections provide scientists with various types of support for their professional activities, prior studies confirm that professional relationships and collaboration on research problems positively impact their research performance and quality (Bozeman et al., 2001).

Although prior studies produced evidence supporting significance of social capital for research performance and paradox of foreigners' higher research performance while having difficulties establishing professional ties, very few studies have examined the social relationships of foreign-born scientists. Focusing on other issues related to scientists, such studies contain mostly fragmented findings on social ties of foreign-born. For example, studies of scientists' social capital have found that foreign-born scientists in the US have higher prevalence of foreign collaborations than US-born scientists (Lee, 2004; Melkers & Kiopa, 2010). Several studies have addressed the international ties of foreign-born scientists and other highly-skilled professionals within their home countries and formation of diasporas. From the individual perspective such ties provide immigrants with easier and often less costly access to resources available at home (Biao, 2005; Woolley & Turpin, 2008). Where organized diaspora is developing research find more active and effective cooperation between host and home countries and among diaspora members themselves leading to increased economic activities and innovation transfer between countries (Agrawal, Kapur, McHale, & Oettl, 2011; Saxenian, 2005; Saxenian, Motoyama, & Quan, 2002) as well as increasing international collaboration in science (Séguin, Singer, & Daar, 2006).

Interviews about the adaptation, integration, and professional experiences of foreign-born scientists reflect the difficulties that they experience establishing social relationships. Foreign-born scientists report being excluded from social networks of academic peers, especially from inner circles of their departments, and having no relationships with professionally influential individuals or lacking their support (Seagren & Wang, 1994; Skachkova, 2007). Foreign-born faculty, regardless of gender and country of origin, also list among the hardest professional challenges they face as lack of collegiality with American colleges, poor quality of professional relationships, and a sense of isolation and loneliness (Bang, 2016; Collins, 2008; Foote et al., 2008; Thomas & Johnson, 2004).

Moreover, in the interviews, scientists reveal the negative impact of poor quality social relationships on their academic performance, receiving little assistance on professional issues such as help on research and publications, advice on working with students and dealing with departmental politics, understanding evaluation and promotion rules, dealing with immigration issues, and simply settling into the host country.

The current literature indicates that indeed foreign-born scientists might face significant difficulties establishing professional relationships. However, studies have yet to explore whether perceived difficulties with social relationships manifest in social capital differences. Moreover, dedicated, comprehensive studies of their social relationships and their impact on research productivity are absent, maintaining the paradox of less social capital and higher research productivity.

1.3. Theoretical implications

The research fills the current gap in knowledge about foreign-born academic scientists by using and extending the *scientific and technical human capital model* (Bozeman et al., 2001). The model provides a comprehensive framework of various forms of “capital” and resources with an impact on research productivity such as equipment, resources, organizational arrangements, skills, training, knowledge, and productive social capital. The framework is extended by a more nuanced model of the impact of foreign origin on the productive social capital of scientists and the consequential impact of these unique social capital attributes on research productivity. To extend the model, this study uses the network theory of social capital (N. Lin, 2001) and the findings from the immigration literature.

The network theory of social capital provides the framework in this study for the analysis of foreign-born scientists' "social network," or social connections and resources accessed through connections (N. Lin, 2001). According to the theory, the productivity of individuals is related to the possession of ties and accessible resources (Bourdieu, 1986; Burt, 2005; Coleman, 1988; N. Lin, 1999a, 2001; Portes, 1998). Moreover, both the STHC model and the network theory of social capital draw attention to the characteristics of social relations, the structural features of scientists' social network, their roles within the network, institutional boundaries, and the amount and characteristics of accessible resources, all factors known to impact productivity (Burt, 2005; Coleman, 1988; Granovetter, 1973; N. Lin, 2001), particularly that of scientists (Bozeman et al., 2001). Using the unique characteristics of the social capital of migrants (Berry, 1997; Nee & Sanders, 2001; Portes, 1995; Rogler, 1994; Williams, 2006), this study extends the STHC model to analyze the tendencies observed among the social networks of foreign-born scientists in the US. It integrates the findings from both the immigration literature and from interviews of immigrant scientists in the US and other developed countries (Ackers & Gill, 2008; Meyer, Barre, Hernandez, & Vinck, 2003; Tejada & Bolay, 2010).

The immigration literature has also prompted a more comprehensive analysis of unique social capital attributes besides the number of relationships, as it finds more efficient social capital use among immigrants (Nee & Sanders, 2001; Ryan et al., 2008). By analogy, foreign-born scientists, while finding it difficult to establishing social ties, could possess other social capital attributes that positively impact their performance. Therefore, the analysis specifically focuses on social network characteristics that are both potentially observable among foreign-born scientists and known to impact research productivity.

This study further extends the STHC model by explaining if the differential social capital of foreign-born faculty influences variability in research performance. To satisfy this purpose, the study complements the model with findings from other studies about the impact of various social capital characteristics on research productivity (Bozeman & Corley, 2004; Fox & Faver, 1984; Katz & Martin, 1997; Melin, 2000).

1.4. Relevance of studying foreign-born scientists' social capital and research productivity

Understanding the factors that lead to the enhanced research productivity of foreign-born scientists is particularly significant given the increasing internationalization of scientific workforce and the increasing proportion of foreign-born scientists in the US workforce. More than 80 million highly-skilled professionals live outside their countries today (United Nations, 2013), and among them, scientists are the most internationally mobile group. Scientists establish contacts and colleagues in many countries, collaborate internationally on research projects, and move to places with funding, facilities, and opportunities (Auriol, 2010; Jones, Wuchty, & Uzzi, 2008; van Noorden, 2012).

As a result of such migration, the scientific workforce in developed countries is largely composed of foreigners. About 27% of the academic workforce with US doctorates in science, engineering, and medicine are foreign-born. The percentage is even larger in engineering with 49% and computer sciences with 50% of foreigners (National Science Foundation, 2016b). As these data do not account for immigrants with non-U.S. degrees, the total proportion of foreigners in academia could be even higher. Similar tendencies have occurred in other developed countries. For example, foreigners account for 57% of natural scientists in Switzerland, 47% in Canada, and 45% in Australia (Franzoni, Scellato, & Stephan, 2012).

The proportion and total number of foreigners in American academia has been steadily rising over last forty years from 13,600 in 1973 to 83,000 in 2013 (National Science Foundation, 2016b), and they are expected to follow similar trends in the future. The major causes of future growth will be high stay rates of foreign doctoral students and post-doctoral fellows in the US. According to NSF data on foreign-born doctorate holders in 2014, foreign-born scientists comprised 48% of post-doctoral positions (75% in engineering and mathematics) (National Science Foundation, 2016b), and more than 70% remained in the US (Grogger & Hanson, 2015; National Science Foundation, 2016a).

The large number of foreign faculty unveils new issues for academic and science policies. Foreign-born scientists provide a necessary workforce and fill empty positions in science and engineering (Levin, Black, Winkler, & Stephan, 2004), particularly in academia, in which foreign-born scholars fill research and teaching positions and foreign students help fill college and university classrooms (Matthews, 2010). As mentioned above, they contribute to the productivity and the quality of American academia (Corley & Sabharwal, 2007; Stephan & Levin, 2001b), build bridges between the scientific communities of the US and other countries, attract resources and knowledge from other countries, and enhance diversity of US science by focusing on issues that would otherwise be under-researched (A. C. Lin, 2004; Matthews, 2010; Wulf, 2005). The influx of foreign scientists, nevertheless, raises concerns about their impact on the declining job opportunities, wages, and working conditions of native scientists (Borjas, 2006; Bound, Braga, Golden, & Khanna, 2015; Freeman, 2005), often crowding out the local workforce comprised of American academic scientists and even US students in STEM fields or at the graduate level (Borjas, 2007; Borjas & Doran, 2012; Orrenius & Zavodny, 2015).

For countries with less developed science systems emigration of scientists cause concerns of loosing their human capital or "brain drain" (Saxenian, 2005). However, recent research emphasizes that scientific diaspora can aid to development of research systems at sending countries by fostering research collaboration between institutions of host and sending countries and providing access to host country resources (Agrawal et al., 2011; Davenport, 2004; Jałowiecki & Gorzelak, 2004; Meyer, 2001). As a result science policies of both host and home countries pay attention to tools that could mobilize scientific diasporas, strengthening networks among diaspora members and with home countries, and utilize diasporas to strengthen research activities (Canadian Science Policy Conference, 2015; International Organization for Migration, 2013; US Department of State, 2016).

Taking into account the high and growing presence of foreigners in the US science system, their impact on productivity and quality of the US science system, and role they play in international research collaboration, it is essential to fill current gaps in knowledge about foreign-born scientists. Understanding better the specific qualities of foreign-born scientists, especially their professional social life, would help improving policies aided at productivity and quality of individual researchers and science systems in whole.

1.5. Organization of the dissertation

This dissertation is organized into four chapters. The first, "Chapter 2. Literature Review and Hypotheses," provides insights into the theoretical foundations of this research. It reviews the social capital concept, the network theory of social capital, and general findings about social capital of immigrants and foreign-born scientists. Based on the theoretical foundations and the STHC model, this work proposes three hypotheses related to the differences between the social capital of foreign- and US-born faculty and two hypotheses pertaining to the potential influence of particular characteristics of social capital on the research productivity of foreign-born scientists.

Chapter 3, “Methodological Approach and Data,” provides a detailed review of the source of data, the construction of variables, and the specific models for the testing of hypotheses. The chapter also provides rationale for selecting particular regression models and methods for testing them. Then Chapter 4, “Results,” present the findings from analysis and hypothesis tests. Finally, Chapter 5, “Conclusions and Implications,” provides a theoretical discussion about the findings and their contributions to the body of knowledge about the social capital and research productivity of foreign-born scientists. The chapter lists several implications for academic and scientific policies.

2. LITERATURE REVIEW AND HYPOTHESES

Understanding factors that influence research productivity, the defining activity of scientists, is central to a discussion about the academic profession (Levin & Stephan, 1991; Ramsden, 1994; Webber, 2012). As the proportion of foreign-born faculty in US academia increases, an understanding of the unique factors impacting their research productivity has become a particularly important goal. Nevertheless, despite the increasing number of foreigners in academia, foreign-born faculty remain under-researched (Mamiseishvili & Rosser, 2009; Mervis, 2004). Thus, this dissertation seeks to fill the current gap in knowledge about foreign-born faculty by devoting effort to identifying the unique characteristics of their professional social capital that distinguish them from US-born faculty and the impact of these characteristics on their research productivity.

This chapter reviews the theoretical foundations for understanding the impact of birthplace on the social capital of scientists and the respective implications on their productivity. It begins with a detailed discussion of what social capital is and how it is formalized in social research, particularly with regard to the *network theory of social capital*. To place social capital issues within the context of science, this study presents the central framework for this dissertation, the *scientific and technical human capital model*, and follows with a discussion about significant aspects of scientists' social capital, their impact on research productivity, and common causes of variations among scientists' social capital. After presenting the fundamentals of social capital, the chapter introduces the unique social capital characteristics of immigrants, the focal population of this dissertation.

The remainder of the chapter focuses on the theoretical model and the related hypotheses of this research. Building on the general overview of social capital, the STHC model, the role of social capital in research productivity, and findings from the immigration literature, it presents the theoretical model and follows with a detailed discussion and hypotheses. The discussion pertains to the scientific and technical human capital model and extends it by addressing the impact of the origin of birth on the social capital attributes of interest and its implications in research productivity. Moreover, the discussion aims to explain if the focal paradox of the higher research productivity of foreign-born scientists is related to the uniqueness of their social capital. Using prior findings about social capital of immigrants and of scientists, it presents three hypotheses regarding the potential differences between the professional social capital of foreign- and US-born academic scientists. Then, using the STHC model and studies related to social capital and scientific productivity, it present two hypotheses regarding the potential impact of such differences on research productivity.

2.1. Social capital and its formalization

The classical definition of social capital is "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition"

(Bourdieu, 1986). An individual's ability to perform labor is directly affected by the possession of social capital, together with other forms of capital: economic capital (wealth), cultural capital (a specific disposition of mind and its manifestations into cultural artifacts and social institutions), and closely related human capital (personality, skills, and knowledge (Bourdieu, 1986; Mincer, 1958). The amount of capital varies among individuals, and any form or amount of capital affects productivity and life achievements (Adler & Kwon, 2002; N. Lin, 2001).

The major benefit of possessing social capital is that through social relationships, individuals have potential access to resources or information that they do not possess themselves but that would be more costly to obtain otherwise (Adler & Kwon, 2002; Coleman, 1988; N. Lin, 2001; Portes, 1998). Access to valuable information is considered the most important benefit of social capital. Other benefits are control and influence through social connections (Adler & Kwon, 2002). The control of others is achieved in two ways, directly by influencing the decisions of other parties through social connections and by demonstrating one's acquaintances to influence others through signals about social credentials, reputation or status, and access to resources (Bourdieu, 1986; N. Lin, 2001). Social relationships strengthen mutual trust between individuals and increase solidarity and reciprocity as a means of fostering further social exchange (Adler & Kwon, 2002). Mutual social connections also are essential for building social groups and allowing individuals to access resources of the group.

Through connections, the group reinforces norms, mutual control, and identity of belonging to the group, which enhances trust between individuals, and thus, intensifies the sharing of individual and group resources (Burt, 2005; Coleman, 1988; N. Lin, 2001; Putnam, 1995). In addition to their access to economically convertible resources and opportunities, individuals use social relationships to improve their cultural and human capital by exchanging knowledge, skills, and attitudes (Portes, 1998).

The network theory of social capital provides a formalization describing social capital as a network of social relationships among individuals and resources accessible through these connections, both of which determine the outcomes of activities through accessing and utilizing the resources (N. Lin, 1999a). The theory follows Bourdieu's definition of social capital, which distinguishes between two elements: social relationships themselves allowing individuals to claim access to resources of others and the quality of resources accessible or provided through relationships (Bourdieu, 1986; Portes, 1998). By advocating this approach, network theory allows the separate conceptualization of social capital elements through observations of the structure of the network, characteristics of relationships, the types and the amount of resources accessible, and an understanding of the relationship between these elements and individual outcomes. Besides providing a conceptual understanding of the social capital, the theory provides a methodological foundation for measuring particular characteristics of the network and resources and evaluating their impact on individual performance.

Prior studies using the network approach to social capital have indicated a number of network characteristics directly affecting individual outcomes. The main finding is that a larger social network size or number of persons with whom an individual has relationships suggests a positive impact on productivity. It informs about a wider range of accessible resources and the potential that the individual will have access to the resources he needs (Borgatti, Jones, & Everett, 1998; Burt, 2000; N. Lin, 2001).

Evidence suggests, however, that besides the network side we should assess the structure of a broader social network because individual performance is related to not only resources possessed by direct contacts but also those available in the broader network of indirect acquaintances (N. Lin, 1999a). Access to such resources is impacted by the network structure of relationships and the configuration of ties (Burt, 2001). The network theory of social capital implies that we should analyze the broader set of social relationships of a larger social group or organization and the position of an individual within it.

One of such measures, density of a network or possession of alternative linkages of individuals within the group (individuals can connect others through several third parties) will indicate that the group is more socially closed. Group closeness enables more successful individual outcomes in activity because of greater trust and intensity among those interacting. Members will have easier access to resources because dense networks enable greater control over individuals allowing for enhanced trust in relationships. Moreover, within such networks, both the intensity of social interactions and the number of exchanges are greater (Borgatti et al., 1998; Coleman, 1988). On the other hand, in socially closed groups, the variety of accessible resources is limited (Granovetter, 1973). Despite their easier access to resources, individuals have fewer opportunities to receive differential resources that would afford them advantages in productivity (Burt, 2001).

Two aspects of the position of an individual within a network are referred as *network centrality* and *bridging*, both of which are positively related to individual productivity outcomes. Individuals who are central in a network are able to access everyone through the lowest number of intermediates and typically have the largest number of connections (Everett & Borgatti, 2005). The central position allows the member easier access other members of the network and receive more resources from the group. Moreover, such member is likely to establish more future connections because the central position serves as a status attribute and provides potential peers with efficient access to the whole network (Borgatti et al., 1998; N. Lin, 1999b). Individuals also benefit from relationships outside of their groups, which provide access to a more diverse range of resources that are not available within the group (Cross & Cummings, 2004; Granovetter, 1973). Such individuals may serve as social “bridges” between two communities that otherwise would not have contact. They benefit from serving as "brokers" who control and ensure the flow of resources between the groups (Burt, 2005).

In addition to constituting the social network structure, the network theory of social capital considers how the properties of relationships themselves impact efficiency and usefulness of each social tie. Central to relational properties are mutually related concepts of *tie strength* and *multiplexity*. Tie strength indicates the level of attachment between individuals (Elfenbein & Zenger, 2014) and such ties are characterized by higher confidence and intimacy (Granovetter, 1973). In such relationships, the higher frequency of interaction, the higher level of reciprocity, and the higher intensity of exchange are observable, allowing individuals easier and broader access to resources. Moreover, such ties often exhibit multiplexity, or the use of a single tie for multiple means and to access more than one type of resource (Borgatti et al., 1998; Burt, 2000; Ibarra, 1993; Verbrugge, 1979). The length of a relationship is associated with higher strength because repeated successful social interactions lead to higher mutual trust, further strengthening attachments and reciprocity and increasing tie multiplexity and more intensive tie use (Elfenbein & Zenger, 2014; N. Lin, 2001). However, the negative side of strong ties is that they usually provide access to limited and homogeneous resources that provide individuals with little productivity advantage (Burt, 2001, 2005; Granovetter, 1973; N. Lin, 2001; McPherson, Smith-Lovin, & Cook, 2001).

Various social capital attributes inherent in the network theory of social capital create an opportunity for a more thorough understanding foreign-born scientists. While foreigners find establishing social connections a challenge, the theory informs the evaluation of a broader set of attributes and an understanding of their cumulative effect on productivity. Moreover, studies of scientists' performance also emphasize that various professional social capital attributes have a diverse impact on research productivity (Bozeman et al., 2001; Bozeman, Fay, & Slade, 2012) and question whether or not the unique characteristics of social capital of foreign-born scientists helps them use their smaller social networks more efficiently.

2.2. Social capital of scientists

The theory of social capital and social networks have been adapted to the scientific environment through the model of "*scientific and technical human capital*" (Bozeman et al., 2001). This section reviews the basics of the STHC model and provides a detailed discussion on how various characteristics of scientists' productive social capital impact their research performance. Further, this sections discusses the known causes of social capital variation among scientists, which provides a basis for discussion regarding the potential impact of foreign origin on social capital.

Overall, the STHC model emphasizes that scientific outputs depend on equipment, material resources, organizational arrangements, as well as scientific and technical human capital embodied in participating individuals (Bozeman et al., 2001). For a particular individual, the STHC is the sum of human capital endowments specific to research activities: cognitive skills, formal training, tacit knowledge, contextual skills, that is, craft and know-how. These activities are complemented by productive social capital network because resources external to an individual are relevant to knowledge production and the further development of individual human capital. Regarding productive social capital, the STHC model emphasizes that research productivity and STHC development depend on structural features of the network, roles of the individuals within the network, connections within and outside institutional boundaries, and the resources of each network partner.

Prior research emphasizes that the key benefit from social capital in knowledge intensive work is attributed to the timely access to valuable information that individuals do not possess themselves (Nahapiet & Ghoshal, 1998). Through social connections, scientists acquire and share, both formally and tacitly, the following knowledge: competencies, skills, methods, and techniques required for conducting research, and the necessary social and management skills (Bozeman & Corley, 2004; Katz & Martin, 1997; Melin, 2000). Through such connections, scientists access funding, data, or equipment they require to carry out their professional activities (Melin, 2000). They use existing ties to "borrow" the prestige and credibility of their colleagues (Bozeman & Corley, 2004) and further develop their professional networks (Katz & Martin, 1997; Melin, 2000). As a result, more highly developed professional social capital has a tangible and evident positive impact on the publication productivity of scientists (Bozeman et al., 2001; Lee & Bozeman, 2005).

In addition to providing access to knowledge and resources, social connections among scientists develop mutual involvement in research tasks, fostering enhanced efficiency and quality of their research (Melin, 2000). Collaboration allows scientists to specialize and divide labor, it is pleasurable, and mutual commitment forces scientists to invest more time and effort (Bozeman & Corley, 2004; Fox & Faver, 1984). In addition, it promotes the exchange, generation, and discussion of ideas, methods, and results, fostering new perspectives on research problems, improving the quality of research (Katz & Martin, 1997; Melin, 2000). The results of such collaboration are more likely to be accepted by leading journals and subsequently cited, according the authors professional advantage in the future (e.g., a higher status and a stronger reputation) (Bozeman & Corley, 2004; Gazni & Didegah, 2011; Katz & Martin, 1997; Melin, 2000).

Evidence aligns with STHC emphasis on the structural features of professional networks. More importantly, findings related to social capital theory about the positive impact of bridging distant communities are also evident in science. Establishing and maintaining ties between separate communities is generally difficult (Burt, 2005; Granovetter, 1973; N. Lin, 2001), and scientific collaboration decreases exponentially with distance between communities because of high communication and administrative costs (Katz & Martin, 1997).

Moreover, costs are particularly high if parties are in culturally and administratively unfamiliar science systems (Agrawal, Cockburn, & McHale, 2006). As a result, collaborations between geographically distant research institutions with dissimilar research profiles are rare (Ponds, van Oort, & Frenken, 2007).

Scientists able to establish foreign ties and collaborate internationally benefit from access the unfamiliar science systems and from serving as bridges between groups of scientists (Agrawal et al., 2006). In addition, as individuals with such ties receive information and resources inaccessible by the rest of their community, these relationships, formed outside of a typical environment, are related to higher productivity in knowledge-intensive work (Cross & Cummings, 2004; Granovetter, 1973). Scientists who have foreign collaborators and joint research with foreign institutions publish more articles, and such co-publications are cited more often (Didegah & Thelwall, 2013; Gazni & Didegah, 2011; Glänzel, 2001). Indeed, prior research has indicated that links with other scientific communities, particularly international collaboration, may boost the productivity and quality of research (Agrawal et al., 2006; Glänzel, 2001; Katz & Martin, 1997; Kretschmer, 2004; Melkers & Kiopa, 2010).

Finally, the properties of relationships, namely stronger ties, are associated with higher research productivity because of greater trust, better understanding between both parties, and easing the transfer of knowledge (Nahapiet & Ghoshal, 1998). Such ties are multiplex, providing a variety of resources and reducing costs associated to social communication, that is, investment in trust building, transmitting and understanding knowledge, and ensuring coordination and management, associated with establishing and maintaining professional ties (Cummings & Kiesler, 2007; Fox & Faver, 1984; Nahapiet & Ghoshal, 1998). As a result, stronger collaborative ties with a high level of trust, “personal chemistry,” “similarity in thinking” (Melin, 2000), and more frequent and intense interactions (Katz & Martin, 1997) are associated with higher research productivity. Moreover, strong ties are instrumental for transferring complex information (Hansen, 1998), allowing scientists to gain access to knowledge and their peers in other disciplines or geographically distant communities (Agrawal et al., 2006). However, while strong ties help scientists to access necessary resources, researchers with strong, close ties reach saturation of their productivity more rapidly (McFadyen & Cannella, 2004) because of the limited and homogeneous resource base of such relationships (Burt, 2005; Granovetter, 1973; McPherson et al., 2001).

In the context of science, multiple demographic and personality attributes as well as institutional and professional contexts are known to impact scientists’ social relationships (Bozeman et al., 2012). To begin with, gender significantly influences the size, composition, and relational properties of scientists’ professional networks. Male scientists build larger networks of ties that provide access to productive resources and have greater access to the “old-boy” network of influential and resource-rich individuals (Feeney & Bozeman, 2008; van

Emmerik, 2006). Female scientists, more often than their male counterparts, collaborate with other women and have larger, denser support networks (Bozeman & Corley, 2004; Bozeman & Gaughan, 2011; Burt, 1998). Such social capital differences are further attributed to the higher research productivity of male scientists and the greater involvement in teaching and service activities of female scientists (Bozeman & Corley, 2004; Feeney & Bozeman, 2008).

The network structure and relational properties are associated with the age of scientists and the length of their professional careers (Levin & Stephan, 1991; Stephan & Levin, 1992). Younger scientists have smaller networks, but the number of their professional connections grows with experience as scientists have more opportunities to meet others (Kiopa, 2013). Furthermore, older scientists build social networks more easily because of their higher professional status (N. Lin, 2001), which is related to career length (Lee & Bozeman, 2005; Stephan & Levin, 2001a). However, as older scientists age, they choose to maintain fewer ties, which each provides them with a larger amount of necessary resources, so the size of their professional networks decreases and the strength of their ties increases (Fox & Faver, 1984; Levin & Stephan, 1991).

Multiple professional and institutional contexts impact the professional network structure (Shin & Cummings, 2010). Scientists develop their social capital according to their career choices, and those with higher research activity will have larger networks of research collaborators (Fox & Mohapatra, 2007). In addition, as graduate school and post-doctoral training are significant periods in which scientists build professional relationships, the academic institutions from which they graduated have an impact on the sizes of their networks and the locations of their ties (Melin, 2000). Finally, the nature of collaborative practices across scientific disciplines and types of academic institutions (Bozeman et al., 2012) impact the professional network size and geographic distribution (Katz & Martin, 1997; Lee & Bozeman, 2005; Shin & Cummings, 2010).

Based on the findings of immigration studies, this study suggests that social capital variations also depend on scientists' place of origin (foreign or domestic), which may consequently influence scientific productivity. The immigration literature indicates that the social capital of immigrants displays unique characteristics (Portes, 1995) that may also be evident in foreign-born scientists. Moreover, the unique characteristics allow immigrants to use smaller social networks more efficiently (Nee & Sanders, 2001), and, if evident in science, such a tendency would provide an explanation for the paradox of foreign-born scientists' who despite their feeling of professional isolation, are more productive in research.

2.3. Social capital of immigrants

Immigration studies have primarily focused on examining the characteristics of lower-skilled immigrants because of their higher population and social and economic activities that differ markedly from those of the host society. At the same time, research on higher-skilled immigrants, including scientists, remains limited although they constitute more than 35% of all migrants (United

Nations, 2013). This chapter provides the context for researching foreign-born scientists by discussing the unique characteristics of the social capital of immigrants in general. It begins with a review of the literature pertaining to lower-skilled immigrants. Although studies differentiate between lower- and higher-skilled immigrants, including scientists (Ackers & Gill, 2008; Ryan et al., 2008), this study discusses the similarities and differences between the two.

As about 244 million people currently reside outside of their countries, research on immigrants has gained importance, and issues of their adaptation and integration and their cultural, social, and economic impact on host societies have become a relevant, far-reaching issue (United Nations, 2013). In such a context, the manner in which integration and economic activities might affect the social capital of immigrants has drawn more interest (Berry, 1997; Portes, 1995). Evidence shows that the social ties of immigrants often differ from those of the native community (Light et al., 1994; Nee & Sanders, 2001; Portes, 1995).

The migration event has had a major impact on immigrants' social capital for several reasons. For one, because their primary networks remain in their countries of origin, they typically have a limited number of social ties in the host country (Rogler, 1994). Further, upon arrival, the establishment of new ties is significantly hindered by the acculturation and adaptation processes of immigrants: the need to establish themselves socioeconomically, to learn and understand local accents of a foreign language, to adapt to the cultural and societal norms, and to cope with related stressors (Berry, 1997). Moreover, they face difficulties establishing ties with the host society because of discrimination, outsider status, limited language skills, and cultural dissimilarities (Gold & Light, 2010).

Because of the above challenges, the social capital of migrants, especially lower-skilled migrants, often exhibits distinct characteristics. The social networks of lower-skilled migrants are significantly smaller than those of the local population (Nee & Sanders, 2001). They usually do not develop connections within the broader host society, and the majority of their social relationships are predominantly ethnic and geographically restricted to closely bound communities forming social and economic enclaves (Light et al., 1994; Light, Sabagh, Bozorgmehr, & Der-Martirosian, 1995). Lower-skilled immigrants also depend on relationships based on ethnicity and the common migration experience (Light et al., 1994; Sanders, Nee, & Sernau, 2002). Their social relationships, characterized by high interdependence, trust, and multiplexity, still satisfy a majority of their professional, household, and social needs (Light et al., 1994, 1995; Verbrugge, 1979), and they use the same ties for economic, social, and emotional support (Sanders et al., 2002). While such strong ties substitute for the lack of social ties with the host society and provide necessary resources, they also limit the economic activities and outputs of immigrants (Light et al., 1994, 1995).

Another distinct characteristic of immigrant social networks is that they generally cover a geographically wider area and include a larger number of transnational links than the networks of the local population (Portes, 1995). Because immigrants lack domestic ties, they develop international ties (Nee & Sanders, 2001), which, for lower-skilled immigrants, typically consist of ties with the home country (Ryan et al., 2008). Such relationships are instrumental, providing not only emotional and social support but also economic benefits such as financial and physical support or assistance. Moreover, links with home countries indicate the simultaneous, dual social participation of immigrants in both communities of the home and host countries (Portes, Guarnizo, & Haller, 2002).

For higher-skilled immigrants such as scientists, whose human capital is highly exportable, which allows the establishment of relationships both locally and internationally, social capital exhibits less pronounced distinctions (Ackers & Gill, 2008; Bauder, 2015). Moreover, highly-skilled immigrants are less often in need of ethnic networks for financial or household assistance (Nee & Sanders, 2001); further, ethnic networks often fail to provide highly specific information or resources that support their professional activities (Ackers & Gill, 2008). Their international ties with their home countries are predominantly personal, so they provide emotional support and fulfill social needs (Ryan et al., 2008).

Despite advantages over their lower-skilled counterparts, higher-skilled workers, according to research, still face difficulties establishing professional and social relationships, so they continue to rely on ethnic ties. For example, Polish professionals in London reported forming few connections with their British colleagues (Ryan et al., 2008), and highly-skilled Brits report difficulties establishing social connections with the local population in Paris and Singapore, so they form their own ethnic social circles, especially those outside of their professional settings (Beaverstock, 2002; Scott, 2006). Similarly, Chinese and Indian engineers and entrepreneurs in Silicon Valley felt marginalized from mainstream American social networks, so they formed relationships within their own ethnic group (Saxenian, 2005). They were also more likely to establish international relationships with professionals of their own nationality both at home and in other countries. Immigrant entrepreneurs maintain links with home countries, where they find suppliers, clients, and business partners (Portes et al., 2002). Establishing ties with multiple communities, immigrant professionals serve as bridges between these communities, facilitate knowledge transfer, and improve learning and innovativeness of their employers (Williams, 2006).

Evidence about differences between the social capital of foreign- and native-born populations among lower-skilled immigrants (Portes, 1995; Rogler, 1994) and suggestions that higher-skilled immigrants could also possess specific social capital is a core issue of this dissertation. They suggest adapting the STHC model to the context of foreign-born scientists by adding foreign origin as a factor with a potential impact on both social capital and research productivity. The following chapters apply such an approach to construct the general theoretical model and hypotheses of this dissertation.

2.4. The general theoretical model

The paradox of higher research productivity among foreign-born faculty in the US, given their perceived difficulties establishing social relationships, is the core focus of this dissertation. The immigration literature provides an initial insight into the issue that suggests that the social capital of foreigners differs from that of the host society with regard to multiple attributes and allows them to use social ties more efficiently (Nee & Sanders, 2001; Portes, 1995; Ryan et al., 2008). Thus, the assumption of this work is that the productive social capital of foreign- and US-born scientists differs, and such differences have implications for their research productivity (Agrawal et al., 2006; Cross & Cummings, 2004; Lee & Bozeman, 2005; Nahapiet & Ghoshal, 1998). With such an approach, the STHC model is adapted to the context of foreign-born scientists and extended to the potential impact of foreign origin of an individual on their research performance (Figure 2.1).

Drawing from findings in the immigration literature about the social capital of migrants (Berry, 1997; Nee & Sanders, 2001; Rogler, 1994; Ryan et al., 2008; Williams, 2006) and from interviews of immigrant scientists in the US and other developed countries (Ackers & Gill, 2008; Meyer et al., 2003; Tejada & Bolay, 2010), it is expected that foreign origin will have evident impact on scientists' professional social capital. On the other hand, as prior research suggests that higher-skilled immigrants such as scientists experience less trouble establishing relationships because of their highly exportable human capital (Ackers & Gill, 2008; Nee & Sanders, 2001), the potential impact of foreign origin on the professional social capital of scientists may be not significant.

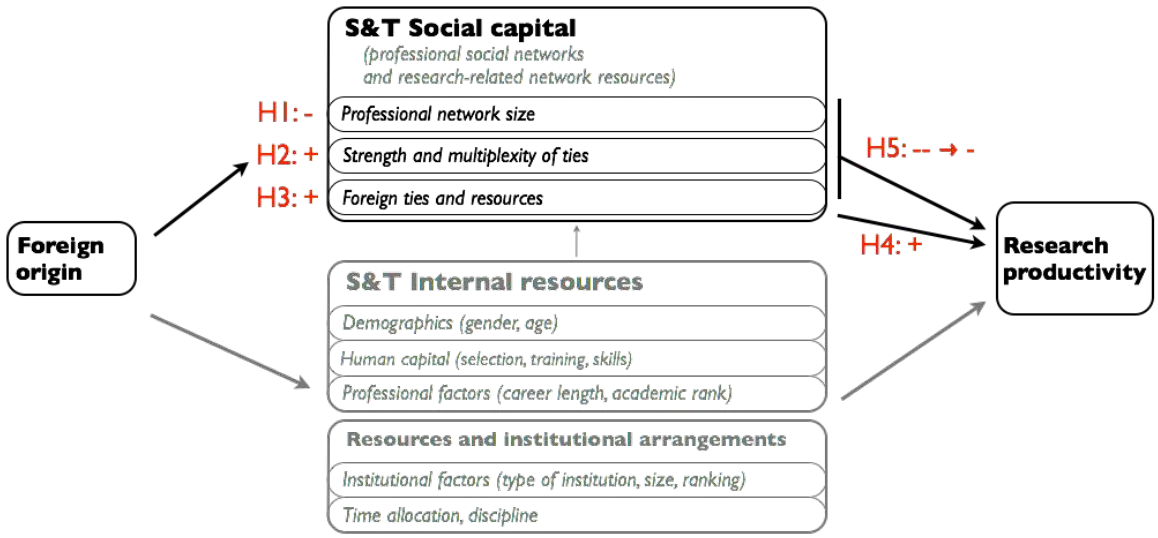


Figure 2.1 The general theoretical model for the impact of foreign origin on social capital and research productivity

Based on findings of the immigration literature, the expectation is that foreign origin will have a negative impact on the sizes of professional networks (Hypothesis 1), a typical characteristic of immigrants' social capital (Light et al., 1994). At the same time, foreign origin will have a positive impact on two other social capital attributes known to improve research performance. First, strength and multiplexity of professional ties in professional social networks of foreign-born scientists will be higher than they are in those of US-born population (Hypotheses 2A/B), a propensity common among immigrants that helps them to use social ties more efficiently (Nee & Sanders, 2001). Second, as immigrants usually have geographically broader social relationships (Portes, 1995), foreign origin is expected to have a positive impact on foreign social capital (Hypothesis 3).

The STHC model and the prior literature about the effect of social capital on research productivity explain how the unique professional social capital characteristics of foreign-born scientists impact productivity. It is expected that the larger amount of foreign social capital will have a positive impact on the research performance of foreign-born scientists (Hypothesis 4), an impact that is common among scientists (Agrawal et al., 2006; Cummings & Kiesler, 2007). Moreover, more efficient use of relationships through higher tie strength an multiplexity, and more extensive international social capital will mitigate the negative impact of a smaller size of professional networks (Hypothesis 5). Such compensation is observable among lower-skilled immigrants (Nee & Sanders, 2001).

Finally, the STHC model is amended with impact of foreign origin on other STHC attributes, resources, and arrangements known from the literature to provide research productivity advantages for foreign-born scientists and to cause variances in scientists' social capital. They include individual STHC attributes, namely, being male and younger or in lower academic ranks (Corley & Sabharwal, 2007; Mamiseishvili & Rosser, 2009). From the perspective of resources and institutional arrangements, attention is drawn to the relationship between the origin of foreign-born scientists and their allocation of more time on research activities, working in disciplines with higher publication rates, or working at large research institutions (Kim et al., 2011; Sabharwal, 2011; Webber, 2012). Finally, the immeasurable advantage of foreigners stronger human capital is added to the model augmented by their supposed stronger skills and training (Kim et al., 2011; Matthews, 2010), harder work, greater diligence, and employment below their skills level (Ackers & Gill, 2008; Skachkova, 2007).

2.5. Professional social capital of foreign-born scientists

A limited number of studies have suggested that the social capital of foreign-born scientists may differ from that of their US-born counterparts. From qualitative studies, interviews with foreign-born scientists in America reveal their difficulties establishing professional relationships. As they feel isolated from social communications in their departments, they report a lack of collegiality with Americans (Skachkova, 2007; Thomas & Johnson, 2004). They also report being excluded from networks of research collaborations and connections with professionally influential individuals and the inner circle of researchers in their departments, and the need to work hard to gain recognition (Seagren & Wang, 1994; Skachkova, 2007). They report not only difficulties establishing social relationships but also a resulting shortage of social capital resources, that is, a lack of support and advice on research and publication concerns as well as other professional or personal issues (Bang, 2016; Collins, 2008; Foote et al., 2008).

The challenge for foreign-born scientists' to establish professional and social relationships is a broader phenomenon that is not unique to American academia. For example, immigrant scientists in Switzerland report that local scientists belong to a closed community (Tejada, 2010) and that they find forming friendships and other social relationships difficult not only within their academic institutions but also outside their professional settings (Dia, 2010; Kwankam, 2010). Eastern European scientists in Germany also perceive discrimination and exclusion from their local academic communities (Ackers & Gill, 2008).

As lower-skilled immigrants face hardship establishing social ties, their social capital exhibits characteristics that differ from those of the host society (Light et al., 1994; Rogler, 1994). Since scientists face similar problems, their social capital is also expected to differ from that of their US-born counterparts.

2.5.1. Size of foreign-born scientists' professional networks

The difficulties migrants face when they establish social relationships in the host society arise because of the consequences of major socio-cognitive mechanisms that help individuals establish and maintain relationships: *homophily, geographic proximity*, and *repeated interactions* (Rivera, Soderstrom, & Uzzi, 2010). The first, homophily, is the tendency for individuals to associate and form ties with those who are similar to them. In other words, they are more likely to connect with others of the same kinship, race, and ethnicity, similar social and economic status or class, age, sex, religion, education, occupation, behavior patterns, abilities, aspirations, values, attitudes, and beliefs. Building ties with similar individuals is easier because they induce sentiment (N. Lin, 2001), and such interactions have a higher payoff and likelihood of reciprocity (Fu, Nowak, Christakis, & Fowler, 2012; Schaefer, 2012). Also among scientists is an servable "flocking together" with peers in the same fields and of similar standing, social, and professional status, and of the same gender (Bozeman & Corley, 2004; Katz & Martin, 1997).

The mechanism of homophily is expected to negatively impact the professional social capita of foreign-born scientists. One reason is that they do not share the most common homophily attributes with their US-born colleagues. Foreign-born scientists often do not share the same ethnicity or race, nor common childhood and schooling experiences as Americans. They often have pronounced accents and behavioral patterns, beliefs, world views, opinions, and values that tend to differ from those of US-born scientists (Foote et al., 2008). Foreign-born scientists mention these differences as causes of discrimination, a "double standard," rejection (Collins, 2008; Foote et al., 2008), and "slightly xenophobic" attitudes (Kwankam, 2010). Moreover, American scientists also report strong preferences for collaborating with individuals who speak fluent English and have U.S. citizenship (Lee, 2004). The lack of homophilic attributes curtail the opportunities for foreign-born scientists to establish professional ties with US-born scientists.

Further disadvantages for foreign-born scientists result from the impact of the second socio-cognitive mechanism, *geographic proximity*. According to this mechanism, people tend to develop ties with others in close proximity: at schools, in work environments, or in voluntary social organizations (Coleman, 1988; N. Lin, 2001). Upon migrating, foreign-born scientists leave their primary social networks and begin to build an entirely new social circle (Tejada, 2010). The mechanism of geographic proximity demands that primary and new social ties not overlap, as both predominantly develop in their respective places of residence, so networks of foreign-born scientists in a host society will be smaller as it is only a part of their whole professional network. The mechanism of geographic proximity is evident in the relationships of many scientists. Ties are established while attending the same graduate school or working in the same laboratory or during the same the postdoctoral period (Melin, 2000). In later professional careers, a large number of research collaborations begin informally from casual conversations with those in close geographical proximity (Bozeman & Corley, 2004). As a result, immediately after arriving in the US, when the number of social connections of foreign-born scientists significantly declines, they have to start building professional networks anew with the help of the geographic proximity mechanism. The result is that the sizes of their social networks will be smaller.

Reduced sizes of social capital occurring after the migration event continue throughout scientists' careers because of the third socio-cognitive mechanism, *repeated interactions*. From social capital theory, social interactions themselves lead to an expanded number of interactions, which include stronger ties, higher multiplexity and use of relationships and providing easier and broader access to resources (N. Lin, 2001). Moreover, established relationships foster the formation of new relationships because they serve as homophilic attributes such as having a common acquaintance or sharing a similar social network position within the group (Coleman, 1988; McPherson et al., 2001; Rivera et al., 2010). In the context of science, common projects lead to more collaboration on future projects (Katz & Martin, 1997). Scientists often chose collaborators among long-time friends and colleagues knowing each other for five or six years before conducting a study together (Melin, 2000). Because foreign-born faculty are expected to have significantly fewer professional relationships when they arrive in the US (Tejada, 2010), their professional social networks will grow more slowly through the mechanism of repeated interactions, and at any time, they will be smaller than the networks of American scientists with a similar age, career length, and experience.

Research indicates that foreign-born scientists may be at a disadvantage when building their professional social relationships since they lack homophilic attributes that could link them to American scientists, and the migration event reduces their social network and negatively impacts the development of professional ties in the long term. Therefore, they are expected to form fewer professional relationships than US-born scientists, and it will become evident by their smaller sizes of professional social networks (Borgatti et al., 1998). Thus, this study proposes the following hypothesis:

Hypothesis 1. Foreign-born scientists will have smaller professional networks than do US-born scientists.

2.5.2. Strength and multiplexity of foreign-born scientists' professional relationships

Migration research finds that difficulty establishing social relationships within the host society necessitates lower-skilled migrants to develop few but at the same time strong ties with a high level of trust and multiplexity and to use each tie for various types of interactions (Light et al., 1994; Nee & Sanders, 2001). Using such a strategy satisfies a majority of their professional, economic, household, and social needs. Prior research finds that highly-skilled immigrants also rely on few but intense relationships both for professional and social needs (Nee & Sanders, 2001; Ryan et al., 2008).

Could the social capital exhibit similar characteristics among foreign-born scientists? Prior research indicates that they may. Interviews of Russian emigrant scientists in Israel revealed that they had formed dense and multiplex ties of collaboration, advice, and support (Toren, 1994). Similarly, Eastern European and Indian immigrant scientists in Western Europe often reported closely intertwined family, friendship, and professional networks (Ackers & Gill, 2008; Dia, 2010).

Two strong binding forces contribute to the development of strong ties among foreign-born scientists. For lower-skilled immigrants, the tendency to build strong and multiplex ties is driven by their difficulty establishing social relationships (Light et al., 1994; Sanders et al., 2002) but facilitated by ethnicity and common migration experience (Ryan et al., 2008; Waldinger, 2005). Ethnicity is among the strongest homophilic factors motivating this trend (McPherson et al., 2001), and it is further amplified by trust and obligations arising from their common national identity, which fosters solidarity and enforceable trust in relationships (Portes, 1995) by requiring all of its members to help and give priority to fellow nationals when possible, without strict reciprocity and before any other social commitments (Miller, 1995).

In addition to ethnic homophily and national obligations, a strong binding force of the shared experience of migration and integration leads to strong ties among immigrants. Shared experience serves as an additional homophilic factor, and it creates an expectation that other immigrants have an understanding of one's needs (Saxenian, 2005). Both binding forces, ethnicity and nationality, and the shared migration experience are stronger in ties established between two immigrants. A common origin is a stronger binding force between two individuals in exile than it is in their home country (Ryan et al., 2008).

While higher-skilled immigrants have options other than common ethnicity and the migration experience to form their social relationships (Ackers & Gill, 2008), prior research suggests that they still prefer these approaches to build ties. For example, Indian and Chinese engineers in Silicon Valley tend to work with immigrants of their own or other nationalities because of the shared experience of migration, exclusion from mainstream American social networks, or commonality of language, education, culture, and history (Saxenian, 2005). Similarly, Eastern European scientists in Germany and Russian scientists in Israel reveal their reliance on ethnic ties to provide a wide range of assistance, beginning with immigration issues and then job placement, and ending with collaboration in laboratories where emigrants of the same nationality work (Ackers & Gill, 2008; Dia, 2010; Toren, 1994). Russian scientists in Israel most often maintained professional relationships with other immigrants from Russia or ex-Soviet countries (Toren, 1994). Moreover, foreign-born scientists often maintain close and valued professional links with their dissertation or post-doctoral supervisors, characterized by high reciprocity and intense publication and teaching collaboration (Ackers & Gill, 2008).

The tendency of foreign-born scientists to build strong ties using the binding forces of ethnicity and nationality and migration experience manifests in the relational properties of their social networks. The network theory of social capital suggests that strong ties are associated with higher trust, longer-term acquaintances and friendships, higher frequency of interaction, and multiplexity. Such relationships are used for multiple purposes and accessibility to more than one type of resource (Borgatti et al., 1998; Burt, 2000; Ibarra, 1993; N. Lin, 2001; Verbrugge, 1979). Thus, as it is assumed that higher multiplexity that contributes to the formation of social networks of foreign-born scientists will be observable in the larger amount of resources available per tie (Borgatti et al., 1998), this dissertation proposes the following hypotheses:

Hypothesis 2A. The professional social network ties of foreign-born scientists will be stronger than those of US-born scientists.

Hypothesis 2B. The professional networks of foreign-born scientists provide more research-related resources per tie than those of US-born scientists.

2.5.3. Geographic location of ties and resources in the professional networks of foreign-born scientists

The social capital of immigrants, in general, covers a geographically wider area and includes a larger number of transnational links than that of the local population (Portes, 1995). Such links, especially within communities in the home countries, allow them to compensate for the lack of relationships with the host community (Nee & Sanders, 2001; Ryan et al., 2008). Could foreign-born scientists be using international ties to satisfy professional relationships they lack in the host community? Studies have addressed this issue but found conflicting evidence.

Some studies found that for highly-skilled migrants, including scientists, ties with home countries are less important because they require financial or household assistance less often (Nee & Sanders, 2001). Another study found that professional activities of scientists require highly specific information and resources that their home country ties usually fail to provide (Ackers & Gill, 2008). As a result, the foreign ties of scientists migrants are predominantly personal rather than professional (Meyer, 2001) and foreign-born scientists in developed countries emphasize the importance of home-country ties for the fulfillment of emotional support and social needs (Ackers & Gill, 2008; Dia, 2010; Kwankam, 2010; Meyer, 2001).

On the other hand, several empirical studies on Chinese (Biao, 2005), Australian (Woolley & Turpin, 2008), and Portuguese (Fontes, 2007) emigrant scientists in various countries have shown that these scientists maintain and use professional relationships with their co-nationals in their home universities, countries, and fields. For Australian emigrant scientists, primary or secondary research networks are based in Australia, and their most important international research collaboration is conducted primarily with Australian colleagues (Woolley & Turpin, 2008). Eastern European (Ackers & Gill, 2008) and Indian (Dia, 2010) emigrant scientists reveal that they collaborate with colleagues in their home countries on joint research projects and publications and maintain close contact with their supervisors, their schools, their institutes, and researchers and junior scientists in similar fields in their home countries. In addition, research on Russian expatriate scientists in Israel shows that most of their professional relationships are not Israeli co-workers, but former Soviet Union or other Eastern European researchers in Israel and abroad (Toren, 1994).

Depending on their ages, two distinct incentives motivate scientists to collaborate with scientists in their home countries. Junior immigrant scientists usually lack established professional networks but seek to collaborate on projects and publications with their former academic institutions, classmates, and colleagues (Biao, 2005; Fontes, 2007). More senior immigrant scientists use home country ties mainly to leverage costs. They depend less on home-country ties because they have established international professional networks in the host countries and gained wider access to resources (Biao, 2005). However, they often remain connected to their home countries in order to recruit graduate students or to run laboratories there at reduced costs (Biao, 2005; Dia, 2010). Foreign-born scientists are able to utilize the human and scientific resources of both home and host societies because they understand both contexts and languages (Tejada, 2010).

Besides economic incentives, foreign-born scientists use the binding force of a common ethnic origin and nationality to establish and maintain international relationships. Their scientific collaborators often are compatriots that reside in not only the host and the home country but also other countries (Ackers & Gill, 2008). Scientists explain that they more readily turn to their compatriots for assistance because they are aware that the national obligation requires them to help and support one another (Foote et al., 2008), and they are more similar in terms of scientific specialty, methods, and research (Toren, 1994). Foreign-born scientists in Western Europe emphasize the role of ethnic relationships in serving a wide range of professional needs. Compatriots located in various countries help each other providing information about research and employment opportunities and helping establish contacts with the local and global scientific communities (Ackers & Gill, 2008; Dia, 2010). In addition to ethnic ties, foreign-born scientists seem to use the binding properties of the common migration experience and more readily collaborate with other immigrants in the host country or abroad (Lee, 2004; Skachkova, 2007).

The factors that motivate foreign-born scientists to retain, establish, and maintain foreign professional ties are not expected to have a similar impact on the development of foreign professional ties among US-born faculty. Compared to foreigners, US-born scientists have a less acute need to seek resources abroad because they are better integrated in the US scientific community and able to receive necessary resources locally, and they do not need to seek international ties for lack of domestic professional relationships. Moreover, as they prefer collaborators of their own nationality (Lee, 2004) and have access to a large number of American peers, they are expected to establish mostly domestic professional ties. Finally, unlike immigrants, they do not simultaneously associate with two communities and have opportunities to build such international associations that bridge two scientific systems. Thus, despite the increasing globalization of science, professional relationships for US-born scientists are expected to be less diverse geographically than those of foreign-born scientists (Waltman, Tijssen, & van Eck, 2011).

Overall, the greater tendency of foreign-born scientists to use international ties for professional activities and the comparably smaller tendency for US-born scientists to do so lead to differences between the professional social capitals of these groups, observable in the professional social networks of both populations. Since a larger share of the peers of foreign-born scientists is assumed to be located abroad, a larger share of their research-related resources will come from foreign ties. However, the share of foreign ties and resources in the professional social capital of the US-born scientists is assumed to be comparatively lower. These assumptions lead to the following hypothesis:

Hypothesis 3. Foreign-born scientists have larger foreign professional networks and more foreign research-related resources than US-born scientists.

2.6. Impact of social capital differences on the research productivity of foreign-born scientists

The potential overall effects of the differential social capital on the productivity of foreign- and US-born scientists are two-fold. For one, smaller professional networks are expected to have a negative impact on all scientists' research performance and quality (Bozeman et al., 2001). However, a higher foreign-orientation of professional social capital will have a positive impact on productivity of foreign-born scientists. Prior research indicates that international collaboration is related to higher research productivity (Agrawal et al., 2006; Glänzel, 2001; Katz & Martin, 1997; Kretschmer, 2004; Melkers & Kiopa, 2010); that is, scientists who have foreign collaborators publish more articles. Moreover, working with foreign peers and institutions also increases the quality and the impact of co-authored research publications, which are also cited more often (Didegah & Thelwall, 2013; Gazni & Didegah, 2011; Glänzel, 2001).

The positive impact of foreign ties on outcomes of research activity, according to the STHC model, is related to the crossing of organization boundaries (Bozeman et al., 2001). As social capital theory notes, establishing and maintaining ties between separate communities is difficult (Burt, 2005; Granovetter, 1973; N. Lin, 2001). The same is observable in knowledge-intensive work and science, in which collaboration decreases exponentially with distance (Haas & Cummings, 2015), particularly because of growing communication and administrative costs (Katz & Martin, 1997). Such costs are particularly high if parties are in unfamiliar, culturally, and administratively different science systems (Agrawal et al., 2006). Thus, collaborations between geographically distant research institutions with dissimilar research profiles are particularly rare (Ponds et al., 2007).

Because of the obstacles that cross-boundary collaborations, individuals who are able to access distant communities receive higher payoffs because through such ties, they receive information and resources inaccessible by others in their research communities (Granovetter, 1973). In knowledge intensive work, ties outside of the usual environment are related to higher productivity in knowledge-intensive work (Cross & Cummings, 2004), and scientists who are able to establish foreign ties and collaborate internationally benefit from access to different science systems (Agrawal et al., 2006). Because international connections provide resources with higher payoffs and have a positive impact on research productivity, foreign scientists with more internationalized professional social capital are assumed to be more productive in their research than those with predominately domestic connections, leading to the following hypothesis:

Hypothesis 4. A higher proportion of foreign ties and foreign research-related resources positively impacts the research productivity of foreign-born scientists.

Similar to lower-skilled immigrants, foreign-born scientists have unique social capital characteristics that help them access necessary resources (Nee & Sanders, 2001). Despite their smaller social networks, their stronger professional ties, each of which provides proportionately more resources than those of US-born scientists, tends to reduce the differences in the number of received resources of both. As network theory of social capital states, scientists use their networks to access resources, which, in turn, impact the outcomes of actions (N. Lin, 2001). Thus, even though the size of the networks of foreign-born scientists is smaller than that of U.S. born scientists, both populations will differ less in their amount of network resources, and the negative impact of smaller professional networks is expected to diminish.

Besides reducing the gap between the amounts of research-related network resources of foreign- and US-born scientists, strong, multiplex ties offer additional intangible benefits to foreigners. Maintaining a smaller number of but more intensive social relationships provides foreign-born scientists necessary resources with smaller communication costs (Fox & Faver, 1984). Moreover, strong ties with a high level of trust, “personal chemistry,” similarity in thinking” (Melin, 2000), and more frequent and intensive interaction (Katz & Martin, 1997) are associated with higher research productivity. Ensuring less conflict and a stronger likelihood of sharing (Borgatti et al., 1998; Burt, 2005), such ties foster greater mutual understanding and facilitate knowledge transfer (Nahapiet & Ghoshal, 1998). Strong ties are also instrumental in helping foreign-born scientists gain easier access to knowledge and scientists in other disciplines or geographically distant communities (Agrawal et al., 2006; Haas & Cummings, 2015). However, researchers with strong, close ties faster reach saturation of their productivity (McFadyen & Cannella, 2004). Because of this dual, conflicting impact, higher resource multiplexity and strength of ties in professional networks might also have a similar dual effect on the productivity of foreign-born scientists.

If foreign ties and resources have a positive impact on the research productivity of foreign-born scientists, the higher prevalence of such ties and resources in networks of foreigners may mitigate the negative effects of smaller professional networks. When combined, both a larger proportion of foreign ties and resources in professional networks and higher tie strength and multiplexity, both of which are distinctive social capital characteristics of foreign-born scientists, are expected to alleviate the comparative shortage of professional ties. Thus, this dissertations proposes the following hypothesis:

Hypothesis 5. A larger number of research-related resources received per professional network tie and a larger proportion of foreign

ties and foreign research-related resources in networks will mitigate the negative impact of smaller professional networks on research productivity of foreign-born scientists.

3. METHODOLOGICAL APPROACH AND DATA

Data for the study are drawn from the NSF-funded *Netwise II* survey, which combines comprehensive data on the social networks of scientists and multiple aspects of their professional experience. These data include 760 foreign-born and 963 US-born scientists in Carnegie-classified research-extensive and research-intensive universities working in four STEM fields (biology, biochemistry, civil engineering, and mathematics).

Survey data are used to construct variables used for testing hypotheses about the social capital differences of foreign-born scientists and their impact on research productivity. Among others, measures of specific social capital attributes, productivity, and other factors with a known impact on the social capital structure or research productivity of scientists are selected. The variables are used to create regression models for testing the hypotheses. Three social capital models are constructed for testing hypotheses about the social capital differences of foreign-born scientists and two publication productivity models for testing the impact of social capital differences on research output.

The chapter begins by describing data sources, implementation of the *Netwise II* survey, summary about foreign-born respondents, and details about data on scientists' social capital. The next section is devoted to a description of variables. Finally, the chapter concludes with a discussion of statistical models and issues related to regression analysis.

3.1. Data source

To address the social capital and research productivity of scientists and to test the hypotheses presented in the previous chapter, this dissertation analyzes data from the NSF-funded *Netwise II* project, an extensive, national study of social networks of academic scientists in the US (Netwise, 2012a). The construction of the survey is based on the *network theory of social capital* and the *STHC model*. The same theoretical framework is used in the dissertation and ensures the adequate construction of models, variables, and deductions. Since a large number of survey respondents are foreign-born scientists, this study is able to statistically compare them with US-born scientists.

The survey includes comprehensive data on the professional social networks of scientists, including their network structure, relational properties, and network resources. In addition to providing network data, the survey includes extensive coverage of scientists' professional life: their education and career paths, job experience, current activities in research, teaching, and service, workload and job satisfaction, and multiple measures of academic productivity. Such a design enables a quantitative analysis of potential relationships between measurements of the structure and resources of scientists' closest professional networks and their career advancement, and professional output indicators (Netwise, 2012b). Finally, a broad section on background includes demographics, the country of origin and citizenship status, among others (Netwise, 2012a). Details on the specific variables, together with basic descriptive statistics, are presented later in this chapter.

3.1.1. *Netwise II* survey population and sampling frame

The *Netwise II* survey responses, which provide comprehensive coverage of STEM faculty in various types of institutions, cover scientists in four STEM disciplines: biology, biochemistry, mathematics and civil engineering. Because the purpose of the study is to explore “how and why professional network structures and resources matter for the career outcomes of women and under-represented minorities in the academic environment” (Netwise, 2012a), the disciplines were chosen such that they included fields with various levels of representation of women: high representation in biology and biochemistry, medium representation in mathematics, and low representation in civil engineering.

The respondent group included faculty in 410 institutions of various types that offer biology, biochemistry, mathematics, and civil engineering degrees. To cover all types of institutions, the 2010 list of the Carnegie Classification, a framework for classifying colleges and universities in the US (Carnegie Foundation, 2010), was used to build the respondent group. It included faculty in all national doctorate-granting institutions (granting at least 20 doctorate degrees a year) that offer degrees in the target disciplines, from those 149 research-extensive (with very high research activity) and 110 research-intensive (with high research activity) institutions. Further, it includes faculty in 96 (or 15% of 611 total) master’s-granting institutions (those granting at least 50 master’s degrees a year). To cover other types of universities, the respondent group included faculty working in all institutions of the following types of institutions offering degrees in the target disciplines: “Oberlin 50” baccalaureate colleges, 49 Hispanic-serving institutions, 43 historically black colleges and universities, and 19 women’s colleges. The institutions partially overlap; for example, the “Oberlin 50” list includes six women’s colleges and research-intensive universities include six historically black colleges and universities (Netwise, 2012a).

The respondent group for the survey was comprised of faculty working in the four target disciplines in the selected 410 academic institutions. The list of all scientific faculty was collected from webpages of the sampled institutions. It included scientists mentioned on the faculty lists of departments of the four target disciplines (biology, biochemistry, mathematics, and civil engineering). Because the focus of the *Netwise II* project was the faculty of underrepresented racial and ethnic minorities, women, and faculty in institutions with lower research intensity, oversampling and *snowballing* (Biernacki & Waldorf, 1981) methods were used for increasing the number of responses from individuals who matched the project goals (Netwise, 2012a).

Oversampling was based on stratification by gender, possibly non-white minority (based on information on faculty web pages[2]), scientific discipline, and type of institution. Of the 112 strata by gender, minority, field, and institutional type, those with less than 200 scientists were all included, while the remaining 28 strata were capped at 200 scientists. The resulting size of the survey sample was 9,925. Sample proportions of the population in each strata are provided in

[2] Self-reported ethnicity, racial, and gender data were used for the analysis.

Appendix A (Netwise, 2012a). Further, the under-represented respondent group of the survey was expanded using the *snowball* technique (Biernacki & Waldorf, 1981): expanding the respondent list using the survey responses. From the survey answers about scientists' professional networks, the names of 574 representatives of underrepresented minorities and women were extracted and added to the survey sample.

From the respondent group of 26,435 scientists, 10,499 scientists from 527 institutions were invited to complete the online survey. Of this group, 5,551 did not return surveys, 634 could not be reached or refused to answer, resulting in 4,313 final responses. Of these, 118 were removed because of ineligible rank or discipline. The final total sample size was 4,196 representing 487 institutions, of which 3,561 were complete and 639 were incomplete, for a 40.4% of usable response rate. The distribution of non-responses was fairly even across the population (matched against gender, discipline, and rank) with slightly more responses from women and fewer from mathematicians (Netwise, 2012a). Given the oversampling approach, the statistical analysis used weighted methods (Dey, 1997). Weights are based on the sampling proportions, the inverse of the probability of selection.

3.1.2. Survey data on foreign-born scientists in research-extensive and research-intensive universities

Owing to the focus of this dissertation on research productivity, only a portion of the final dataset was used for the analysis. In the US postsecondary population, data on academic scientists working in Carnegie-classified research-extensive and research-intensive institutions are used to answer questions about the implications of scientists' social capital and research productivity. Faculty working in other institutions were excluded from the analysis because those at non-research institutions represent a significantly different population from those at research universities (Austin, 1990). While the faculty at teaching institutions allocate more time to teaching and service activities, the faculty at research universities conduct more research (Bellas & Toutkoushian, 1999; Fulton & Trow, 1974; Michalak & Friedrich, 1981), and each type of institution has unique research and publishing practices (Ruscio, 1987). Moreover, as the goals of teaching institutions strongly emphasize student development, service, engagement with the local community over research, they differ markedly from that faculty of research universities (Hermanowicz, 2005; Morphew & Hartley, 2006), and the academic activities of faculty are impacted by the mission and evaluation and motivation systems of their institutions (Nelson, 1994; Tien & Blackburn, 1996).

The analysis included 1,723 *Netwise II* survey responses from academic faculty in Carnegie-classified research-intensive and research-extensive universities. They constitute a representative group of foreign- and US-born faculty in both types of institutions and all four research disciplines (Table 3.1). The sample included 1,723 respondents, 963 (56%) of whom were US-born and 760 (44%) foreign-born, covering 142 of 149 research-extensive and 94 of 110 research-intensive institutions The sample, consistent with the NSF data, reflected the dominance of Asians among foreign-born scientists (National Science Foundation, 2016a). The biggest group of the *Netwise II* foreign-born respondents came from East Asia (228 of whom 171 from China, Taiwan, and Hong Kong, 27 Koreans, and 17 Japanese) and South Asia (97 of whom 82 from India). The second largest group were Europeans (144), led by emigrants from the United Kingdom (26), Germany (22) and Russia (19). Neighboring countries followed with 31 Canadians and 11 Mexicans. Foreign-born respondents also covered both types of institutions (468 in research-extensive 292 in research-intensive universities) and all four surveyed STEM fields (190 in biology, 119 in biochemistry, 211 in civil engineering, and 222 in mathematics).

Table 3.1 Survey sample data of respondents in research-intensive and research-extensive institutions by origin, institution, and field.

	Foreign-born	US-born	Sum
By origin	760	963	1723
East Asia	228		
South Asia	97		
Europe	144		
Neighboring countries	42		
Other regions	249		
By institution type			
Research intensive (94 of 110)	292	423	715
Research extensive (142 of 149)	468	540	1008
By field			
Biology	190	361	551
Biochemistry	119	200	319
Civil engineering	211	222	433
Mathematics	222	166	388

Moreover, the consistency of data was verified by comparing the inferences of the surveyed population with external sources about foreign-born scientists in the US. Weighted statistics of survey responses indicate that the *Netwise II* population is consistent with the NSF data about academic scientists (Table 3.2).

Table 3.2 Proportion of foreign-born scientists in the *Netwise II* population in research-intensive and research-extensive universities by institution and field, weighted statistics.

	Sample N	% foreign-born, in population, weighted	(sd)
In whole *Netwise II* population	1723	51.3%	(0.50)
By institution type			
Research intensive	715	44.5%	(0.50)
Rsearch extensive	1008	53.4%	(0.50)
By field			
Biology	551	38.0%	(0.49)
Biochemistry	319	43.6%	(0.50)
Civil engineering	433	58.7%	(0.49)
Mathematics	388	65.2%	(0.48)
*By field (scientists with US PhD)**			
Biology	460	28.3%	(0.45)
Biochemistry	256	30.7%	(0.46)
Civil engineering	403	56.4%	(0.50)
Mathematics	331	60.7%	(0.49)

** Compared to the NSF data on US doctorate holders*

According to the NSF data on academic scientists with US doctoral degrees, foreigners in computer science and engineering constituted roughly half of the population, and about a quarter in life sciences (National Science Foundation, 2016b). The *Netwise II* survey data indicate a similar tendency of foreign-born scientists to be employed in “number heavy” fields. According to the weighted data, foreign-born scientists in the four STEM disciplines constitute approximately half of the academic population in research universities.

Foreigners constitute more than a half (53%) of the population in research-extensive universities, which is significantly higher than the proportion of foreigners (45%) at research-intensive institutions. Further, the prevalence of foreign-born scientists varies among disciplines. In civil engineering and mathematics, foreign-born scientists constitute around 60% of the population, and in biology and biochemistry, they constitute roughly 40%. Moreover, the *Netwise II* data are in line with prior research showing that foreigners are more often encountered in research-extensive institutions (Kim et al., 2011).

3.1.3. Demographic and professional differences between foreign- and US-born scientists

An initial descriptive analysis of data indicates that foreign-born scientists differ from US-born with regard to several demographic and professional attributes (Table 3.3). The differences are consistent with prior research and persist even though a majority of foreigners have had long-term experience and commitments in the US. About 77% of foreign faculty received doctoral training in the US, more than half (54%) of foreign-born respondents at research-extensive and research-intensive institutions hold US citizenship, and a majority have been citizens for over 20 years. Almost all remaining foreigners (40%) hold permanent visas. Despite living in the US for a long time, several characteristics of foreign-born faculty significantly differ from those of their US-born counterparts.

Results of the analysis show (Table 3.3) only 14.9% of foreign-born scientists are females, compared to 27.9% in the US. In addition, foreign-born scientists in the four STEM disciplines are significantly younger and earlier in their careers than their US-born colleagues. These findings agree with those of prior research, which emphasizes male dominance and younger ages of foreign-born scientists in the US (Corley & Sabharwal, 2007; National Science Foundation, 2016b). Moreover, a significantly larger proportion of foreign-born scientists, compared to US-born scientists, are assistant professors, and considerably fewer are full professors, confirming prior research that foreigners hold lower academic ranks (Z. Lin et al., 2008).

Table 3.3 Weighted comparison of the main demographic and professional attributes of foreign- and US-born faculty

	Foreign Born		**US Born**			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Demographics						
Female	14.9%	(0.36)	27.9%	(0.45)	<	(-7.75)
Age, years	48.46	(10.16)	52.17	(11.12)	<	(-8.13)
Professional context						
Career length, years	17.67	(10.27)	22.53	(11.81)	<	(-10.53)
US doctoral degree	77.1%	(0.42)	98.9%	(0.10)	<	(-17.21)
Post-doctoral experience	72.7%	(0.45)	68.7%	(0.46)	>	(2.14)
At research-extensive institutions	79.4%	(0.40)	73.0%	(0.44)	>	(-3.10)
Rank						
Assistant professor	30.4%	(0.46)	19.2%	(0.39)	>	(6.30)
Associate professor	28.6%	(0.45)	30.1%	(0.46)	=	(-0.81)
Full professor	41.1%	(0.49)	50.7%	(0.50)	<	(-4.68)
Activities						
Weekly workload, hours	53.94	(15.57)	54.84	(10.85)	=	(-1.62)
Research load, % of time	51.87	(19.21)	42.28	(22.82)	>	(9.28)
Research hours, weekly	28.59	(14.49)	23.64	(13.97)	>	(6.99)

Foreign- and US-born populations of scientists also differ regarding their research experience and activities. Foreigners more often work in postdoctoral training positions and research-extensive universities, findings consistent with those of prior research (Kim et al., 2011; Mamiseishvili & Rosser, 2009). However, the survey indicated an interesting aspect of professional activity. In the surveyed population, the weekly workload of foreign- and US-born scientists did not statistically differ. At the same time, foreigners devote a significantly higher proportion of their time on research activities (51% for foreign- and 41% for US-born scientists). In other words, foreigners do not work more hours than US-born scientists, but the number of hours they spend weekly on research activities is significantly higher. These statistics, however, do not support the responses of foreign-born scientists in prior interviews that report more work hours than US-born faculty (Collins, 2008; Skachkova, 2007). However, the results of the analysis strongly agree with those of prior research that found that foreigners devote a higher proportion of their time on research, supporting the finding that they spend more hours on research activities (Sabharwal, 2011; Webber, 2012).

The presence of the expected demographic and professional differences in the *Netwise II* population emphasizes alternative explanations for variances in scientists' social capital and research productivity included in the general theoretical model (see Chapter 2.4). As mentioned earlier, studies have found that differences in demographic and professional attributes are associated with foreigner-born scientists' advantage over foreign-born scientists in research performance (Kim et al., 2011; Mamiseishvili & Rosser, 2009). Also, such differences are related to differences in their professional social capital composition (Bozeman et al., 2012). The differences appearing in the initial descriptive statistics underscore the importance of controlling for alternative social capital and research productivity variance explanations rather than foreign origin.

3.1.4. Survey data on scientists' professional networks and network resources

The survey extensively explores scientists' professional relationships. It employs an ego-centric design (Netwise, 2012a) that focuses on a single actor (ego) and the ego's connections with other individuals (alters) (Everett & Borgatti, 2005; Wasserman & Faust, 2009). Information about professional relationships was collected from *name generators* and *name interpreters* (Burt & Minor, 1983). Using *name generators*, respondents named individuals in their closest professional networks. Then, using *name interpreters*, respondents provided a comprehensive description of the relationship with each named individual. Altogether, for the 1,723 scientists in the research-intensive and research-extensive institutions, 14,903 alters were named across all *name generators* and respective relationships described in survey responses.

Respondents of the *Netwise II* survey were asked to name individuals in their professional networks: their closest research and teaching collaborators within and outside of their universities, individuals with whom they discuss departmental and career issues, mentors, dissertation chairs, and post-doctoral advisers (Table 3.4). Each relationship was thoroughly described addressing structural and relational parameters such as the length and frequency of communication, and the demographics and geographic location of the alter, among others. Finally, questions covered a comprehensive list of network resources received from the particular alter: collaborating on publications, grants, or teaching, receiving advice on work activities or issues related to one's job, department, or career, or providing other kinds of support such as funding, introductions, or invitations (Netwise, 2012a).

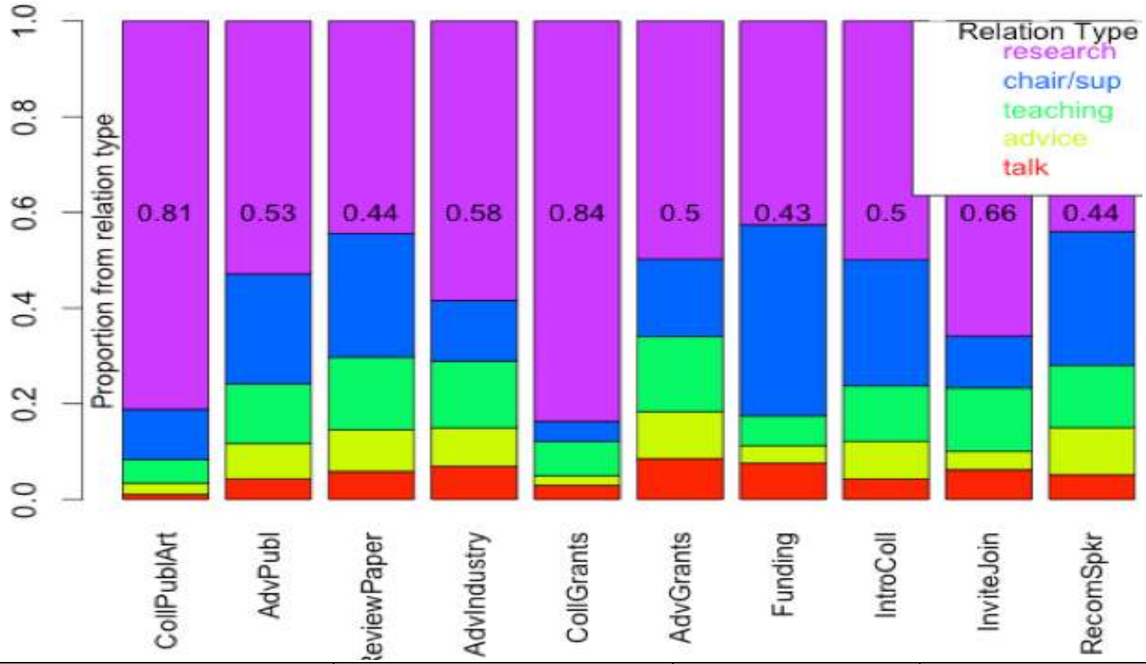
Table 3.4 Types of relations, research-related network resources, and related survey questions

Relation Type	***Netwise II* Survey Question** *("Over the past two academic years, with which individuals…")*
Research collaborators	*"…have been closest research collaborators"*
Teaching collaborators	*"…discussed teaching and classroom related issues"*
Advice networks	*"…sought advice about career or professional development"*
Talk about dept. issues	*"…talked to about important university or department related issues"*
Network Resource	*(individuals in the professional networks who...)*
Network resources that help prepare publications	
Collaborate on article	*"…published one or more articles together"*
Advise on article	*"…advised on publishing"*
Review article	*"…reviewed papers or proposals prior to submission"*
Advise on industry	*"…advised on collaborating with industry or government"*
Network resources that help secure funding for research activities	
Collaborate on grants	*"…collaborated on a research grant proposal"*
Advise on grants	*"…advised on grant getting"*
Provide funding	*"…provided with research or other funding"*
Network resources that help develop new research collaborations	
Introduce to collaborator	*"…introduced to potential research collaborators"*
Invite to the team	*"…invited to join a teaching or research grant proposal team"*
Recommend as speaker	*"…recommended as an invited speaker/panel member"*

The dissertation focuses on a wide variety of resources and support that scientists receive from their social networks and use in their research activities (Bozeman & Corley, 2004; Melin, 2000; Nahapiet & Ghoshal, 1998; Smith & Katz, 2000). Following prior research, it analyzes research-related network resources that help scientists prepare publications (collaboration, advice, or review articles), ensure research funding (collaboration or advice on grants, or funding), or develop new professional relationships (introductions to others, invitations to join a team, or recommendations) (Table 3.4).

This dissertation uses data on network ties and resources in the entire professional network because a preliminary analysis of the *Netwise II* data shows that scientists receive research-related support from multiple sources, not just their closest research collaborators (Figure 3.1). Such a tendency is consistent with prior research indicating that the term "research collaboration" has vague boundaries and that scientists receive necessary advice and resources from a broader range of professional relationships that are often not formally named as research collaborations (Katz & Martin, 1997; Moody, 2004; Ynalvez & Shrum, 2011).

Among *Netwise II* respondents, the networks of the closest research collaborators are significant, but not always the principal source of research-related network resources. Collaborators closely overlap with peers who have "published one or more articles together" or "collaborated on a research grant proposal" with a scientist. However, a significant amount of such assistance also comes from individuals not named among the closest research collaborators: 19% of individuals who actually collaborated on publications and 16% of those who collaborated on grants. The roles of the closest research collaborators in providing other kinds of assistance are even less dominant, constituting about half of individuals who provide advice on publications and grants or work with industry, or those who are invited to join the research team.



Relation type \ Research-related resource	Collaborate on article	Advise on article	Review article	Advise on industry	Collaborate on grants	Advise on grants	Provide funding	Introduce to collaborator	Invite to the team	Recommend as speaker
Research collaborators	81%	53%	44%	58%	84%	50%	43%	50%	66%	44%
Diss.chair & postdoc.sup.	10%	23%	26%	13%	4%	16%	40%	26%	11%	28%
Teaching collaborators	5%	12%	15%	14%	7%	16%	6%	12%	13%	13%
Advice networks	2%	7%	9%	8%	2%	10%	4%	8%	4%	10%
Talk about dept. issues	1%	4%	6%	7%	3%	9%	8%	4%	6%	5%

Figure 3.1 The proportion of each research-related network resource received from each type of relationship
(sample averages; only resources from ties that appear only in one relation)

Teaching networks also play a significant role in supporting research activities, and 10-15% of individuals who provide each kind of research-related resource come from such a relationship type. Another significant source of research-related network resources are dissertation chairs and post-doctoral supervisors. They provided funding in 40% of cases and constitute about a quarter of connections who advised *Netwise II* respondents on publications or reviewed them. Also, chairs and supervisors often fostered the development of professional ties by introducing respondents to collaborators or recommending them as speakers. As a result, focusing only on the closest research collaborations would have left out information about important resources received from other types of relationships.

3.2. Variables

To test the hypotheses, this study uses the STHC model adapted to the context of foreign-born scientists (see Figure 2.1 in Chapter 2.4). Using two types of models, it tests the impact of foreign origin on the attributes of scientists' professional social capital and the impact of such social capital variances on scientists' research productivity. Three social capital models are used in the analysis: to test Hypothesis 1, if origin has the impact on the sizes of the professional networks of scientists; to test Hypotheses 2A and B, if origin has the impact on the strength and multiplexity of professional ties; and to test Hypothesis 3, if origin has the impact on the number of foreign ties and resources in professional networks. The dependent variables of these three models represent the mentioned social capital attributes. According to the hypotheses, the attributes depend on foreign origin, which it is used as an independent variable in all three models. Furthermore, all models will further include variables for factors also known to impact the social networks and the resources of scientists.

Further, two publication productivity models are used: to test Hypothesis 4, if the proportion of foreign ties (and resources) in professional networks has an impact on the performance of foreign-born scientists, and to test Hypothesis 5, to determine whether or not multiplexity and proportion of foreign ties mitigate the negative effect of smaller professional networks. In both models, publication productivity is the dependent variable. Its variance is explained by independent variables representing the foreign social capital and multiplexity of ties. Both models also include variables for factors that, according to the STHC model and prior literature, impact the research productivity of scientists.

3.2.1. Dependent variables - social capital (Hypotheses 1 to 3)

Seven dependent variables are constructed for testing the impact of the foreign origin on social capital. First, *professional network size* is used to test Hypothesis 1. Three variables—*tie length*, *tie frequency*, and *friendship*—are used to assess the average strength of ties (Hypothesis 2A), and the *number of research-related network resources per tie* indicates average tie multiplexity (Hypothesis 2B). Finally, *the number of foreign ties (and resources) in professional networks* (Hypothesis 3) is used for evaluating the internationality of professional networks.

Professional network size (Hypothesis 1) – This variable is constructed as the number of individuals that the *Netwise II* survey respondents named in any of their professional networks as their closest research and teaching collaborators, individuals with whom they discussed departmental and career issues, mentors, advisers, and supervisors. In the network theory of social capital, network size (or network degree), calculated as the number of individuals with whom the ego has connections (Borgatti et al., 1998), indicates the range of accessible resources and opportunities for accessing necessary resources (Borgatti et al., 1998; Burt, 2000; N. Lin, 2001). Prior studies on the social capital of scientists and their publication productivity have mostly focused on research collaboration networks (Bozeman et al., 2001; Katz & Martin, 1997). The analysis also includes other types of professional ties, for they are used for attracting the resources necessary for research activities (see Chapter 3.1.4.).

Number of research-related resources (used to construct dependent variables for testing Hypotheses 2B and 3) – This variable is constructed as the sum of research-related resources provided by alters of the survey respondents. As mentioned in Chapter 3.1.4, the dissertation focuses on network resources known to have an impact on research activities, that is, those helping scientists prepare publications (collaborating on, advising on, and reviewing articles, and advising on collaboration with industry), ensuring research funding (collaborating on grants, advising on grants, providing funding), or developing new professional relationships (introducing to collaborators, inviting to join a team, recommending as a speaker) (Table 3.4). The amount of each individual resource was counted as the number of individuals providing respective assistance, and the variable was the sum of individual resources.

The *number of research-related resources*, the sum of individual research-related network resources, represents the amount of research-related social capital. As the network theory of social capital asserts, the amount of individual resources is related to intangible level of the overall social capital (N. Lin, 1999a) and the internal consistency among individual resource variables confirms it. The high internal consistency with McDonald's omega ω=0.91 indicates that variables likely to measure the same latent variable, in this case, the amount of research-related social capital. Moreover, the sum is a good choice as an index variable for research-related network resources because it follows the multivariate variance of resources. The sum of resources correlates at r=0.995 with the first principal component from the individual resource variables and explains 52% of their variance. The high correlation with the principal component indicates that the sum variable adequately captures the variance of individual resources (Johnson & Wichern, 2007).

The testing of Hypothesis 2A uses the following proxies for measuring the relationship strength: tie length, frequency, and friendship (Granovetter, 1973; Kiopa, 2013; N. Lin, 2001).

Tie length (Hypothesis 2A) – This proxy represents the average length of relationships in the professional network. The length of a tie has a value of 3 if it has lasted more than five years, 2 if it has lasted two to five years, and 1 if it has lasted fewer than two years.

Tie frequency (Hypothesis 2A) – This proxy represents the average frequency of interactions in the professional network. The frequency of a tie has a value of 4 if the individual is contacted at least daily, 3 if contacted more or less weekly, 2 if contacted about monthly, and 1 if contacted less often.

Friendship (Hypothesis 2A) – This proxy represents the average proportion of friends in the professional network. The respondent had to mark every network relationships as either a "close friend" or not.

Number of research-related resources per tie (Hypothesis 2B) – This variable, representing the resource multiplexity of professional ties, is constructed as the average number of research-related resources that respondents receive from each tie in their professional networks. The higher number of resources per tie indicates a higher multiplexity of ties and more efficient use of social connections (Borgatti et al., 1998; Burt, 2000; Verbrugge, 1979).

Number of foreign ties in professional networks (Hypothesis 3) – This variable, calculated as the count of foreign ties in the professional networks, describes the geographic location of scientists' social capital. A tie is presumed to be foreign if survey responses indicated that the peer "primary works in foreign research or academic institution" (Netwise, 2012a).

Number of foreign resources in professional networks (Hypothesis 3) – This variable is calculated as the number of research-related network resources received from foreign ties.

3.2.2. Dependent variables - research productivity (Hypotheses 4 and 5)

The analysis uses publication productivity as the dependent variable in the two models to test if foreign orientation of professional networks has a positive impact on the productivity of foreign-born scientists (Hypothesis 4) and if multiplexity and the proportion of foreign ties mitigate the negative effect of smaller professional networks (Hypothesis 5).

Publication count (Hypotheses 4 and 5) is used to measure research productivity. The *Netwise II* survey respondents were asked to report their "average number of peer-reviewed articles published per year, over the last five academic years." In prior research, the count of peer-reviewed publications is the most frequently used measure for scientific productivity (Lee & Bozeman, 2005). Studies have found that the five-year average correlates well with the long-term academic performance of scientists and excludes the impact of fluctuations caused by momentary life or professional events (Fox & Faver, 1984; Levin & Stephan, 1991). In addition, self-reported data do not raise doubts as studies have shown that they accurately reflect actual publication performance (Fox & Mohapatra, 2007; Ramsden, 1994).

3.2.3. Key independent variables of interest

Foreign origin (Hypotheses 1, 2, 3, and 5) is the major independent variable as the major focus of this dissertation is examine and explain the impact of foreign origin on variations in scientists' social capital and publication productivity. Foreign origin is constructed as the self-reported citizenship status and coded as a dummy variable that indicates if the respondent was born outside the US. It has a value of “0” if the respondent is a “native-born US citizen” and “1” if the respondent is a naturalized or non-US citizen with a visa.

The proportion of foreign ties in professional networks and **the proportion of foreign resources in professional networks** (Hypotheses 4 and 5) are used to indicate the “foreign orientation” of professional social capital and to test its influence on publication productivity. The first variable is calculated as the number of foreign ties in professional networks divided by the size of the professional network, and the second as the number of foreign research-related network resources divided by the total number of resources. As proportion allows the comparison of “foreign orientation” of social capital of different sizes, it is used instead of count. Counts of foreign ties and resources alone would not indicate the “foreign orientation” of the capital because they depend on overall size of professional network or the sum of research-related resources (e.g., a scientist with two foreign ties out of eight ties in total has lower foreign orientation of social capital than a scientist with one foreign tie out of three ties).

Professional network size and **the number of research-related resources per tie** (Hypothesis 5), the two variables described in previous section, are used to test if tie multiplexity and the foreign orientation of social capital mitigate the negative impact of smaller social networks.

3.2.4. Other independent variables

Both social capital and productivity models include a number of control variables based on the STHC model and known to influence both social capital and research performance. Including other factors is particularly important because foreign-born scientists significantly differ from US-born in their demographic, institutional, and professional characteristics (Corley & Sabharwal, 2007; Kim et al., 2011; Mamiseishvili & Rosser, 2009), and these differences, rather than foreign origin, may contribute to variances in social capital or research productivity.

Female (gender), the self-reported selection of gender, coded as a dummy variable by "0" for "male" and "1" for "female." Prior research indicates that gender has an impact on the size, the composition, and the relational properties of professional networks (Bozeman & Corley, 2004; Bozeman & Gaughan, 2011; van Emmerik, 2006) and that female scientists generally publish fewer articles than their male counterparts (Cole & Cole, 1973; Fox, 1983, 1991, 2005; National Research Council, 2001; Smith-Doerr, 2004);

US PhD - a dummy variable coded "1" if the scientist received a doctoral degree from a US institution. Respondents were asked to report their PhD institutions. The names were later matched against the Federal School Code list (former FICE) (U.S. Department of Education, 2010) and marked if the institution was foreign.

Postdoctoral experience - a dummy variable coded "1" if the respondent "ever held a post-doc appointment," and "0," otherwise. Both *US PhD* and *postdoctoral experience* were included because prior research indicates that graduate school and post-doctoral training are significant periods in which individuals building professional relationships (Melin, 2000), and both impact the size of networks and the location of ties. Further, better education and training are associated with higher publication productivity in later life (Carayol & Matt, 2006; Davis, 2005; R. Long, Crawford, White, & Davis, 2008);

Career length - the number of years in 2011 since the self-reported year of receiving a doctoral degree. Career length is used as a proxy measure for other factors that influence professional networks and productivity: age, faculty rank, and status (Lee & Bozeman, 2005). All three are highly correlated with each other and with career length, but they will not be included in the regression models for the purpose of avoiding multicollinearity, inflated bias, and standard errors of estimates (Wooldridge, 2010). The length of a professional career causes variances in social capital (Fox & Faver, 1984; Levin & Stephan, 1991; Stephan & Levin, 1992), and scientists are most productive in the middle of their professional lives (Levin & Stephan, 1991; Stephan & Levin, 2001a). Because of the U-shaped impact of career length on social capital and research productivity (Fox & Faver, 1984; Levin & Stephan, 1991), the models include both linear and quadratic forms of *career length*;

Research hours, weekly – the number of hours spent on research activities weekly. The hours were calculated by multiplying the self-reported "average number of weekly work hours" and the self-reported "percentage of weekly load allocated to research activities." Prior research indicates that scientists who devote more time on research produce more publications (Bellas & Toutkoushian, 1999; Fox & Mohapatra, 2007; Tien & Blackburn, 1996), and their professional networks consist of more ties that provide research-related resources (Fox & Mohapatra, 2007).

Research-extensive (type of institution) - a dummy variable coded “1” if the respondent works in a research-extensive institution according to the Carnegie classification (Carnegie Foundation, 2010) and “0” if in a research-intensive institution. The coding is based on the institutional sample data.

Field (or scientific discipline) – coded as four dummy variables for *biology*, *biochemistry*, *mathematics*, and *civil engineering*. The coding is based on the departmental name and derived from *Netwise II* sampling information. In the models, *field* is included as three dummy variables for *biology*, *biochemistry*, and *civil engineering* while scientists in *mathematics* are used for reference. Both variables, *research-extensive* (type of institution) and *field*, are included in the models to account for variances between the collaboration practices of the two types of academic institutions (Bozeman et al., 2012) and scientific disciplines (Katz & Martin, 1997; Lee & Bozeman, 2005; Tsai, Corley, & Bozeman, 2016), and to control for differences between their publication practices (Bozeman et al., 2012; Carayol & Matt, 2006; De Bellis, 2009; Levin & Stephan, 1991; J. S. Long & McGinnis, 1981; R. Long et al., 2008).

Sociability – the psychometric index measure of sociability (i.e., “social closeness”) scored from 1 to 4. The *Netwise II* survey includes ten social closeness questions as specified by the Multidimensional Personality Questionnaire (MPQ) methodology (Boyle, Matthews, & Saklofske, 2008), and the index is constructed accordingly. As the methodology explains, a high scorer "is sociable, likes to be with people; takes pleasure in and values close interpersonal ties; is warm and affectionate; turns to others for comfort and help"; by contrast, a low scorer "likes to be alone; can do without close ties; is aloof and distant; prefers to work problems out on her (his) own." Sociability is included as a control variable for two reasons. It influences the extent of social capital because more sociable people establish social connections quickly, have larger networks, and use them more efficiently (Asendorpf & Wilpers, 1998). Second, it is essential in publication productivity models, for it is instrumental to professional network size, and therefore appears in first-stage estimations of social capital models (see Chapter 3.3.2 for details).

3.2.5. Sample statistics and correlation analysis of variables

Multicollinearity of variables could be a source of inflated bias and standard errors in regression models (Wooldridge, 2010). To address this issue, this study lists sample statistics of variables in Table 3.5 and correlations among variables in Table 3.6.

Table 3.5 Un-weighted sample statistics of variables

Variable	N	mean	(sd)	min	max
Demographics and psychometrics					
Foreign origin	1723	44.1%	(0.50)	0	1
Female	1723	45.0%	(0.50)	0	1
Sociability	1557	2.78	(0.42)	1.1	4
Professional context					
Career length, years	1708	18.36	(10.74)	1	51
US doctoral degree	1692	87.4%	(0.33)	0	1
Postdoctoral experience	1722	66.4%	(0.47)	0	1
Research extensive institution	1723	58.5%	(0.49)	0	1
Field					
Biology	1691	32.6%	(0.47)	0	1
Biochemistry	1691	18.9%	(0.39)	0	1
Civil engineering	1691	25.6%	(0.44)	0	1
Mathematics	1691	22.9%	(0.42)	0	1
Research activity					
Research, h/week	1685	25.18	(14.01)	0	84
Publication count/year	1514	3.47	(4.98)	0	53
Professional network					
Professional network size	1723	8.65	(4.28)	0	26
Tie length	1676	2.65	(0.35)	1	3
Tie frequency	1649	2.13	(0.50)	1	4
Friendship	1680	26.4%	(0.24)	0	1
Research-related network resources					
Collaborate on article	1723	2.26	(2.07)	0	17
Advise on article	1723	2.50	(2.56)	0	18
Review article	1723	1.92	(2.16)	0	19
Advise on industry	1723	0.83	(1.70)	0	19
Collaborate on grants	1723	2.27	(2.35)	0	16
Advise on grants	1723	2.62	(2.71)	0	19
Provide funding	1723	1.17	(1.56)	0	16
Introduce to collaborator	1723	2.13	(2.50)	0	19
Invite to the team	1723	1.99	(2.23)	0	19
Recommend as speaker	1723	1.44	(1.90)	0	19
Number of research-related resources	1723	19.13	(15.26)	0	165
Number of resources per tie	1680	2.18	(1.26)	0	8.7
Geographic location of social capital					
Foreign ties in professional networks	1723	0.55	(0.90)	0	5
Foreign research-related resources	1723	1.33	(2.93)	0	29
% of foreign ties in professional networks	1680	6.6%	(0.12)	0	1
% of foreign research-related resources	1649	7.6%	(0.16)	0	1

Table 3.6 Un-weighted correlations among variables in sample data
(only correlations significant at α=0.05 are shown, having values r≥0.0475)

	foreign	female	sociability	career length	US PhD	post-doc	res. ext.	biology	biochem	civil eng.	math	research, h	publications
Foreign	1												
Female	-.17	1											
Sociability	.10	.10	1										
Career length	-.14	-.23	-.07	1									
Post-doc					-.14	1							
Res. ext.	.06	.09				.16	1						
Biology	-.13	.09		.05		.30	-.06	1					
Biochem	-.06	-.07		.12	-.10	.28	.09	-.34	1				
Civil eng.	.06			-.13	.12	-.40	.07	-.41	-.28	1			
Math	.15					-.18	-.08	-.38	-.26	-.32	1		
Research, h	.16			-.14	-.13	.20	.30	.06	.17		-.25	1	
publications	.11	-.11		.10	-.09	.05	.09		.07	.05	-.09	.26	1
Network size	-.27	.09	.09	.08	.05	.15	.07	.14	.10	-.06	-.18	.06	
Tie length	-.05	-.11	-.05	.48		-.05				-.08	.07	-.16	.10
Tie frequency	-.21		.07		.08	-.19	-.14		-.06	.08		-.12	
Friendship	-.10		.13	.08	.05	-.07		.05	-.06				.07
Coll. article		-.08				.05	.12					.21	.23
Adv. article	-.05	.05	.10	-.10		.15		.15		-.11	-.09	.12	.05
Rev. article	-.07	.07	.07	-.10		.08		.20		-.07	-.16	.07	
Adv. industry			.10			-.11		-.06	-.06	.30	-.18	.06	
Coll. grants			.11	-.07			.07			.25	-.28	.23	.12
Adv. grants	-.07	.08	.13	-.17		.11		.12	.07		-.23	.14	
Funding	-.12		.08		.07	.10	-.08	.09			-.09		
Intro. collab.	-.10		.16	-.09		.06		.08			-.13	.09	
Invite team	-.13		.11		.08			.07		.16	-.21	.05	.08
Recom. spkr.	-.10		.08	.09		.08		.06	.06		-.09	.07	.07
Number of res.	-.09		.14	-.08		.08		.11		.08	-.21	.16	.08
Res. per tie	.11		.12	-.22					-.07	.19	-.15	.19	.13
Foreign ties	.17	-.06	.05	.08	-.33	.17	.09	.06		-.16	.07	.15	.09
Foreign res.	.09	-.05	.06	.09	-.14	.12	.07	.05		-.09		.12	.10
% foreign ties	.23	-.08		.08	-.40	.12				-.14	.12	.13	.09
% foreign res.	.15	-.08		.16	-.22	.07				-.12	.14	.08	.06

Table 3.6 Un-weighted correlations among variables in the sample data.
(continued, only correlations significant at α=0.05 are shown, having values r≥0.0475)

	network size	tie length	tie frequency	friendship	coll. article	adv. article	rev. article	adv. industry	coll. grants	adv. grants	funding	intro. collab.	invite team	recom. spkr.	number of res.	res. per tie	foreign ties	foreign res.	% foreign ties	% foreign res.
Network size	1																			
Tie length	-.08	1																		
Tie frequency	.14		1																	
Friendship	.16	.16	.18	1																
Coll. article	.49		.12	.12	1															
Adv. article	.49	-.07	.12	.21	.44	1														
Rev. article	.41	-.07	.11	.22	.21	.51	1													
Adv. industry	.32		.12	.16	.26	.31	.29	1												
Coll. grants	.52	-.12	.15	.07	.44	.33	.28	.45	1											
Adv. grants	.54	-.15	.12	.17	.31	.70	.53	.44	.52	1										
Funding	.37		.08	.13	.25	.33	.34	.34	.33	.41	1									
Intro. collab.	.48		.11	.22	.36	.51	.48	.52	.45	.58	.47	1								
Invite team	.49		.16	.19	.36	.40	.40	.49	.60	.55	.52	.64	1							
recom. spkr.	.43	.10	.07	.20	.32	.42	.41	.37	.30	.43	.39	.53	.47	1						
Numberof res.	.66	-.06	.17	.25	.57	.74	.65	.63	.68	.81	.60	.80	.78	.66	1					
Res. per tie	.05		.13	.21	.34	.51	.46	.47	.45	.55	.43	.59	.55	.44	.70	1				
Foreign ties	.27		-.06		.26	.19	.09		.06	.10	.09	.11		.16	.15		1			
Foreign res.	.25	.05		.09	.28	.30	.18	.07	.13	.22	.24	.24	.17	.27	.30	.17	.78	1		
% foreign ties			-.12		.10			-.10	-.09	-.06			-.11				.83	.59	1	
% foreign res.		.07	-.10		.09			-.10	-.12	-.09			-.10		-.06	-.09	.72	.70	.82	1

The correlation analysis provides initial verification of the methodological approach. The index variable *number of research-related network resources* highly correlates with individual numbers of resources, professional network size, and publication productivity. Moreover, because of high correlations between individual resource variables, using the index variable removes the potential multicollinearity problem. Other risks of multicollinearity are low because high correlations between variables of the same mode are not observed. Finally, variables used in the estimation of instrumental variables (see Chapter 3.3.2) have suitable relationships, and *sociability* is correlated with social capital variables but has no influence on publication productivity.

Moreover, the correlation analysis supports the decision to analyze all professional ties. The number of closest collaborators correlates less with publication performance (*r=0.12*) than does the number of individuals who actually collaborated on articles (*r=0.23*, Table 3.6). Moreover, publication performance is significantly correlated with research-related network resources that are not directly related to publication activities (e.g., with funding or assistance with establishing professional ties). Such resources are largely provided by individuals other than the named research collaborators.

The correlation data also provide initial insight into the hypothesized relationships. Foreign origin, indeed, is correlated with a lower proportion of women, an earlier career stage, employment at research-extensive institutions and more time spent on research. Foreigners are associated with a higher number of publications. As expected, foreign-born scientists are likely to have smaller professional networks but a larger number of foreign ties and resources. Although foreigners are expected to receive more research-related resources from each tie, the correlation analysis does not indicate stronger relationships. Finally, foreign origin correlates with a lower number of research-related resources, especially those related to funding and assistance, or related to establishing new professional relationships. However, foreign origin appears to have no influence on the number of individuals who collaborated with the scientist on publications or grants.

3.3. Statistical models

This analysis entails two types of statistical models. The first, “social capital models,” test the impact of foreign origin on social capital variables (Hypotheses 1 to 3). The second, “publication productivity models,” are used to test the impact of foreign origin and several social capital attributes on the publication count of scientists (Hypotheses 4 to 5) (Table 3.7). Besides the variables of interest, the models include other factors that influence social capital or publication productivity. The main method of testing the hypotheses is multivariate regression analysis, which allows us to measure the particular impact of the independent variables on the expected value of dependent variables while controlling for the impacts of other factors (Wooldridge, 2010). The analysis must be constructed in such way that it resolves potential endogeneity in productivity models and the non-linear forms of dependent variables.

Table 3.7 Summary of statistical models and their variables

	Dependent Variables	Independent Variables	Control Variables
Social capital models			Gender, career length, research activity, type of institution, discipline, US doctoral, education, postdoctoral experience
Hyp 1	Professional network size	Foreign origin	
Hyp 2A	Tie length, tie frequency, friendship		
Hyp 2B	Network resources per tie		
Hyp 3	Number of foreign ties, number of foreign resources		
Publication productivity models			
Hyp 4	Publication productivity (in foreign-born population)	Proportion of foreign ties (and resources) in professional networks	
Hyp 5	Publication productivity	Foreign origin, professional network size, network resources per tie, proportion of foreign ties (resources)	

3.3.1. Regression models for testing social capital hypotheses 1 to 3

Three regression models are used for testing the impact of foreign origin on the various parameters of scientist's social capital. The models are similar because they are constructed on the basis of the same social capital explanatory model. They share the same explanatory variable, *foreign origin*, and the same control variables, factors that influence the size and the structure of social capital. The general forms of the regression models are as follows:

(H1) *Professional network size*
or (H2A) *Tie length*
or (H2A) *Tie frequency* $= \beta_0 +$
or (H2A) *Friendship*
or (H2B) *Number of network resources per tie*
or (H3) *Number of foreign ties (resources) in professional networks*

$+ \beta_1 *$ *foreign origin* $+ \gamma_1 *$ *female* $+ \gamma_2 *$ *sociability* $+ \gamma_{31} *$ *career length* $+$
$+ \gamma_{32} *$ *(career length)*^{2} $+ \gamma_4 *$ *research load* $+ \gamma_5 *$ *US PhD* $+$
$+ \gamma_6 *$ *postdoctoral experience* $+ \gamma_7 *$ *research extensive* $+$
$+ \gamma_{81} *$ *biology* $+ \gamma_{82} *$ *biochemistry* $+ \gamma_{83} *$ *civil engineering*

The three models use six dependent variables to test the following hypotheses:

- Dependent variable *professional network size*, for testing Hypothesis 1—that *foreign origin* will negatively impact the size
- Dependent variable *tie length*, for testing Hypothesis 2A—that *foreign origin* will positively impact length
- Dependent variable *tie frequency*, for testing Hypothesis 2A—that *foreign origin* will positively impact frequency
- Dependent variable *friendship*, for testing Hypothesis 2A—that *foreign origin* will positively impact friendship
- Dependent variable *number of network resources per tie*, for testing Hypothesis 2B—that *foreign origin* will positively impact the number
- Dependent variable *number of foreign ties (or resources) in professional networks*, for testing Hypothesis 3—that *foreign origin* will positively impact the number

3.3.2. Regression models for testing productivity hypotheses 4 and 5

Two tests address the variance of publication productivity among scientists. Both regression models are constructed on the basis of the same explanatory mode of scientists' publication productivity, use the same dependent variable, *publication count*, and the same control variables. However, each model has its own focal independent variables.

First, to test Hypothesis 4—that a larger proportion of foreign ties (and resources) will positively impact the productivity of foreign-born scientists—a regression analysis of the foreign-born population is conducted. Two regressions are constructed with the focal independent variables *proportion of foreign ties in professional networks* and *proportion of foreign resources in professional networks*. The models are controlled for *professional network size* (or n*umber of research-related resources*). Such a design allows us to test whether foreign-born scientists with more internationally oriented networks have higher publication productivity than other scientists with comparable sizes of network and number of resources. The models are not able to use only the number of foreign ties or resources as explanatory variables. Individuals with more foreign ties or resources could instead experience a positive impact of larger networks (Lee & Bozeman, 2005) rather than tie locations. The general form of the regression model for testing Hypothesis 4 is the following:

$$\begin{aligned}
&\textit{publication count} = \beta_0 + \\
&+ \beta_1 * \textit{proportion of foreign ties (resources) in professional networks} + \\
&+ \gamma_1 * \textit{female} + \gamma_{21} * \textit{career length} + \gamma_{22} * (\textit{career length})^2 + \gamma_3 * \textit{research hours} + \\
&\qquad + \gamma_4 * \textit{US PhD} + \gamma_5 * \textit{postdoctoral experience} + \gamma_6 * \textit{research extensive} + \\
&\qquad + \gamma_{71} * \textit{biology} + \gamma_{72} * \textit{biochemistry} + \gamma_{73} * \textit{civil engineering} + \\
&\qquad + \gamma_8 * \textit{professional network size (or number of research-related resources)}
\end{aligned}$$

The second publication productivity model is used to test Hypothesis 5—that a higher multiplexity of ties and a larger proportion of foreign ties and foreign research-related resources in networks will mitigate the negative impact of smaller professional networks on the productivity of foreign-born scientists. The mitigation effect will be analyzed in an evaluation of whether the impact of *foreign* *origin* is mediated through social capital variables; that is, if its effect changes when additional independent variables are added to the model (Baron & Kenny, 1986). This study employs four models of the following general form, adding an independent variable in each step:

$$
\begin{aligned}
&\textit{publication count} = \beta_0 + \\
&+ \beta_1 * \textit{foreign origin} + \\
&+ \beta_2 * \textit{professional network size} + \\
&+ \beta_3 * \textit{number of research-related resources} + \\
&+ \beta_4 * \textit{proportion of foreign ties (resources) in professional networks} + \\
&+ \gamma_1 * \textit{female} + \gamma_{21} * \textit{career length} + \gamma_{22} * (\textit{career length})^2 + \gamma_3 * \textit{research hours} + \\
&\qquad + \gamma_4 * \textit{US PhD} + \gamma_5 * \textit{postdoctoral experience} + \gamma_6 * \textit{research extensive} + \\
&\qquad + \gamma_{71} * \textit{biology} + \gamma_{72} * \textit{biochemistry} + \gamma_{73} * \textit{civil engineering}
\end{aligned}
$$

As in the previous model, regressions will be controlled for professional network size (or number of research-related resources) to allow testing the impact of more internationally oriented networks for scientists with comparable network size and number of resources.

3.3.3. Functional forms of the regression models

As the literature indicates that dependent variables of both social capital attributes and publication productivity are not normally distributed, several potential functional forms of the regression models are tested. Details of testing functional forms are provided in Appendices B and C.

Professional network size (Hypothesis 1) is a count variable that is not normally distributed, and several alternative nonlinear regression models are anticipated. Several potential forms have been mentioned in studies, some of which have found that social network sizes and resources have a power-law distribution and suggested using the logarithm of size in linear regressions (Barabasi et al., 2002; Clauset, Shalizi, & Newman, 2009). Other publications have argued that social networks do not follow the power law but instead have an exponential tail, as in Poisson's distribution (Adamic & Adar, 2005). Finally, some authors have argued that network data are overdispersed and fat-tailed, and suggested using a negative binomial distribution because it fits such data better than Poisson's distribution (Schilling & Phelps, 2007). Thus, this study tests linear, log-linear, Poisson's, and negative binomial models and evaluates their fit to the data.

The log-linear model uses a transformed dependent variable because value of logarithm is not defined for zero and some scientists possess zero-sized professional networks. To overcome this problem, regression analysis uses an inverse hyperbolic sine transformation of the professional network size as the dependent variable in the log-linear model. The transformation is defined as

$$y_{ihs} = \log(y+(y^2+1)^{½}),$$

which is approximately equal to *log(y)+log(2)*. It has a value of *y=0,* and it can interpreted as the standard logarithmic variable (Burbidge, Magee, & Robb, 1988).

Tests of functional forms confirm a linear relationship between the professional network size and the explanatory variables. Error terms of the linear model are normally distributed, and the RESET test supports that the model has a linear form. Further, the Breusch-Pagan test upholds the homoscedasticity assumption. The estimates of the linear model are unbiased, and the linear ordinary least squares (OLS) model with non-robust standard errors is chosen to test Hypothesis 1. The fit of the regressions and tests of their functional forms are presented in Appendix B.

Tie length, tie frequency, friendship, and number of network resources per tie (Hypothesis 2) are estimated using linear OLS models because the prior literature does not indicate the distribution of such network attributes.

Number of foreign ties (resources) in professional networks (Hypothesis 3) describe the amount of social capital, and the functional form of the regression model will match the one that is selected for testing Hypothesis 1, the linear OLS.

Publication count (Hypotheses 4 and 5) is a count variable known to have a non-normal distribution. Prior research has shown that publications could follow the power law or Poisson's distribution (De Bellis, 2009). As a result, the relationship between the dependent and explanatory variables is non-linear, and the use of the ordinary linear model leads to biased estimators (Wooldridge, 2010). The log-linear and Poisson's regression models are constructed and their fit to the data is verified. For the log-linear form, the publication productivity variable is transformed using the inverse hyperbolic sine because it is defined as $y=0$.

The tests of functional forms indicate that the log-linear model with the inverse hyperbolic sine transformation of the dependent variable exhibits the closest fit to the actual data. The error terms of the log-linear model do not fully fit the normal distribution, but the RESET test supports the usability of the form. However, the Breusch-Pagan test rejects the homoscedasticity assumption, and the analysis uses the results of the log-linear model with heteroscedasticity-robust standard errors. The fit of the three regressions for the productivity model and tests of their functional forms are provided in Appendix C.

3.3.4. Resolving endogeneity in the productivity models

As the publication productivity models are prone to endogeneity, they could produce inconsistent estimators if they include social capital variables. Endogeneity is caused by the potential reverse causation between the dependent variable, publication productivity, and the explanatory variable, professional network size. Prior research has shown that publication productivity depends on network size (Lee & Bozeman, 2005). At the same time, more productive scientists may find it easier to establish professional ties (Bozeman & Corley, 2004). Moreover, both the publication productivity and the professional network size of a scientist could correlate with the amount and quality of human capital (N. Lin, 2001), which are unobservable.

Potential endogeneity is resolved by the instrumental variables approach (Wooldridge, 2010). The sociability variable, used for instrumenting professional network size, is a good candidate as the instrument. A suitable instrument variable has to satisfy two conditions: It has to correlate with the endogenous explanatory variable, and it has to impact the dependent variable only through the explanatory variable (Wooldridge, 2010). Sociability satisfies both requirements. First, personality traits impact the number of relationships.

Therefore, more extroverted and sociable individuals have more peers, and their networks grow faster (Asendorpf & Wilpers, 1998). Second, personality is relatively stable after the age of 30 (McCrae & Costa, 1994), and the sociability trait is not affected by the social structure of the individual (i.e., larger networks do not lead to a more sociable personality) (Asendorpf & Wilpers, 1998). The stability of the sociability variable, its immunity to variance in productivity, and its correlation with potential network size allows us to use sociability as an instrument in the publication productivity model.

3.3.5. Implementation of the regression analysis

A generalized linear model is used for testing single-stage estimations and the generalized method of moments (GMM) for estimating instrumental variable regressions. Both methods are selected because they yield consistent and efficient estimates (Wooldridge, 2010), and they are capable of performing non-linear estimations. To test the validity of regression models, this study employs standard procedures. One such procedure, Q-Q plots, are used for examining the normality of residuals, and another, scatterplots of residuals against fitted values, are used to detect the non-linearity of error variance or its dependency on an explained variable. The standard RESET test is used in the verification of functional forms and the Breusch-Pagan test for homoscedasticity (Wooldridge, 2010).

Testing of the instrumental variable models follows the standard protocol for the verification of linear two-stage least squares estimations. First, the dependent variable is regressed on the instrument alone, and in such regression it should have a significant impact. Then the dependent variable is regressed on the instrument in the presence of the endogenous explanatory variable, and the instrument should not have a significant coefficient. Finally, the endogenous explanatory variable is regressed on both the instrument and all other explanatory and control variables, and the instrument should be significant (Wooldridge, 2010). The functional forms of both stages are verified by the RESET test and by assessments of the distribution of residuals. In addition, the endogeneity of the model is measured by the Durbin-Wu-Hausman test (Wooldridge, 2010). Details of the verification of the instrumental variable estimations are provided in Appendix D.

For the analysis of the data, this study employs the R statistical framework. In addition to the basic configuration of the framework, the analysis uses R packages “MASS” (Ripley et al., 2015), “weights” (Pasek, 2012), “ltm” (Rizopoulos, 2013), “lmtest” (Hothorn et al., 2015), and “gmm” (Chausse, 2015) to estimate linear and non-linear models, weighted statistics, instrumental and variable estimations as well as other needs.

4. RESULTS

The purpose of this dissertation is to identify and explain the unique characteristics of professional social capital of foreign-born scientists and the impact of such these characteristics on their research productivity. It proposes five hypotheses based on prior findings from the immigration literature and the STHC model of research productivity (Bozeman et al., 2001), and tests them using the “social capital” and “publication productivity” statistical models described in Chapter 3. First, this study employs “social capital models” to test the impact of foreign origin on social capital attributes (Hypotheses 1 to 3): the professional networks, the strength of ties and multiplexity, and the size of foreign professional social capital. The “publication productivity models” test the impact of social capital characteristics on the research productivity of foreign-born scientists (Hypotheses 4-5), that is, the impact of foreign social capital on productivity, and if tie multiplexity and foreign social capital mitigate the negative impact of smaller professional networks on productivity.

This chapter is organized into five sections. The first three sections describe the analysis used in the test of each of the three social capital hypotheses and the fourth section describes the tests of the publication productivity hypotheses. Each section begins with relevant descriptive data specific to the tested hypotheses and follows with the regression results. The chapter concludes with a summary of the results and hypothesis tests.

4.1. Network sizes and resources of the professional social capital of foreign-born scientists

The first hypothesis states that foreign origin will negatively impact the size of scientists' professional networks. To contextualize this hypothesis, descriptive results (comparison of means) of the various aspects of the professional social capital of foreign- and US-born scientists are shown in Table 4.1 and Table 4.2. From the analysis, results show that the professional social capital of foreign-born scientists significantly differs from that of US-born scientists. The differences lie in both the professional network structure (Table 4.1) and the number of received research-related resources (Table 4.2). Each professional network of the foreign-born scientists is significantly smaller than that of their US-born counterparts, and they have significantly fewer of almost all types of professional relationships and research-related resources. However, the professional social capital of both populations differ less with regard to the number of ties and resources that are closely related to research activities.

Statistically, the greatest difference between foreign- and US-born scientists is their sizes of teaching collaboration networks. The average size of the teaching collaboration network of foreign-born scientists is 2.1 individuals, 46% smaller than that of US-born scientists, with 3.47 peers. Their populations of peers who provided "indirect" support to their professional development also significantly differ. Foreigners have on average 43% fewer individuals with whom they discuss departmental issues or who have provided essential career advice.

Table 4.1 Weighted comparison between the professional networks of foreign- and US-born scientists

	Foreign-born		US-born			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Professional network size	7.24	(4.02)	9.55	(4.19)	<	(-13.55)
*Number of ties by relation type **						
Research collaborators	3.35	(2.30)	3.80	(2.35)	<	(-4.65)
within university	1.46	(1.27)	1.74	(1.35)	<	(-5.20)
outside university	1.89	(1.42)	2.06	(1.49)	<	(-2.73)
Teaching collaborators	2.10	(2.10)	3.47	(2.28)	<	(-15.10)
within university	1.65	(1.49)	2.57	(1.45)	<	(-15.19)
outside university	0.45	(0.95)	0.90	(1.28)	<	(-9.54)
Talk about departmental issues	1.32	(1.24)	2.10	(1.34)	<	(-14.62)
Receive career advice	0.95	(1.30)	1.29	(1.44)	<	(-5.98)
Other professional support ("mentors")	0.25	(0.58)	0.27	(0.63)	=	(-0.84)
Dissertation chairs	0.91	(0.28)	0.95	(0.22)	<	(-3.28)
Post-doctoral supervisors	0.62	(0.48)	0.63	(0.48)	=	(-0.59)

** the sum of relations is bigger than the professional network size because a single peer could be represented in more than one relation type*

While the networks of foreign- and US-born populations differ markedly, their social relationships that relate to research activities do not differ as much. Foreigners have 0.45 fewer researchers in their collaboration networks than US-born faculty, and this difference is notably less statistically significant (one-third of the t-statistics value) than the difference between the teaching networks of both populations. In addition, while foreign-born scientists have considerably fewer peers within their universities than US-born scientists, both populations have a similar number of research collaborators outside of their universities (1.89 for foreign- and 2.06 for US-born) and a similar average number of other research-related relationships, most notably mentors and post-doctoral chairs.

Foreign-born scientists also receive a significantly smaller total number of research-related network resources (Table 4.2) from their professional networks than US-born scientists, but the number of network resources directly related to publications of the two groups shows only a slight difference. Moreover, foreigners have significantly more individuals in their networks that collaborated with them on writing articles. In addition, the numbers of individuals who provided advice to the two groups about preparing publications or about working with industry did not significantly differ. The only disadvantage for foreigners is observable in the smaller number of individuals who reviewed their articles before publication.

Table 4.2 Weighted comparison of foreign- and US-born scientists' research-related network resources

	Foreign-born		**US-born**			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Sum of research-related network resources	16.74	(14.84)	19.85	(14.70)	<	(-5.10)
Sum of research-related network resources by type						
Sum of publication-related resources	7.20	(6.22)	7.73	(5.95)	<	(-2.11)
collaborated on article	2.57	(2.22)	2.38	(2.13)	>	(2.09)
advised on article	2.39	(2.55)	2.59	(2.70)	<=*	(-1.78)
reviewed article	1.59	(2.06)	1.99	(2.11)	<	(-4.68)
advised on working with industry	0.65	(1.59)	0.77	(1.59)	<=	(-1.85)
Sum of funding-related resources	5.09	(5.03)	6.03	(4.99)	<	(-4.54)
collaborated on grants	1.93	(2.28)	2.20	(2.25)	<	(-2.90)
advised on grants	2.18	(2.49)	2.57	(2.73)	<	(-3.66)
provided funding	0.98	(1.46)	1.26	(1.49)	<	(-4.49)
Sum of social capital-related resources	4.45	(5.01)	6.09	(5.56)	<	(-7.49)
introduced to collaborator	1.71	(2.27)	2.22	(2.53)	<	(-5.14)
invited to join a team	1.50	(2.04)	2.08	(2.18)	<	(-6.70)
recommended as a speaker	1.24	(1.71)	1.78	(2.10)	<	(-6.86)

** "<=": difference significant at a=0.10 level*

However, they received significantly less professional assistance of other kind. For example, compared with their US counterparts, they received assistance related to securing research funding from a significantly smaller number of individuals, they received advice and offers of collaboration on preparing grants from fewer individuals, and they received funding from fewer individuals. Finally, both populations significantly differ with regard to the number of individuals who help them develop professional social capital. Foreigners in their networks have significantly fewer peers who invited them to join the teams, introduced them to research collaborators, and recommended them as speakers.

4.1.1. Impact of foreign origin on professional network size

According to Hypothesis 1, foreign origin is responsible for the smaller professional network size of foreign-born scientists. While the descriptive statistics show that foreigners have smaller professional networks, this difference could be the result of demographic and professional variations between both populations. Therefore, this hypothesis if tested by a regression analysis.

The regression results confirm Hypothesis 1: that foreign origin has a negative effect on the size of the professional network (Table 4.3). The regression analysis further reveals the impact of other context variables on professional network size, and the findings are in line with those of prior research. Thus, the expected number of professional ties is significantly higher for individuals with a higher value of social closeness. At the same time, the impact of gender on network size, while positive, is marginal and does not reach significance at $\alpha=0.05$.

Table 4.3 Regression of professional network size on foreign origin

	professional network size		
	coef.	**(se)**	**sign.**
Foreign origin	**-2.404**	**(0.245)**	***
Female	0.392	(0.225)	.
Sociability	1.147	(0.247)	***
Professional context			
Career length	0.127	(0.038)	***
Career length^2	-0.002	(0.001)	**
Research hours weekly	0.020	(0.008)	*
US PhD	-0.485	(0.356)	
Postdoctoral experience	0.828	(0.266)	**
Research extensive	0.258	(0.228)	
Field			
Biology	1.050	(0.317)	***
Biochemistry	0.840	(0.363)	*
Civil engineering	0.697	(0.315)	*
(intercept)	3.800	(0.941)	***

*Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1*

The regression analysis further indicates the significant impact of other attributes on professional network size. One notable impact on professional relationships is the career length, with a U-shaped tendency, reaching a maximum network size in the 27th career year. Scientists who spend more time on research activities are expected to have significantly more professional ties. Furthermore, postdoctoral experience helps scientists develop professional networks, but the location of their graduate school (in the US or not) does not impact their number of relationships. Finally, although the sizes of professional networks are expected to be the same in research extensive and intensive institutions, the differences between the social capital of scientific disciplines are significant, with mathematicians (the reference group in the regression model) having significantly smaller networks than scientists in other fields.

Moreover, the negative impact of foreign origin on professional network size is larger than the statistical difference between the mean network sizes of both populations in Table 4.1. The regression shows that foreign origin reduces the expected professional network size by 2.4 while foreign-born scientists on average have 2.33 fewer individuals in their professional networks. It is possible that the negative impact of foreign origin is alleviated by differences between the populations of foreign- and US-born scientists. For example, foreigners have higher mean values of sociability (2.81 v/s 2.69 for US-born) and spend more hours on research activities (28.6 v/s 23.6 for US-born), and the regression shows that both factors positively influence the size of professional networks.

4.2. Strength and multiplexity of foreign-born scientists' professional relationships

As discussed earlier, in addition to professional network sizes, the professional social capital of foreign- and US-born scientists differ with regard to their relational properties. The second hypothesis states that foreign origin has a positive impact on tie strength (Hypothesis 2A) and the number of research-related resources received per professional network tie (Hypothesis 2B). To contextualize this hypothesis, this study begins by comparing the means of various tie strength and tie multiplexity measures of foreign- and US-born scientists. The descriptive results exhibit a dual nature. The professional networks of foreign-born scientists have significantly lower scores on all tie strength measures but significantly higher scores on the resource multiplexity of ties (Table 4.4).

Table 4.4 Weighted comparison of tie strength and multiplexity in the professional networks of foreign- and US-born faculty

	Foreign-born		US-born			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Tie strength						
Tie length	2.65	(0.34)	2.70	(0.31)	<	(-3.05)
Tie frequency	2.01	(0.53)	2.20	(0.45)	<	(-7.53)
Friendship	0.25	(0.27)	0.30	(0.25)	<	(-3.48)
Tie multiplexity						
Resources per professional network tie	2.22	(1.28)	2.02	(1.13)	>	(3.34)

4.2.1. Impact of foreign origin on tie strength and multiplexity

To test Hypothesis 2A—that foreign origin has a positive impact on tie strength measures—and Hypothesis 2B—that it has a positive impact on tie multiplexity, this study employs two regression models. The results of the first regression do not support Hypothesis 2A, since foreign origin does not exhibit a decisively significant positive impact on tie strength measures (Table 4.5). Only one of the measures—the length of relationships—has a higher expected value for foreign-born scientists. At the same time, the average frequency of interaction and the proportion of friends in professional networks is significantly lower for foreign-born scientists.

The results also indicate a mixed impact of various factors on network tie strength measures. Females are expected to interact less frequently with their peers and have a significantly smaller proportion of friends in professional networks. Further, career length is associated with longer relationships and an larger number of friends (old friends are not “dumped”). Finally, possessing postdoctoral experience is associated with lower values for all tie strength measures in professional networks.

Table 4.5 Regressions of tie strength measures on foreign origin

	Tie length			Tie frequency			Friendship		
	coef.	**(se)**		**coef.**	**(se)**		**coef**	**(se)**	
Foreign origin	**.04**	**(.02)**	*	**-.24**	**(.03)**	***	**-.05**	**(.01)**	***
Female	-.01	(.02)		-.06	(.03)	*	-.03	(.01)	*
Sociability	-.01	(.02)		.12	(.03)	***	.09	(.01)	***
Professional context									
Career length	.05	(.00)	***	.00	(.00)		.01	(.00)	*
Career length^2	.00	(.00)	***	.00	(.00)		.00	(.00)	*
Research hours weekly	.00	(.00)	*	.00	(.00)		.00	(.00)	
US PhD	.08	(.03)	**	-.07	(.04)		.00	(.02)	
Postdoctoral experience	-.03	(.02)		-.15	(.03)	***	-.05	(.02)	**
Research extensive	.03	(.02)	.	-.10	(.03)	***	.03	(.01)	*
Field									
Biology	-.02	(.02)		-.02	(.04)		-.01	(.02)	
Biochemistry	-.06	(.03)	*	-.04	(.04)		-.06	(.02)	**
Civil engineering	-.04	(.02)		.00	(.04)		-.06	(.02)	**
(intercept)	2.07	(.07)	***	2.23	(.11)	***	.05	(.06)	

*Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1*

Unlike Hypothesis 2A, Hypothesis 2B (i.e., regarding the positive impact on tie multiplexity) holds. That is, foreign origin significantly increases (by 0.165) the expected number of research-related resources that scientists receive from each tie in their professional networks (Table 4.6). Regarding the significance of the impact of other factors, it is important to mention that higher tie multiplexity is also expected among individuals working more hours per week on research and those who are more sociable. However, for females, the expected tie multiplexity is lower.

Table 4.6 Regression of research-related resources per tie on foreign origin

	research-related resources per professional tie		
	coef.	**(se)**	**sign.**
Foreign origin	**0.165**	**(0.073)**	*****
Female	-0.152	(0.067)	*
Sociability	0.312	(0.074)	***
Professional context			
Career length	-0.019	(0.011)	.
Career length^2	0.000	(0.000)	
Research hours weekly	0.015	(0.003)	***
US PhD	0.090	(0.107)	
Postdoctoral experience	-0.017	(0.080)	
Research extensive	-0.095	(0.068)	
Field			
Biology	0.315	(0.095)	***
Biochemistry	0.101	(0.109)	
Civil engineering	0.546	(0.095)	***
(intercept)	1.063	(0.281)	***

*Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1*

4.2.2. Higher tie multiplexity or strategic selection of relationships

The dual nature of the results presented in the previous section requires a more detailed analysis of professional relationships and network resources. The analysis shows that foreign origin does not have a significant positive impact on tie strength; at the same time, it does have a positive impact on the multiplexity of ties. Such results require resolving if a higher number of resources received per professional tie is the result of foreigners' focusing on maintaining ties with individuals who provide necessary resources or if it is the result of the multiplexity of such ties. In the first case, foreigners are expected to have a higher proportion of individuals who provide research-related resources in their networks; and in second case, every individual provides foreigners with more resources.

Statistics support that foreign-born scientists focus on maintaining ties with individuals, who provide necessary resources (Table 4.7). Foreign-born scientists have a significantly higher proportion of individuals who provide them with some research-related resource in their networks (Table 4.7). The analysis, however, does not support the second alternative. If only ties that provide research-related resources are analyzed, the number of resources per tie is similar in both populations (Table 4.7). Foreigners receive slightly more resources per tie, but the difference is not statistically significant. Having no differences between populations regarding tie multiplexity further supports the rejection of Hypothesis 2A. No evidence supports that the professional networks of foreign-born scientists have higher tie strength than the networks of their US-born counterparts.

Table 4.7 Weighted comparison of foreign- and US-born scientists' ties that provide research-related resources

	Foreign-born		**US-born**			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Proportion of ties in professional networks that provide research-related resources	74.3%	(0.24)	67.9%	(0.22)	>	(6.73)
Number of ties that provide research-related resources	5.42	(3.42)	6.56	(3.58)	<	(-7.82)
Research-related resources per each tie that provides research-related resources	2.93	(1.22)	2.88	(1.14)	=	(1.11)

A potential explanation for why foreign-born scientists have a higher proportion of ties in professional networks that provide research-related resources is that their teaching network differs from those of US-born scientists.

Foreign-born scientists have smaller teaching networks than US-born scientists in both size and proportion of the professional network (Table 4.1). Because teaching networks contain fewer relationships that provide research-related resources (Figure 3.1, Chapter 3.1.4), having a smaller number of such ties in professional networks increases the ratio of instrumental relationships.

4.3. Geographic location of ties and resources in foreign-born scientists' professional networks

Hypothesis 3 suggests that foreign origin will have a positive impact on the number of foreign ties and resources in scientists' professional networks. To provide the context for this hypothesis, the basic descriptive statistics indicate that foreign-born scientists do indeed have more foreign professional ties, and they receive more research-related resources from abroad than US-born scientists (Table 4.8). On the other hand, they have significantly smaller domestic networks and fewer domestic research-related resources.

Table 4.8 Weighted comparison of foreign- and US-born faculty by sizes of foreign and domestic networks and resources

	Foreign-born		US-born			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Foreign ties						
professional network size	0.83	(1.04)	0.50	(0.87)	>	(8.32)
number of research-related network resources	1.86	(3.33)	1.35	(3.08)	>	(3.79)
Domestic ties						
professional network size	6.41	(3.69)	9.05	(4.01)	<	(-16.48)
number of research-related network resources	14.88	(13.83)	18.50	(14.21)	<	(-6.23)

When introducing control variables for other factors, however, the regression analysis does not confirm Hypothesis 3: that foreign origin is responsible for either the larger number of foreign ties of immigrant scientists or foreign research-related resources (Table 4.9). According to the results of the analysis, the impact of foreign origin is insignificant on both parameters of social capital: the size of the foreign professional network and the number of foreign resources. The regression also reveals other factors with a significant impact on the amount of foreign professional capital. Individuals with higher sociability as well as those spending more time on research activities and those having postdoctoral training have more international professional social capital. Possessing US doctoral training, however, has a significant negative impact on foreign social capital.

Table 4.9 Regression of the number of foreign ties and foreign network resources on foreign origin

	Foreign professional network size			*Number of foreign research-related network resources*		
	coef.	**(se)**	**sign.**	**coef.**	**(se)**	**sign.**
Foreign origin	**.048**	**(.051)**		**.194**	**(.180)**	
Female	-.078	(.047)	.	-.240	(.165)	
Sociability	.124	(.051)	*	.479	(.182)	**
Professional context						
Career length	.014	(.008)	.	.013	(.028)	
Career length^2	.000	(.000)		.000	(.001)	
Research hours weekly	.007	(.002)	***	.023	(.006)	***
US PhD	-.781	(.074)	***	-.887	(.262)	***
Postdoctoral experience	.174	(.055)	**	.463	(.196)	*
Research extensive	.090	(.047)	.	.189	(.168)	
Field						
Biology	-.155	(.066)	*	-.188	(.233)	
Biochemistry	-.275	(.075)	***	-.447	(.267)	.
Civil engineering	-.322	(.065)	***	-.581	(.232)	*
(intercept)	.569	(.195)	**	-.216	(.692)	

*Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1*

Possessing a US graduate degree has the largest negative impact on the expected number of foreign ties and foreign resources in scientists' professional networks. Such a result could indicate that the positive impact of foreign origin is observed as a negative impact of a US degree if the impact of the US degree on foreign social capital is stronger and captures the impact of origin, and because a large proportion of foreigners have foreign degrees. The correlation data support such a possibility, indicating a higher correlation between the number of foreign ties and possession of a US degree *(r=-0.33)* than between the number of foreign ties and foreign origin *(r=0.17)*, and a large negative correlation between foreign origin and US degree *(r=-0.39)* (Table 3.6, Chapter 3.2.5).

4.3.1. Particular impact of foreign origin and place of education on the geographic location of social capital

In light of the results above, an additional analysis was conducted. The indefinite results require further exploratory analysis to explain to what extent the variance in the geographic location of social capital is the result of foreign origin and to what extent it is the result of US doctoral education. The analysis compares the domestic and foreign social capital of three groups: foreign-born scientists with foreign education, foreign-born scientists with a US doctoral degree, and US-born scientists with a US degree.[3]

[3] US-born faculty with foreign education are not included in the analysis because they comprise only 1% of the *Netwise II* sample, and the data contain too few cases for statistical inference.

Table 4.10 Weighted comparison of locations of ties by origin and by the education of scientists

	diff. (v/s Fb-US Phd)	(t-stat)	US-born population with US PhD (n=939) mean	(sd)	diff. (v/s Fb-f.Phd)	(t-stat)
Foreign professional network size	>	*(4.32)*	0.50	(0.87)	<	*(-12.54)*
Frgn. ties provide res.-rel. resources	>	*(3.94)*	0.44	(0.81)	<	*(-7.61)*
Foreign research-related resources	>	*(2.56)*	1.35	(3.07)	<	*(-4.65)*
Domestic professional network size	<	*(-15.77)*	9.09	(3.99)	>	*(9.91)*
Dom. ties provide res.-rel. resources	<	*(-9.43)*	6.14	(3.46)	>	*(6.53)*
Domestic research-related resources	<	*(-5.51)*	18.55	(14.21)	>	*(4.46)*

Foreign-born population

	With US PhD (n=557) mean	(sd)	diff.	(t-stat)	With foreign PhD (n=221) mean	(sd)
Frgn prof. network size	0.68	(0.99)	<	*(-9.48)*	1.35	(1.04)
Frgn ties w/ res. resources	0.60	(0.94)	<	*(-5.03)*	0.95	(1.01)
Frgn. res.-rel. resources	1.71	(3.32)	<	*(-2.94)*	2.41	(3.42)
Dom. prof. network size	6.40	(3.64)	=	*(-0.63)*	6.56	(3.68)
Dom. ties w/ res. resources	4.75	(3.11)	=	*(0.00)*	4.75	(3.02)
Dom. res.-rel. resources	15.02	(14.33)	=	*(0.33)*	14.73	(12.12)

The statistical analysis indicates that foreign-born scientists, regardless of their education, have larger foreign professional social capital and significantly smaller domestic capital than US-born scientists (Table 4.10). The results, nevertheless, reveal significant social capital differences among foreign scientists depending on their place of education. Those with foreign education have significantly larger foreign professional social capital than those with US degrees. Having a US doctoral degree, however, does not improve the domestic social capital of foreigners. The amount of domestic professional social capital is similar among all foreigners regardless of their place of education.

To clarify the particular impact of foreign origin and degree, three regressions of foreign professional network size are performed, matching the comparisons of the statistical analysis. The first regression estimates the impact of US doctoral training on foreign social capital among foreign-born scientists (matching the bottom comparison in Table 4.10). For such a purpose, the "social capital" model is constructed with a _US PhD_ as an independent variable and without a _foreign origin_ variable because the regression is estimated in the foreign-born sample. The second regression estimates the impact of foreign origin on the amount of foreign social capital among scientists with a US education (matching the left comparison in Table 4.10). The model includes _foreign origin_ as an independent variable and excludes a _US PhD_ as the regression is executed in a sub-sample of US-educated scientists. Finally, the third regression compares foreign-born scientists with foreign education to US-born scientists with a US degree (matching the right comparison in Table 4.10). The coefficient of the dependent variable _foreign origin_ indicates the expected variance between two groups and the _US PhD_ variable is excluded because it represents the same division of groups.

Results of the regression analysis reveal that only foreign-born scientists with a foreign education account for significantly more foreign professional ties (Table 4.11). Individuals with a US education have a similar number of foreign ties regardless of their origin (Table 4.11, the second model). Foreigners with a foreign education differ, for they have significantly larger foreign professional networks than foreigners with a US education (Table 4.11, the first model) and as a result, they have significantly larger foreign networks than their US-born counterparts (Table 4.11, the third model).

Table 4.11 Regressions of the foreign professional network size on foreign origin and US doctoral education in several populations

	Foreign professional network size								
	Among foreign-born scientists			Among scientists with US education			Foreign-born with foreign education vs. US-born with US PhD		
	coef.	**(se)**		**coef.**	**(se)**		**coef**	**(se)**	
Foreign origin				**.03**	**(.05)**		**.83**	**(.07)**	***
Female	-.14	(.08)	.	-.10	(.05)	*	-.03	(.06)	
Sociability	.18	(.09)	.	.10	(.05)	*	.12	(.06)	*
Professional context									
Career length	.00	(.01)		.02	(.01)	*	.02	(.01)	.
Career length^2	.00	(.00)		.00	(.00)	.	.00	(.00)	
Research hours weekly	.01	(.00)	*	.01	(.00)	***	.01	(.00)	***
US PhD	**-.78**	**(.09)**	***						
Postdoctoral experience	.02	(.09)		.24	(.05)	***	.22	(.07)	**
Research extensive	.10	(.08)		.12	(.05)	*	.06	(.06)	
Field									
Biology	-.03	(.11)		-.21	(.07)	**	-.16	(.08)	.
Biochemistry	-.24	(.13)	.	-.32	(.08)	***	-.24	(.09)	**
Civil engineering	-.43	(.10)	***	-.31	(.06)	***	-.24	(.09)	**
(intercept)	.71	(.32)	*	-.22	(.18)		-.28	(.21)	

*Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1*

Statistically, however, foreign-born scientists still appear to have, on average, more foreign ties and resources than US-born scientists. Foreigners with a US education have about the same foreign social capital as US-born scientists and foreigners with a foreign education have more foreign ties and resources, which increases the mean value of the foreign-born population. Similar regressions were also performed on the number of foreign research-related network resources. The results, provided in Appendix E, exhibit similar trends.

When looking closer at domestic networks, foreign-born scientists, regardless of the location of their education, have a higher proportion of instrumental ties within their own institutions (Table 4.12). Foreign-born, foreign-educated scientists have more than half of the ties that provide research-related resources within their own universities, and about 40% of such ties within their own departments. These proportions are significantly higher than they are among scientists, both foreign- and US-born, with a US education. While US-educated foreigners have comparably more ties outside their institution than foreign-educated foreigners, a considerable proportion of their ties that provide research-related resources are still within their own departments. Moreover, around 30% of the closest research collaborators of both groups of foreign-born scientists, compared with 26% of American scientists, are at the same universities.

The findings indicate a disadvantage for foreign-born scientists with a US doctoral education. They do not develop as many international ties as their local colleagues, and their domestic social capital is smaller than that of US-born scientists. The statistics (Table 4.10) and regression analysis (Appendix E) of the three groups reveal that US doctoral training does not increase the number of domestic professional ties nor the number of domestic research-related resources. Regardless of their education, foreigners have a similar number of domestic ties and resources, but they have significantly fewer than US-born scientists. At the same time, foreign-born scientists with a foreign education also have small domestic networks, but their international networks are larger than those of both other groups. US-born scientists are better off. Even though they have the same number of foreign ties as their foreign-born, US-educated counterparts, their domestic networks are better developed.

Table 4.12 Weighted comparison of the proportion of domestic ties within the institution by the origin and the education of faculty

	diff. v/s FB/US PhD	(t-stat)	**US-born population** (n=939) mean	(sd)	diff. v/s FB/f.PhD	(t-stat)
% of ties that provide research-related resources within the university	=	*(0.14)*	46.8%	(0.24)	<	(-2.88)
within the department	>	*(2.84)*	*32.2%*	*(0.23)*	<	*(-3.95)*
% of the closest research collaborators within the university	>	*(2.73)*	26.3%	(0.21)	<	(-2.42)

Foreign-born population	**With US PhD** (n=557) mean	(sd)	diff.	(t-stat)	**With foreign PhD** (n=221) mean	(sd)
% of ties that provide resrch-rel. res. within univ.	47.0%	(0.27)	<	*(-2.68)*	52.5%	(0.28)
within the department	*35.6%*	*(0.27)*	<	*(-2.00)*	*39.4%*	*(0.26)*
% of the closest res. collab. within the univ.	29.1%	(0.24)	=	*(-0.70)*	30.4%	(0.25)

4.4. Social capital impact on the research productivity of foreign-born scientists

After identifying the differences between foreign- and US-born scientists regarding various professional social capital attributes, the analysis turns to testing the hypotheses pertaining to the impact of such social capital differences on the research productivity of foreign-born scientists. To provide some context, this study presents a descriptive analysis that compares several publication productivity measures of foreign- and US-born scientists in Table 4.13. The analysis shows that foreign-born scientists tend to publish more articles than US-born scientists, approximately one per year. Moreover, the higher research productivity of foreign scientists in the US extends beyond articles in peer-reviewed journals. Some productivity variations among disciplines and types of research outputs occur.

Table 4.13 Weighted comparison of foreign- and US-born scientists' research productivity

	Foreign-born		**US-born**			
	mean	(sd)	mean	(sd)	diff.	(t-stat)
Average publications/year (over last 5y)	4.12	(5.66)	3.14	(3.97)	>	(4.54)
Average publications/year, by field:						
Biology	4.23	(6.24)	3.26	(3.78)	>	(2.47)
Biochemistry	5.02	(7.38)	4.34	(5.53)	=	(0.74)
Civil engineering	5.53	(7.45)	3.22	(3.98)	>	(3.62)
Mathematics	3.26	(3.33)	2.28	(3.21)	>	(3.80)
Produced in last 2 years, by type:						
Journal articles	8.28	(13.32)	5.50	(7.94)	>	(6.00)
Conference proceedings	3.73	(7.15)	1.55	(2.82)	>	(8.23)
Conference presentations	5.40	(10.39)	2.68	(4.14)	>	(7.48)
Book chapters	1.24	(2.54)	1.05	(2.07)	>=*	(1.66)

** ">=": difference significant at a=0.10 level*

Regarding disciplines, while foreign engineers and mathematicians are considerably more productive than their US-born colleagues, the productivity difference between the two groups is smaller in other disciplines. In biochemistry, for example, the productivity difference between foreign- and US-born scientists is not statistically significant. In biology, foreigners are significantly more productive than their US-born colleagues, but the difference between the mean productivity of both populations is statistically smaller than that between the two populations in either engineering or mathematics. Regarding types of research outputs, besides publishing more journal articles, foreign-born scientists in STEM fields produce more conference proceedings and presentations than US-born scientists. However, both populations are very similar in the number of book chapters written in the last two years.

4.4.1. Impact of foreign social capital on the publication productivity of foreign-born scientists

The Hypothesis 4 suggests that the research productivity of foreign-born scientists is positively impacted by the higher proportion of ties and foreign research-related resources in professional networks; that is, foreigners with a higher proportion of foreign social capital are more productive than foreigners with lower proportion of social capital. To test the hypothesis, this study constructs two regressions in the foreign-born population. The first regresses the publication count on the proportion of foreign ties and the second does so on the proportion of foreign resources (Table 4.14). Regressions are controlled for the size of professional networks and number of resources. Such a design allows testing if scientists with more internationally oriented social capital have higher productivity than other scientists with a comparable number of resources.

Table 4.14 Regression of foreigners' publication productivity on the proportions of foreign ties and foreign research-related resources

	log(publication count/year)					
	impact of foreign ties			impact of foreign resources		
	coef.	**(se)**	**sign.**	**coef.**	**(se)**	**sign.**
% of foreign ties	**.005**	**(.265)**				
Professional network size	.103	(.053)	.			
% of foreign research-related netw. resources				**.096**	**(.174)**	
Number of research-related network resources				.020	(.010)	*
Female	-.233	(.074)	**	-.199	(.069)	**
Professional context						
Career length	.003	(.015)		.007	(.013)	
Career length^2	.000	(.000)		.000	(.000)	
Research hours weekly	.012	(.003)	***	.011	(.003)	**
US PhD	-.050	(.099)		-.086	(.084)	
Postdoctoral experience	.031	(.107)		.093	(.092)	
Research extensive	-.072	(.089)		-.014	(.078)	
Field						
Biology	-.132	(.119)		-.126	(.112)	
Biochemistry	-.200	(.124)		-.151	(.106)	
Civil engineering	.306	(.100)	**	.214	(.106)	*
(intercept)	.560	(.368)		.900	(.214)	***

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1
Regression estimated in foreign-born population.
GMM instrumental variable regression, sociability used to instrument professional network size and number of research-related network resources

The regression analysis does not support Hypothesis 4: that higher foreign orientation of research-related social capital positively affects the publication productivity of foreign-born scientists. Foreigners with a higher proportion of international ties and resources do not have higher expected productivity than other foreigners with a comparable number of research-related network resources. Moreover, the analysis emphasizes the importance of social capital size for foreign-born scientists; that is, having more professional ties and more research-related resources positively impacts publication count for foreign-born scientists. Among other factors, the regression results show that being male and spending more time on research activities have a significant positive impact on research productivity. In addition, publication productivity variances among disciplines occur, with civil engineering having a significantly higher publication rate than mathematics (used as references in the models).

4.4.2. Mitigating effect of the social capital attributes

The analysis concludes by testing if the unique social capital characteristics of foreign-born scientists could help mitigate the negative impact of their smaller professional networks on the productivity. Hypothesis 5 suggests that the higher resource multiplexity of ties and the larger proportion of foreign ties and foreign research-related resources in networks have such a positive effect. To fully understand the impact and to test the hypothesis, this study constructs four regression models to test if social capital attributes mediate the impact of foreign origin on scientists' publication productivity (Table 4.15).

The first regression model tests the impact of foreign origin on publication productivity when social capital attributes are not taken into account. Foreign origin of the scientist significantly increases the expected average number of publications per year, by 17% (Table 4.15, the first model). However, this percentage is smaller than statistical productivity difference between foreign- and US-born scientists, 31% (Table 4.13). The actual higher productivity difference could be a combination of foreign origin and other factors associated with foreign-born scientists: being younger, predominantly male, more employment at

Table 4.15 Regression of publication productivity on foreign origin with and without controlling for social capital variables

	log(publication count/year)											
	Model without network size			Model with network size			Model with number of research-related resources			Model with number of research-related resources and % of foreign resources		
	coef.	**(se)**	**sign.**	**coef.**	**(se)**	**sign.**	**coef.**	**(se)**	**sign.**	**coef.**	**(se)**	**sign.**
Foreign origin	**0.159**	**(0.047)**	***	**0.331**	**(0.105)**	**	**0.189**	**(0.055)**	***	**.163**	**(.055)**	**
Professional network size				0.084	(0.037)	*						
Number of research-related network resources							0.018	(0.008)	*	.016	(.007)	*
% of foreign research-related network resources										.315	(.135)	*
Female	-0.158	(0.042)	***	-0.196	(0.047)	***	-0.160	(0.044)	***	-.169	(.044)	***
Professional context												
Career length	0.024	(0.007)	***	0.014	(0.009)		0.024	(0.007)	***	.021	(.007)	**
Career length^2	-0.000	(0.000)	*	-0.000	(0.000)		-0.000	(0.000)	*	.000	(.000)	
Research hours weekly	0.020	(0.002)	***	0.018	(0.002)	***	0.017	(0.002)	***	.017	(.002)	***
US PhD	-0.050	(0.070)		-0.034	(0.081)		-0.069	(0.074)		-.058	(.075)	
Postdoctoral experience	0.066	(0.051)		0.033	(0.068)		0.083	(0.057)		.074	(.057)	
Research extensive	0.125	(0.045)	**	0.088	(0.053)		0.125	(0.049)	*	.101	(.050)	*
Field												
Biology	-0.039	(0.059)		-0.141	(0.079)	.	-0.152	(0.076)	*	-.113	(.075)	
Biochemistry	-0.030	(0.067)		-0.112	(0.079)		-0.117	(0.074)		-.081	(.076)	
Civil engineering	0.191	(0.057)	***	0.145	(0.072)	*	0.093	(0.077)		.139	(.076)	.
(intercept)	0.697	(0.123)	***	0.095	(0.309)		0.456	(0.175)	**	.467	(.177)	**

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

OLS estimation without professional network size, GMM instrumental variable estimation with professional network size and number of research-related network resources. Sociability used to instrument professional network size and number of research-related network resources research-extensive institutions, and spending significantly more hours on research. Such differences between populations were demonstrated in Chapter 3.1.3, and the regression model indicates that their presence has a significant positive impact on the publication productivity of scientists.

The second model confirms the negative impact of smaller networks on the research productivity of foreign-born scientists. After controlling for professional network size, the expected positive impact of foreign origin on publication productivity increases from 17% to 39% (Table 4.15, the second model). Such a result indicates that foreign-born scientists are almost 40% more productive than US-born scientists with professional networks of comparable sizes. However, their smaller professional networks negatively impact foreigners' performance, and their observed productivity is only by 17% higher than productivity of US-born scientists.

The amount of received research-related resources mitigates the negative effect of foreigners' smaller professional networks. While the higher strength and multiplexity of professional ties could not be confirmed for foreign-born scientists (see Chapter 4.2), more strategic tie selection, in fact, does create some mitigating effect. As observable in the basic statistics of foreign-born scientists' social capital, while the professional networks of foreign-born scientists have 24% fewer ties than those of their US counterparts (Table 4.1, Chapter 4.1), foreigners receive only 16% fewer research-related network resources than domestic scientists (Table 4.2, Chapter 4.1).

The regression analysis further confirms that smaller difference between the numbers of research-related network resources of foreign- and US-born scientists helps the former alleviate the negative impact of smaller professional networks, and it partially explains their publication productivity. When the regression model is estimated using the number of research-related network resources instead of the size of professional networks, the impact of foreign origin on publication productivity diminishes to 21% (Table 4.15, 3rd model). This finding indicates that foreign-born scientists are 39% more productive than US-born scientists with professional networks of similar size, but only 21% more productive than US-born with a similar number of research-related network resources.

Results of the last regression indicate that the greater foreign orientation of research-related social capital further slightly mitigates the impact of smaller professional network sizes of foreign-born scientists (Table 4.15, the fifth model). When both the number of research-related resources and the foreign orientation of social capital are taken into account, foreigners are only 18.5% more productive than US-born scientists with comparable social capital resources. The last difference is comparable to the 17% premium between both groups of scientists when their social capital is not taken into account, nearly eliminating the negative impact of smaller professional networks on foreign-born scientists.

4.5. Summary of findings

The purpose of this dissertation was to identify and explain the effects of foreign origin on the composition of scientists' social capital and through social capital, explain variances of research productivity. It tested five hypotheses, three of which addressed the impact of origin on the size of professional networks, the strength and multiplexity of ties, and the geographic location of social capital. The last two hypotheses addressed the impact of foreign social capital on the research productivity of foreigners and determined if the unique characteristics of foreigners' social capital alleviated the negative productivity effect of smaller networks. Overall, the results showed a mix of support for these expected relationships (Table 4.16) and found a significant impact of foreign origin on the professional social capital of scientists and the implications of such differences on productivity.

This study found that the measures of the social capital size of foreign-born scientists are smaller than those of US-born scientists. They have a significantly smaller number of ties in professional networks than their US-born counterparts. The regression analysis supports Hypothesis 1: that this difference is based on foreign origin and not other factors associated with foreign-born scientists. It is worth mentioning that both populations exhibit the greatest statistical difference in their sizes of teaching networks. However, they differ to a lesser extent in their number of ties that are more closely related to research activities.

The two hypotheses related to the establishment of stronger ties in foreign-born scientists' professional networks and their receiving more resources per tie were partially supported. Hypotheses 2A, related to stronger ties in the professional networks of foreign-born scientists, was rejected. The ties of foreigners have similar multiplexity and higher longevity, but smaller interaction and friendship measures than those of US-born faculty. At the same time, Hypothesis 2B was confirmed: Foreign-born scientists receive more research-related resources per tie in their professional networks. However, such an advantage is achieved by more selective development of relationships with individuals who provide support for research activities rather than by relational properties. By receiving more research-related resources per tie in their professional networks, foreign-born scientists are able close the gap between the number of research-related network resources of both populations. Moreover, the resource-level analysis indicated that foreign-born scientists differed only slightly from their US-born colleagues regarding the number of network resources that were directly related to preparing publications.

Hypothesis 3, which addressed whether there are more foreign ties and resources in the professional networks of foreign-born scientists, was partially supported. Statistically, foreign-born scientists have significantly more foreign professional ties and foreign research-related resources. However, a more in-depth analysis revealed that a larger number of foreign ties and resources was not explained by the origin of a scientist, but rather by their place of education.

Regardless of their origin, the numbers of foreign ties and resources were similar among scientists with US degrees. Only foreigners with a foreign education had larger foreign social capital than both foreigners and US-born scientists with a US education.

Having found significant differences between the social capital attributes of foreign- and US-born scientists, the analysis proceeded to determine the potential impact of such differences on publication productivity. Hypothesis 4, which posited that foreign ties and resources have a positive impact on the research productivity of foreign-born scientists, was not supported by the analysis. The higher prevalence of foreign social capital had no positive impact on the research productivity of foreign-born scientists. For these scientists, the overall number of relationships and the number of research-related resources were significant predictors for higher publication productivity, but the geographic locations of ties and resources were not important. Thus, the number of received network resources, not the location, was important.

Hypothesis 5, which posited that receiving more research-related resources per professional tie and having more international social capital alleviate the negative impact of smaller networks, was supported. The analysis found foreign-born scientists to be more productive than US-born scientists in a broad range of research outputs. Moreover, the analysis found that smaller networks potentially have a negative impact on the research of foreign-born scientists and that their unique social capital alleviates deficiencies. Receiving more research-related resources per tie narrowed the difference between the numbers of network resources of both populations. The regression analysis also found that this factor greatly minimizes the negative impact of smaller networks on foreigners' productivity. Having a larger proportion of foreign resources further slightly improved the negative effect of a smaller network size on productivity. However, the effect may have been the result of the favorable impact of foreign social capital on the productivity of the US-born population. Altogether, the unique characteristics of foreigners' social capital almost fully compensate for the disadvantage of their smaller professional networks. These results are presented in this next chapter.

Table 4.16 Summary of the results of the hypothesis tests

	Hypothesis	Supported	Specific results
H1	Foreign-born scientists will have smaller professional networks than do US-born scientists.	YES	Foreign origin has a negative impact on the size of a scientist's professional network.
H2A	The professional social network ties of foreign-born scientists will be stronger than those of US-born scientists.	NO	Foreign origin does not have a positive impact of tie strength measures. It has a positive impact on tie length, no impact on tie multiplexity, and a negative impact on both interaction frequency and friendship.
H2B	The professional networks of foreign-born scientists provide more research-related resources per tie than those of US-born scientists.	PAR-TIALLY	Foreign-born scientists receive more research-related resources per professional network tie that US-born scientists. This finding is the results of a higher proportion of ties in foreigners' professional networks, which provide research-related resources. The resource multiplexity of such ties in both populations does not differ.
H3	Foreign-born scientists have larger foreign professional networks and more foreign research-related resources than US-born scientists.	PAR-TIALLY	The hypothesis is verified in a comparison between foreign- and US-born populations. However, foreign-born scientists with a US doctoral education have foreign social capital similar to that of US-born scientists. Foreign-born, foreign-educated scientists make the difference because they have considerably more foreign ties and resources.
H4	A higher proportion of foreign ties and foreign research-related resources positively impacts the research productivity of foreign-born scientists.	NO	The higher proportion of foreign ties and research-related support does not impact research productivity of the foreign-born population. The amount of received resources, not the location of such resources, is important.
H5	A larger number of research-related resources received per professional network tie and a larger proportion of foreign ties and foreign research-related resources in networks will mitigate the negative impact of smaller professional networks on research productivity of foreign-born scientists.	YES	Foreign origin has a positive impact on scientist's publication productivity. Moreover, the impact of foreign origin on productivity is even higher when network size is controlled for. Thus, smaller networks negatively affect foreigners' productivity. However, the different social capital attributes mitigate the negative impact. The strongest reduction is the result of their receiving more research-related resources per professional network tie and further alleviated by the higher proportion of foreign social capital. Both differences almost fully eliminate the negative impact of the smaller professional networks of foreign-born scientists on their publication productivity.

5. FINDINGS, CONCLUSIONS, AND IMPLICATIONS

The purpose of this dissertation is to address the paradox of how foreign-born faculty are able to have consistently high rates of research productivity (Corley & Sabharwal, 2007; Stephan & Levin, 2001b) even though they constantly report difficulties establishing professional relationships (Collins, 2008; Foote et al., 2008; Skachkova, 2007). Such an observation appears to contradict social capital theory that associates the possession of social capital with positive productivity outcomes of individuals in general (Adler & Kwon, 2002; N. Lin, 2001), particularly in science (Bozeman & Corley, 2004; Melin, 2000). The dissertation examines whether or not the explanation of this paradox could be related to the differences among the social capital of foreigners discussed in the immigration literature (Nee & Sanders, 2001; Portes, 1995; Ryan et al., 2008). Understanding the unique factors impacting the research productivity of foreign-born scientists has become particularly salient given their increasing presence in US academia, but this topic remains under-researched (Mamiseishvili & Rosser, 2009; Mervis, 2004).

To address the productivity of foreign-born scientists, the dissertation uses the scientific and technical human capital model (Bozeman et al., 2001), which provides a framework within which we can analyze the factors that impact research performance. The dissertation focuses on the productive social capital of scientists and uses findings from the immigration literature to extend the model. Its purpose is to provide a more comprehensive understanding of the unique characteristics of social capital of foreign-born scientists, if they actually exist, determine their implications for research productivity. This chapter presents the findings and an interpretation of the results, along with their implications for theory. Findings are specifically presented for the purpose of expanding the STHC model with regard to the impact of foreign origin on the productive social capital of scientists. The implications of the findings provide a more in-depth understanding of immigrants' social capital, namely, indications of restricted social capital among foreign-born scientists, factors that mitigate the smaller social networks of immigrants, and the differential use of foreign and domestic social capital by immigrants and host populations. Finally, this chapter discusses the implications for policy, limitations of the study, and directions for future research.

5.1. Core findings and extension of the STHC model

The dissertation contributes to the body of knowledge pertaining to the research performance of foreign-born faculty by addressing gaps in the literature. One gap is the uncertainty regarding the difference between the professional social capital of foreign- and US-born scientists. From the findings of this study, the STHC model of research productivity can be amended to include the origin (foreign or native) of a scientist as an important factor impacting the various attributes of scientists' productive social capital. According to foreign-born scientists, they have smaller professional networks; nevertheless, they have a higher number of foreign ties and resources in their social capital and use the ties established within these networks more efficiently. Moreover, the STHC model can also be amended with findings that show how these unique characteristics of social capital impact scientists' productivity.

This work extends the STHC model with the finding that foreign-born scientists have less productive social capital. Compared to US-born scientists, foreigners have smaller professional social networks and fewer research-related network resources. Such results indicate that findings of the immigration literature are relevant also for understanding of scientists' social capital. The results indicate that foreign-born scientists, like other migrants, possess a smaller amount of social capital (Light et al., 1994; Nee & Sanders, 2001; Portes, 1995). Further, they also suggest that factors affecting the social capital of immigrants in general also apply to foreign-born scientists, namely, factors such as the need to rebuild relationships after the migration event (Rogler, 1994) and difficulties establishing ties with the host society because of discrimination, their lack of homophilic attributes, or both (Gold & Light, 2010). Moreover, findings confirm that difficulties establishing ties within the host professional society, previously reported by foreign-born faculty (Bang, 2016; Collins, 2008; Foote et al., 2008; Seagren & Wang, 1994; Skachkova, 2007; Thomas & Johnson, 2004) manifest in their measurably smaller social capital.

The findings of this dissertation also show that foreign-born scientists use their social ties more efficiently than US-born scientists, thus validating that similar tendencies among lower-skilled immigrants (Nee & Sanders, 2001) also apply to scientists. However, the analysis in this work found that the more efficient use of ties by foreign-born scientists is not the result of the same factors as it is by lower-skilled immigrants. The professional ties of foreign-born scientists do not possess higher strength or multiplexity, as typically observed among lower-skilled immigrants, than those of US-born scientists, (Light et al., 1994, 1995; Sanders et al., 2002; Verbrugge, 1979). The findings indicate that foreign-born scientists tend to select relationships more strategically, and, as also observed among scientists in later careers, they maintain the relationships that supply them with resources they need for their primary research activity, research (Fox & Mohapatra, 2007), which reduces costs associated with establishing and maintaining relationships (Fox & Faver, 1984). By receiving more research-related resources per tie, foreign-born scientists largely compensate for their smaller professional networks. As a result, foreign- and US-born scientists differ to a lesser extent regarding the number of research-related resources they receive.

Findings show that the more frequent use of foreign professional social capital cannot be universally assigned to all foreign-born scientists, as was observed among lower-skilled immigrants (Nee & Sanders, 2001; Portes, 1995; Ryan et al., 2008). Such use is evident only among foreigners with foreign education. Prior research suggests that such ties are the result of professional networks they have established before arriving in the US, such as those with former classmates, colleagues, or advisors—ties that they continue to use for accessing resources abroad (Biao, 2005; Borjas, 1994; Fontes, 2007; Meyer, 2001). Moreover, such findings emphasize the important role of educational institutions and early careers in the formation of scientists' professional social capital (Melin, 2000). Moreover, since formation of the STHC is a cumulative process over one's career (Bozeman et al., 2001), migration disrupts this formation; migrants retain old ties and form new ones at a lower rate.

At the same time, the findings suggest that factors associated with foreign origin do not foster the development of international professional social capital because US-educated foreigners do not possess increased levels of foreign social capital. Consequently, the findings cannot confirm that factors previously thought to foster the development of foreign ties (e.g., common ethnicity, migration experience, pressure from small domestic capital, or economic motivations) (Foote et al., 2008; Lee, 2004; Skachkova, 2007; Toren, 1994) are sufficient for overcoming the costs associated with establishing and maintaining relationships with geographically distant or different scientific communities (Agrawal et al., 2006; Haas & Cummings, 2015; Ponds et al., 2007).

According to the findings, the positive impact of foreign professional social capital on productivity does not apply to all scientists, suggested in the literature (Agrawal et al., 2006; Glänzel, 2001; Katz & Martin, 1997; Melkers & Kiopa, 2010). Larger foreign social capital does not bring additional productivity advantage to foreign-born scientists. However, evidence suggests that social capital ties allow them to substitute their reduced domestic social capital with foreign resources, consistent with observations of lower-skilled immigrants (Nee & Sanders, 2001).

Altogether, the findings provide some insight into the productivity paradox of foreign-born scientists and do not conflict with social capital theory. Smaller professional network size, indeed, decreases the productivity of foreign-born scientists, as predicted by the network theory of social capital (N. Lin, 2001) and also observed in science (Lee & Bozeman, 2005). However, the negative impact of smaller social networks on scientists' productivity is mitigated by their unique characteristics of professional social capital. Foreign-born scientists reduce the largest proportion of the negative impact by receiving more research-related resources per professional network tie. Such a finding confirms the network theory of social capital that states that resources acquired through social connections, rather than the relationships themselves, impact productivity (N. Lin, 2001). In addition, possessing larger foreign social capital slightly reduces the negative impact. The findings also confirm that the higher productivity of foreign-born scientists is related to their gender and age, their employment at larger research institutions, and their greater amount of time devoted to research activities (Corley & Sabharwal, 2007; Kim et al., 2011). As in prior studies, this dissertation, after controlling for the effects of social capital, is not yet able to explain fully the higher productivity of foreign-born scientists.

5.2. Theoretical contributions

Besides answering the research questions and extending the STHC model, this dissertation further contributes to the discussion related to whether foreign-born scientists have sufficient professional capital because of their highly exportable human capital (Ackers & Gill, 2008). Moreover, it contributes to the broader immigration literature insights into how the unique characteristics of social capital help immigrants mitigate their reduced number of social connections. Finally, the findings present finer arguments that add to the discussion about the use and the impact of “foreign” social capital on the productivity of various populations.

5.2.1. Indications of restricted social capital among foreign-born scientists

The dissertation provides some insight into the discussion about whether the highly exportable human capital of foreign-born scientists facilitate their establishment of useful social ties (Ackers & Gill, 2008). From one perspective, Ackers and Gill concluded that the social capital of immigrant scientists is predominately shaped by professional opportunities and that they do not suffer the severe limitations typically faced by lower-skilled migrants. From another perspective, however, the real-life experiences of skilled immigrants, including scientists, reveal difficulties establishing social and professional relationships and the limited nature of their social capital (Beaverstock, 2002; Collins, 2008; Kwankam, 2010; Scott, 2006).

The findings provide evidence that although foreign-born scientists are highly-skilled immigrants, their access to social capital remains restricted.

Difficulty establishing social ties, previously revealed in interviews, manifests in the measurable, unique characteristics of social capital resembling those observed among lower-skilled immigrants, that is, smaller networks and fewer network resources, geographically restricted domestic networks, more efficient use of ties, and use of international connections.

With regard to the social networks of all migrants and US-born scientists, the findings indicate that similar to lower-skilled immigrants, foreign-born scientists have significantly smaller professional networks and receive significantly fewer network resources than their US counterparts. Such findings are in line with the experiences of lower-skilled immigrants; that is, they mention their smaller social networks as a significant characteristic of their social capital and their struggle with establishing contacts with the local population (Berry, 1997). Moreover, findings provide quantitative support, manifested in their poorer social capital, of the struggle often mentioned in interviews with foreign-born scientists, who find establishing professional connections difficult (Ackers & Gill, 2008; Seagren & Wang, 1994; Tejada & Bolay, 2010).

Foreign-born scientists exhibit another social capital characteristic typically exhibited by lower-skilled migrants: reliance on social circles established in close proximity to where they live and work (Rogler, 1994). Lower-skilled immigrants often rely on individuals in their neighborhoods, ethnic social circles, or workplaces because of their limited access to the domestic society and difficulty establishing social relationships (Nee & Sanders, 2001). A high proportion of foreign-born scientists' domestic professional ties are also in geographically close proximity within their university and even within their departments Especially important is the finding that the tendency of using geographically restricted networks is pronounced among foreign-born, foreign-educated faculty, indicating their weak integration with the US scientific system.

Another characteristic migrants share is their more efficient use of ties for acquiring needed resources. Because of smaller social networks, lower-skilled immigrants use a small number of strong ties very intensively (Nee & Sanders, 2001). Such intensive use of ties is also observable among foreign-born scientists, and they acquire a larger number of different kinds of resources from their professional ties than US-born scientists. Evidence suggests that unlike lower-skilled migrants, foreign-born scientists are not forced to use their ties more intensively (Light et al., 1994) and their professional relationships do not exhibit higher strength or multiplexity measures. Instead, confronted by difficulty establishing relationships, they choose to maintain a limited number of the most valuable ties, such as those with peers who help with their research, their primary activity (Fox & Faver, 1984) (Fox & Mohapatra, 2007). Such composition of their social capital reflects that they face higher cost of establishing and maintaining social connections and manage them by being selective of relationships. By contrast, lower-skilled immigrants, who face overwhelming limitations in establishing new relationships, must use their sparse networks more intensively.

Like other migrants, foreign-born scientists also maintain more foreign ties, potentially signaling their weak integration in the host country (Portes, 1995; Ryan et al., 2008). Although prior studies have reported that these migrants access their home countries for needed resources (Biao, 2005; Meyer et al., 2003; Séguin et al., 2006), findings of the dissertation indicate that this group of scientists do not establish foreign ties because of their economic advantage and that such ties do not increase their productivity. Instead, such ties serve as substitutes for the lack of domestic social capital resulting from weak integration of foreign-born scientists into the scientific community of the host country.

5.2.2. Factors mitigating immigrants' smaller social networks

The findings demonstrate several ways in which foreign-born scientists mitigate the negative impact of smaller professional networks on productivity, which contributes to the general understanding of the aspects of immigrants' social capital as it relates to productivity. The immigration literature shows that the social capital of immigrants has unique attributes that result from difficulties with establishing social relationships (Portes, 1995). Furthermore, the literature argues that despite these difficulties, such social capital characteristics help migrants access the support that they need (Nee & Sanders, 2001; Rogler, 1994). This dissertation contributes to the discussion by providing evidence for how unique social capital attributes impact the productivity of foreign-born scientists and explaining how the mechanisms for compensating for smaller networks could work for immigrants in general.

The dissertation findings confirm prior assumptions in the immigration literature that the more intensive use of social networks helps migrants to compensate for the smaller sizes of the networks (Nee & Sanders, 2001). Because of their more efficient use of networks, foreign-born scientists have only 16% fewer research-related resources than US-born scientists despite their 24% smaller networks. Moreover, the findings further emphasize that scientists tailor their professional relationships to their primary activity (Fox & Mohapatra, 2007). As a result. the more efficient use of professional networks accounts for 18% of the productivity premium of foreign-born scientists, reducing the unexplained difference in their productivity from 39% to 21%. Such a finding demonstrates that their more efficient use of networks, a dominant strategy of migrants (Light et al., 1994; Rogler, 1994), is instrumental for increasing productivity regardless of restricted social capital.

Despite the findings of prior studies that show that migrants use foreign ties to access necessary social and economic resources (Portes, 1995; Ryan et al., 2008), this dissertation finds that the explanation for the impact of foreign social capital on the productivity of foreign-born scientists is more complex. For one, the findings do not support the hypothesis that foreign origin helps scientists develop more foreign professional ties. Previously hypothesized factors such as lack of domestic ties (Nee & Sanders, 2001; Saxenian, 2005), common ethnicity (Foote et al., 2008), shared migration experience (Ryan et al., 2008), and readiness to collaborate internationally (Skachkova, 2007) have not been found to be sufficient initiators of new international relationships.

The findings also do not support the assumption that possessing foreign social capital provides an advantage to foreign-born scientists. Scientists who arrive in the US at later stages of their professional careers appear to have a larger number of international ties, indicating that their foreign professional networks developed before they arrived (Biao, 2005; Borjas, 1994; Fontes, 2007). While prior research argues that foreign ties provide scientists with necessary resources and students, collaborators, or access to infrastructure and knowledge (Biao, 2005; Tejada, 2010), the findings of this dissertation suggest that these resources serve as an alternative source of resources that compensate for difficult access to resources in the host country. In the context of the general migration literature such results suggest that the foreign social capital of immigrants predominantly consists of relationships developed before migration, and they could be used it as a substitute for the shortage of domestic support.

5.2.3. Use of "foreign" social capital in different populations

Finally, the dissertation recommends a reassessment of the assumptions made by prior studies: one, that the presence and the higher number of foreign professional relationships to higher research performance and quality (Glänzel, 2001; Katz & Martin, 1997) and another, that the higher quantity, quality, and diversity of resources are accessible through such relationships (Agrawal et al., 2006; Cross & Cummings, 2004; Katz & Martin, 1997; Melkers & Kiopa, 2010).

The findings show that the way in which foreign-born scientists use “foreign” and “domestic” ties distinctly differs from the way in which US-born scientists use them. Moreover, the impacts that such ties have on the research productivity of both populations also differ.

The dissertation finds that foreign-born scientists use foreign ties less intensively than US-born scientists. In addition, the sizes of the foreign professional networks of both populations differ significantly, but the number of resources they acquire from abroad differs to a lesser extent. While the foreign ties of Americans provide mostly research-related resources, those of foreigners provide wider set of resources that go beyond those of research. The opposite is observable in domestic ties.

Differing costs of establishing and maintaining social relationships serve as a potential explanation for differences between both populations in their use of foreign (and domestic) ties. The costs associated with establishing geographically distant ties are well described in the literature and include various languages and cultures, institutional settings, academic backgrounds, research approaches, methods, and topics, work cultures, and the technical difficulties of long-distance communication (Agrawal et al., 2006; Katz & Martin, 1997). Because of increasing costs of maintaining distant ties, individuals have become more selective in their relationships and maintain only those that provide more of the resources they value (Burt, 2005; Ponds et al., 2007)

For US-born scientists, foreign ties do mean higher costs than domestic ties and evidence suggests higher efficiency of foreign tie use among US-born scientists. The foreign ties for foreign-born scientists often are actually not "foreign" at all (Haas & Cummings, 2015) because they comprise former colleagues or classmates (Foote et al., 2008) and representatives of the same nationality (Biao, 2005). Communication with them has lower costs for foreigners and, as a consequence, foreign tie use has lower efficiency among foreign-born scientists. Moreover, the differing costs and efficiency of foreign-tie use are related to differing productivity impact of the foreign ties of foreign- and US-born populations. Observations of US-born scientists follow those of prior research that show that having a higher number of foreign professional relationships positively impacts productivity (Agrawal et al., 2006; Cross & Cummings, 2004). Nevertheless, among foreign-born scientists, this finding does not hold true.

As a result, the mere presence or number of particular ties does not lead to accurate interpretation because populations (in this case, foreign- and US-born scientists) differ in their use of "foreign" and "domestic" ties, with productivity implications. Therefore, using "foreign ties" as an explanation for the characteristics of social capital or for publication performance could lead to ecological fallacy and misinterpretation of their actual impact.

Finally, issues pertaining to "foreign" and "domestic" ties highlight a more fundamental problem with using network size as a proxy for the number of social capital resources. Network size does not capture how intensively individuals use their networks. The analysis revealed that the number of network resources individuals receive from similar-sized networks depends on their individual or professional characteristics. More sociable individuals receive more resources per tie, foreigners receive more from all ties, and Americans receive more from international ties. In such a way, particular demographic groups efficiently compensate for their lower number of ties. Such finding questions the basic assumption in the network theory of social capital that states that social ties provide resources, and resources help to achieve greater outcomes from actions (N. Lin, 2001) and methodological applications suggesting network size as a proxy for resources (Borgatti et al., 1998). It also questions a similar approach in studies of research productivity that use the number of research collaborators as explanations (Bozeman et al., 2001; Katz & Martin, 1997; Melin, 2000). As the findings suggest, the number of ties may not provide information about the actual number of network resources that a particular group receives, which could result in misleading inferences about the impact of ties on individual performance.

5.3. Policy implications

The two findings of this dissertation raise major implications for US science and higher education policies. First, they indicate the insufficient integration of foreign-born PhD students into the US scientific community and second, the limited use of foreign-born scientists as potential bridges to foreign scientific communities. The findings also suggest a broader issue: that foreign-born scientists are weakly integrated into the host society and poorly connected to the US scientific community, which could have negative consequences for their individual performance and for the whole US science system, which loses their great potential. Finally, findings of the dissertation suggest that host and sending countries can use knowledge about specific social capital characteristics of foreign-born scientists to develop more efficient diaspora policies.

To alleviate such consequences, the scientific community must attend to the needs of foreign-born students at the US graduate schools. As the findings of this dissertation have shown, foreign-born individuals have weaker social capital than other groups. Graduate studies is a time when students integrate in the scientific community and form their strongest professional ties for future careers (Melin, 2000), but evidence suggests that foreign-born graduate students miss opportunities to integrate, and they do not develop sufficient ties within the US scientific community. They possess the same amount of domestic professional social capital as other foreigners, but it is significantly less than their US-born counterparts. Moreover, the US graduate education system seems to provide both foreign- and US-born doctoral students with similar opportunities for international collaboration and the establishment of foreign relationships. As a result foreign-born students do not leverage their shortfall of domestic ties by developing access to professionals and resources abroad, developing just as many foreign ties as do graduate students born in the US.

Another major issue elucidated in this dissertation is the insufficient integration of foreign-born scientists with foreign doctoral degrees into the broader US scientific community. The findings show that scientists who arrive at the US at later stages of their professional careers possess very limited domestic professional networks, most of which are limited to the institutions in which they work and comprised of peers and collaborators who also work in the same institution or department. As a result, only institutions in which foreigners are employed benefit from access to external knowledge through foreign-born scientists which ultimately curtails opportunities of other institutions. This dissertation suggests that if these scientists are properly integrated into the broader US scientific community, they could serve as structural “bridges” (Burt, 2001), providing American science with access to other science systems (Jackson, 2003; Matthews, 2010). Evidence supports that they have significantly better developed foreign networks than other scientists, and studies have emphasized that the US scientific community, by promoting international connections, could bring in new ideas and approaches and gain access to foreign technologies and resources and a skilled and cost-efficient workforce (Biao, 2005; Fontes, 2007; Tejada, 2010). However, because of the restricted domestic networks of foreign-born scientists, such resources are not yet accessible to the broader scientific community, only to receiving institutions.

Overall, the dissertation suggests an increasing awareness of the social integration of foreign-born graduate students and scientists in the American scientific system. The immigration literature indicates that lack of integration significantly reduces the potential performance of immigrants (Matthews, 2010;

Nee & Sanders, 2001). Moreover, if integration issues are not addressed, “ethnic economies,” or professional ethnic enclaves, will develop (if they have not already done so) within American science, further reducing quality and productivity. Although ethnic economies could help foreign-born scientists improve their wellbeing and satisfaction (Bokek-Cohen & Davidovitch, 2010), the immigration literature emphasizes that such ethnic enclaves inhibit the integration of these individuals into the host society and suppress their productivity (Light et al., 1995). Similar indications also evident in science demonstrate the negative impact of ethnic collaboration on the quality of research (Freeman & Huang, 2014).

Efforts devoted to enhancing the social integration of foreign-born scientists must occur at the government and institution level via new and improved policies. First, new policies must strengthen the overall measures of current policies by protecting the rights of foreign-born professionals and eliminating discrimination, streamlining immigration procedures, providing access to citizenship, and assuring job and social security (Gahungu, 2011; Lodovici, 2010). Further, institutional policies must incorporate stronger integration measures because findings suggest that foreign-born scientists receive less assistance with developing professional relationships than US-born scientists. US academia must provide foreign-born students with greater opportunities for socialization with the US scientific community and the establishment of professional relationships. In addition, both the government and institutions should establish policies that foster collaboration between foreign-born scientists and others outside of their institutions. For example, they could fund activities that require collaboration of both immigrant and US-born individuals; it has been proven successful integration tool for lower-skilled immigrants (Gold & Light, 2010).

Finally, findings of the dissertation support the current policies of the US and sending countries aimed at mobilization of scientific diasporas and provide suggestions for furtherance of these policies. Current diaspora policies of sending countries are focusing on government support for fostering diaspora mobilization in particular target countries and in general by providing means of community building and networking, and professional support (European Commission, 2016; RASA-USA, 2016; Saraiva, 2016; Serti, 2016). The dissertation finds, these policies could be more efficient if the target audience of assistance is broadened. *Id est*, assistance to development of professional relationships at the host countries should be targeted not only to student diaspora but also to established emigrant scientists. On the other hand, fostering of collaboration between diaspora and research institutions at home countries should actively involve student population abroad. In the light of recent diaspora policies of sending countries and findings of the dissertation, sending countries should further advance policies aimed at activating diaspora organizations (Canadian Science Policy Conference, 2015; US Department of State, 2016). Active diaspora organizations could help foreign-born scientists reduce shortages of their professional capital leading to increased individual performance and international collaboration benefiting the science system of the host country.

5.4. Limitations of the dissertation

While the dissertation has made several contributions to the body of knowledge by elucidating the unique characteristics the professional social capital of foreign-born scientists and implications in their productivity, it also has several limitations. For one, despite their strong roles in immigrants' social capital, the importance of both ethnicity and nationality in the formation of professional relationships remains under-researched. The *Netwise II* dataset used in the analysis in this dissertation does not provide accurate information about the ethnicity or geographic location of individuals in networks of scientists. Without such data, the exact binding mechanism behind the international ties of foreign-born scientists (and US-born scientists) remains unexplored.

The dissertation proposed only one alternative for foreign-born scientists to make up for their smaller professional networks in the US: that they use their prior professional networks in their home countries (Fontes, 2007). However, with exact ethnicity and location data of peers, researchers could explore three other alternatives. Foreigners could establish foreign ties with compatriots internationally using a common language or nationality as a binding factor (Light et al., 1995; Ryan et al., 2008). In such case majority of their peers would share the same ethnicity or nationality as the foreign-born scientist. Another option, they could use their shared migration experience to establish connections with other migrant scientists in other countries (Saxenian, 2005; Skachkova, 2007) and location of peers would not match with their nationality. Finally, foreign-born scientists could establish connections based purely on professional concerns and interests (Ackers & Gill, 2008) and prominence of peer's institutions would be predicting factor rather than nationality or location.

Data about the nationality of peers would also help us understand if immigrant scientists form “ethnic economies,” or enclaves, within the US scientific community, as it has been observed in other groups of immigrants. For example, the prevalence of geographically bounded, closed, and tight social and economic communities with their compatriots is evident among lower-skilled migrants (Borjas, 1994; Light et al., 1994; Nee & Sanders, 2001). Similar ethnic economies, although to a lesser extent, have also been observed in immigrant engineers, entrepreneurs, and other higher-skilled professionals (Harvey, 2008; Saxenian et al., 2002; Scott, 2006). The potential for identifying “ethnic economies” among foreign-born scientists has been revealed in interviews, which suggest that immigrant scientists have formed ethnic migration channels when they work within the same departments as their compatriots (Fontes, 2007; Meyer, 2001). Evidence of the presence of an “ethnic economy” was also revealed in a finding of geographically restricted domestic networks of foreign-born scientists. However, without data on the ethnicities of peers, this topic remains only speculative in nature.

Finally, the findings of this dissertation may not be generalizable to other disciplines of science with a smaller number of foreign-born scientists. This study uses data from scientists in STEM fields that are known to be heavily populated by foreign-born scientists (National Science Foundation, 2016b). However, in other disciplines, the numbers of foreign-born individuals are significantly lower. Such a difference could influence how scientists in other disciplines form social networks. Findings from the immigration literature have suggested that the presence of a diaspora in the host society is shaping the social capital of highly-skilled immigrants (Beaverstock, 2002; Harvey, 2008; Scott, 2006). For example, if the number of co-nationals in a host society is small, ethnic networks do not form, and those could also be absent in disciplines with very few foreign-born scientists. Moreover, as prior research has predominantly focused on individuals in science and engineering, the understanding of foreign-born scientists in other disciplines is very limited (Mamiseishvili, 2013).

5.5. Issues for further research

While the dissertation provides insights into the social capital and the productivity of foreign-born scientists, it raises issues that future research could explore: the applicability of other findings of the immigration literature to foreign-born scientists, the broader range of factors impacting the formation of social capital, and a micro-level analysis of types of ties and their roles in forming social capital.

To begin, the findings have initiated a discussion regarding the extent to which the immigration literature applies to scientists and the extent to which other social, cultural, or economic activities typically carried out by immigrants are observable among foreign-born scientists. This study identified one such aspect - that foreign-born scientists possess several unique social capital characteristics previously observed among lower-skilled immigrants. However, this analysis was limited to available data. As mentioned above, an interesting direction for future research would be to determine the exact binding mechanisms behind the social ties of foreign-born scientists. Are they related to common ethnicity or to economic considerations? Moreover, the significant implications for the policy and the sociology of science could produce evidence through observations of the formation of "ethnic economies" among foreign-born scientists in the US similar to those among lower-skilled immigrants (Gold & Light, 2010).

Another direction of research could conduct a detailed analysis of other factors that potentially impact the social capital of foreign-born scientists. For example, stronger scientific activity of the home country could be linked to the higher prevalence of foreign professional social capital, which could provide access to a wider range and higher quality of resources (Biao, 2005; Harvey, 2008; Tejada & Bolay, 2010). Furthermore, cultural similarity between the host and home countries could have an impact on the composition of foreign-born scientists' professional networks, as such a similarity is related to the success of immigrants' social integration (Beaverstock, 2002; Harvey, 2008; Meyer, 2001;

Scott, 2006). Finally, few researchers have examined how the social capital of foreign-born scientists develops over time despite evidence that the integration process is related to the formation of relationships with the host society (Berry, 1997; Fuertes, Gottdiener, Martin, Gilbert, & Giles, 2012). This last issue has significance for the general immigration literature because of limited research about the development of immigrants' social relationships over time.

This dissertation has also raised questions about foreigners' professional social capital that is related to other aspects of academic productivity and career advancement besides research. The dissertation describes social capital that is closely related to research productivity. However, the findings provide initial indications that foreign-born scientists possess substantially fewer professional ties and resources related to other academic activities. Future research should be directed at examining the differences between the social networks related to the teaching and career advancement of foreign- and US-born populations and if any differences are related to differences between their teaching or service productivity, or advancement.

Finally, this dissertation indicates that the potential for future research in social capital theory will lie in the micro-level analysis of individual ties. This work, like the majority of social capital research, was conducted at the network level. However, it has provided several findings that indicate how distinct attributes of the ego impact the use of a particular type of tie. Such findings suggest the potential for future research to explore the impact of various actor-level attributes (e.g., geographic location) on the development of individual relationships, their properties, and the amount and type of resources provided. Such research could satisfy the need for a deeper understanding of the role of ego-level attributes as modifiers of the various social capital attributes that impact productivity.

APPENDICES

Appendix A. Netwise II survey sampling proportions for each strata.

Appendix table 1. Sampling proportions for each strata.

Population	Type of Institution						
	RE	RI	MS	HBCU	WMN	LA	HSI
Biology							
m.nm	0.059	0.199	0.244	0.851	1	0.971	0.519
m.m	0.428	1	1	1	1	1	1
f.nm	0.174	0.510	0.551	1	1	1	0.962
f.m	1	1	1	1	1	1	1
Biochemistry							
m.nm	0.187	1	1	1	1	1	1
m.m	1	1	1	1	1	1	1
f.nm	0.781	1	1	1	1	1	1
f.m	1	1	1	1	-	1	1
Civil Engineering							
m.nm	0.124	0.552	0.430	1	1	1	1
m.m	0.372	1	1	1	-	1	1
f.nm	0.778	1	1	1	1	1	1
f.m	1	1	1	1	-	1	1
Mathematics							
m.nm	0.053	0.186	0.214	0.873	1	0.727	0.485
m.m	0.323	1	1	1	1	1	1
f.nm	0.379	0.702	0.635	1	-	1	1
f.m	1	1	1	1	1	1	1

Legend:
m.nm - non-minority male, m.m – minority male, f.nm - non-minority female, f.m – minority female
RE – research extensive, RI – research intensive, MS – master's granting, HBCU – Historically black colleges and universities, WMN – women's colleges, LA – "Oberlin 50" baccalaureate colleges, HSI – Hispanic serving institutions.
Source: Netwise II Phase I: 2011 Survey Codebook (Netwise, 2012a)

Appendix B. Tests of functional forms for social capital models

Several forms for regressions of network size are tested: linear, log-linear, negative binomial, and Poisson's.

<u>Linear model</u>

Appendix table 2. Linear model for the regression of professional network size

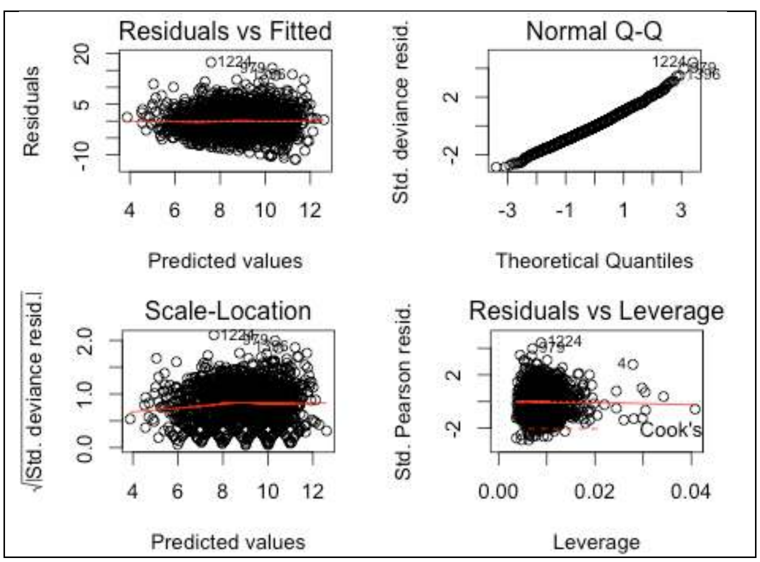
	professional network size		
	coef.	**(se)**	**(rob.se)**
Foreign origin	-2.404	(0.245)	(0.242)
Female	0.392	(0.225)	(0.227)
Sociability	1.147	(0.247)	(0.240)
Professional context			
Career length	0.127	(0.038)	(0.038)
Career length^2	-0.002	(0.001)	(0.001)
Research hours weekly	0.020	(0.008)	(0.008)
US PhD	-0.485	(0.356)	(0.361)
Postdoctoral experience	0.828	(0.266)	(0.264)
Research extensive	0.258	(0.228)	(0.228)
Field			
Biology	1.050	(0.317)	(0.319)
Biochemistry	0.840	(0.363)	(0.364)
Civil engineering	0.697	(0.315)	(0.310)
(intercept)	3.800	(0.941)	(0.925)

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

AIC: 8277.4

RESET = 0.40428, df1 = 2, df2 = 1463, p-value = 0.6675

BP = 37.579, df = 12, p-value = 0.0001799



RESULTS:
Error terms are normally distributed.

The RESET test supports that the model has linear form.

The Breusch-Pagan test upholds the homoscedasticity assumption.

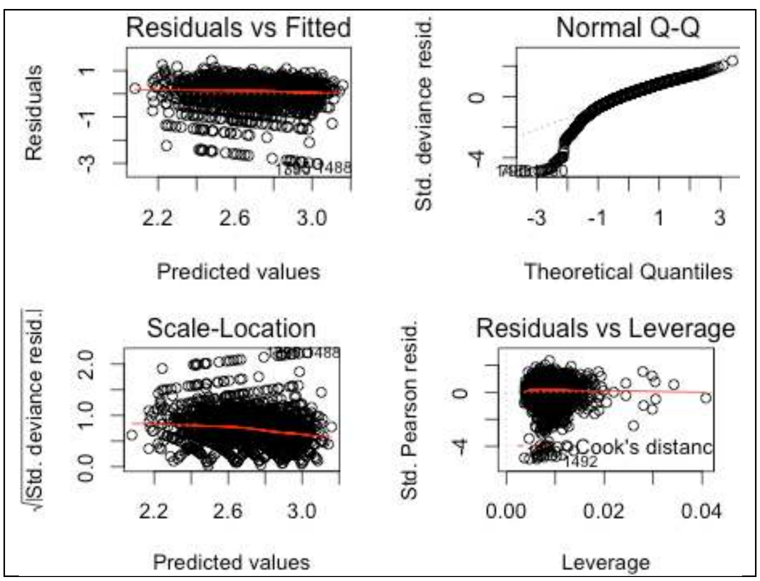
Estimates of the linear model are un-biased, and the analysis can use non-robust standard errors.

Log-linear model

(with the inverse hyperbolic sine transformation of the dependent variable)

Appendix table 3. Log-linear model for the regression of professional network size

	log(professional network size)			
	coef.	**(se)**	**(rob.se)**	Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1
Foreign origin	-0.360	(0.038)	(0.040)	
Female	0.015	(0.035)	(0.035)	
Sociability	0.119	(0.038)	(0.034)	
Professional context				AIC: 2774.7
Career length	0.013	(0.006)	(0.006)	
Career length^2	0.000	(0.000)	(0.000)	RESET = 0.72065, df1 = 2, df2 = 1463, p-value = 0.4866
Research hours weekly	0.002	(0.001)	(0.001)	
US PhD	-0.092	(0.055)	(0.059)	
Postdoctoral experience	0.118	(0.041)	(0.042)	
Research extensive	0.015	(0.035)	(0.036)	BP = 24.238, df = 12, p-value = 0.01888
Field				
Biology	0.164	(0.049)	(0.052)	
Biochemistry	0.149	(0.056)	(0.059)	
Civil engineering	0.124	(0.049)	(0.053)	
(intercept)	2.256	(0.146)	(0.138)	



RESULTS:
Distribution of error terms is less normal than in the OLS model.

RESET and BP tests allow using the model with non-robust standard errors.

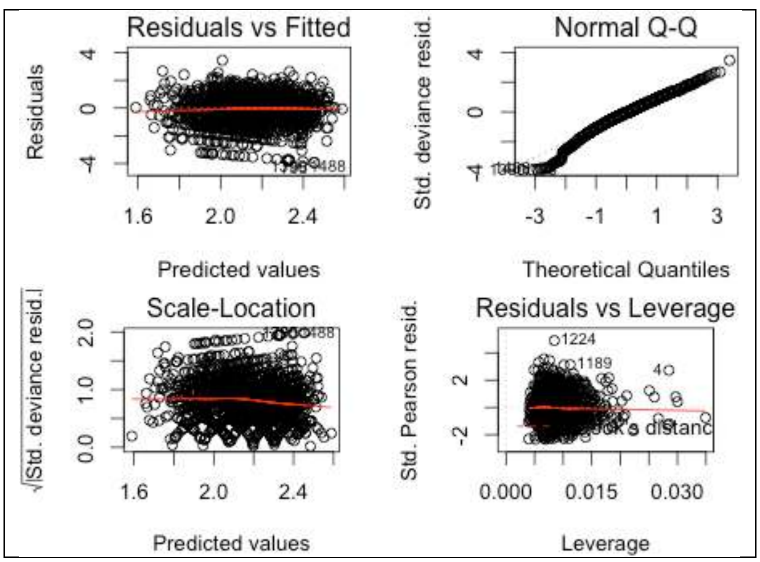
Negative-binomial model

Appendix table 4. Negative-binomial model for the regression of professional network size

	professional network size		
	coef.	**(se)**	**(r.se)**
Foreign origin	-0.284	(0.029)	(0.030)
Female	0.042	(0.026)	(0.026)
Sociability	0.126	(0.029)	(0.027)
Professional context			
Career length	0.015	(0.004)	(0.005)
Career length^2	0.000	(0.000)	(0.000)
Research hours weekly	0.002	(0.001)	(0.001)
US PhD	-0.066	(0.042)	(0.044)
Postdoctoral experience	0.097	(0.031)	(0.031)
Research extensive	0.034	(0.027)	(0.026)
Field			
Biology	0.127	(0.037)	(0.039)
Biochemistry	0.104	(0.043)	(0.043)
Civil engineering	0.088	(0.038)	(0.039)
(intercept)	1.611	(0.111)	(0.108)

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

AIC: 8313.8



RESULTS:
Distribution of error terms is slightly less normal than in the OLS model.

Model is harder to interpret than the OLS model.

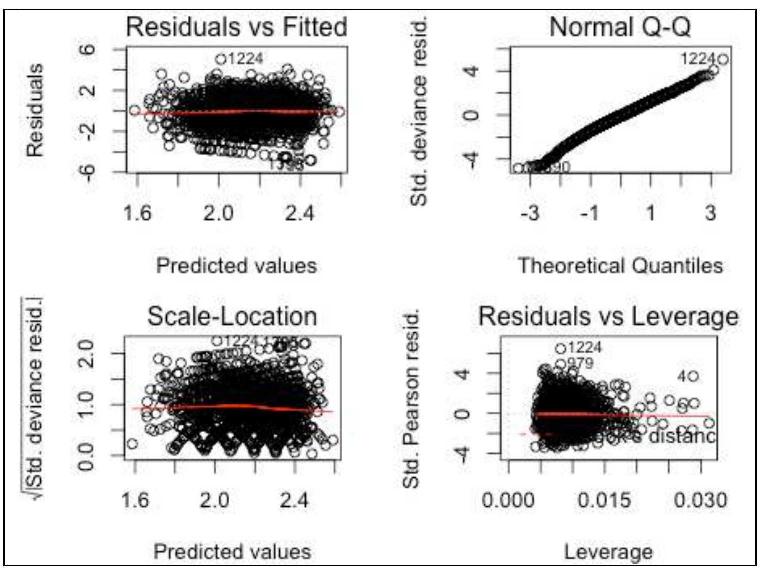
Poisson's model

Appendix table 5. Poisson's model for the regression of professional network size

	professional network size		
	coef.	**(se)**	**(r.se)**
Foreign origin	-0.283	(0.022)	(0.030)
Female	0.041	(0.019)	(0.025)
Sociability	0.128	(0.021)	(0.026)
Professional context			
Career length	0.015	(0.003)	(0.005)
Career length^2	0.000	(0.000)	(0.000)
Research hours weekly	0.002	(0.001)	(0.001)
US PhD	-0.069	(0.031)	(0.044)
Postdoctoral experience	0.098	(0.023)	(0.031)
Research extensive	0.030	(0.019)	(0.026)
Field			
Biology	0.125	(0.028)	(0.038)
Biochemistry	0.102	(0.031)	(0.043)
Civil engineering	0.091	(0.028)	(0.039)
(intercept)	1.606	(0.081)	(0.107)

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

AIC: 8618.4



RESULTS:
Distribution of error terms is acceptably normal.

Model shows a good fit but it is harder to interpret than the OLS model.

Appendix C. Tests of functional forms for publication productivity models

Several forms for regressions of network size are tested: log-linear, negative binomial, and Poisson's.

<u>Log-linear model</u>

(with the inverse hyperbolic sine transformation of the dependent variable)

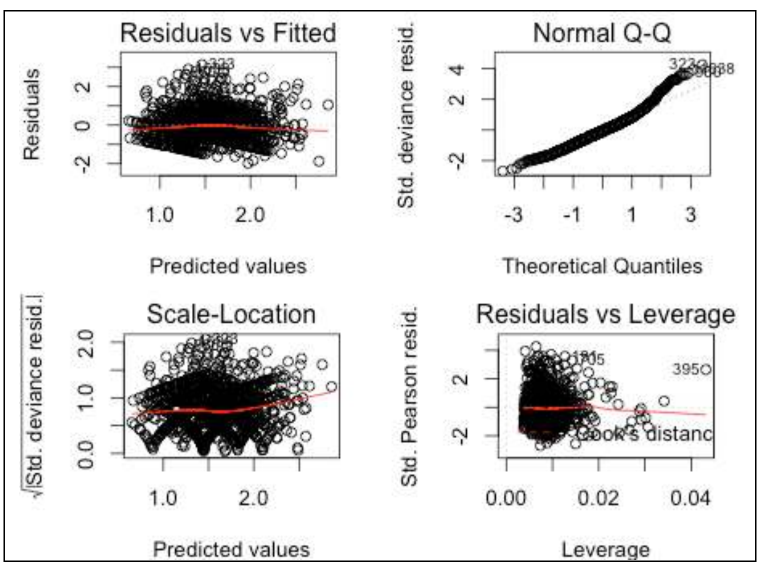
Appendix table 6. Log-linear model for the regression of publication productivity

	log(publication count/year)		
	coef.	**(se)**	**(rob.se)**
Foreign origin	0.159	(0.047)	(0.047)
Female	-0.158	(0.042)	(0.042)
Professional context			
Career length	0.024	(0.007)	(0.007)
Career length^2	0.000	(0.000)	(0.000)
Research hours weekly	0.020	(0.002)	(0.002)
US PhD	-0.050	(0.067)	(0.070)
Postdoctoral experience	0.066	(0.050)	(0.051)
Research extensive	0.125	(0.043)	(0.045)
Field			
Biology	-0.039	(0.059)	(0.059)
Biochemistry	-0.030	(0.068)	(0.067)
Civil engineering	0.191	(0.059)	(0.057)
(intercept)	0.697	(0.123)	(0.123)

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

AIC: 3218
RESET = 2.7476, df1 = 2, df2 = 1420, p-value = 0.0644

BP = 17.8463, df = 11, p-value = 0.08522



RESULTS:
Error terms not quite normally distributed.

However the RESET test supports that the linear form of the model could be used.

The Breusch-Pagan test indicates presence of heteroskedasticity.

The analysis should use heteroskedasticity-robust standard errors.

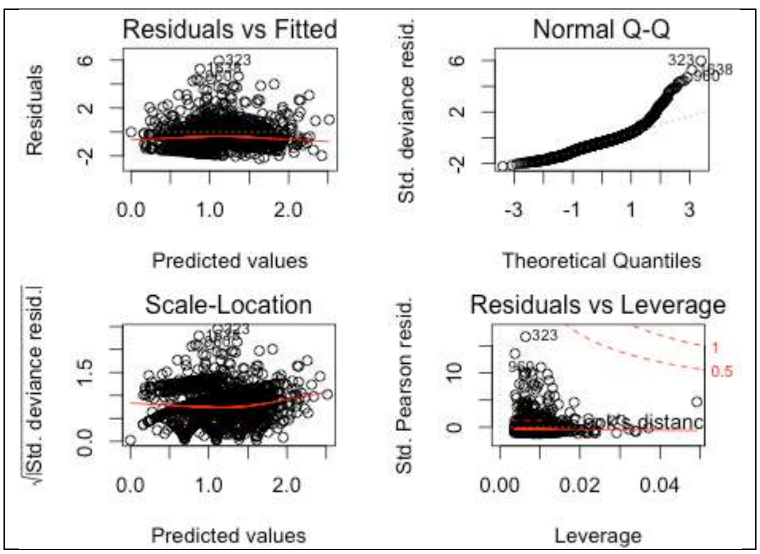
Negative-binomial model

Appendix table 7. Negative-binomial model for the regression of publication productivity

	publication count/year		
	coef.	**(se)**	**(rob.se)**
Foreign origin	0.236	(0.058)	(0.080)
Female	-0.181	(0.053)	(0.072)
Professional context			
Career length	0.035	(0.009)	(0.012)
Career length^2	-0.001	(0.000)	(0.000)
Research hours weekly	0.021	(0.002)	(0.003)
US PhD	-0.007	(0.080)	(0.105)
Postdoctoral experience	0.088	(0.063)	(0.102)
Research extensive	0.085	(0.054)	(0.085)
Field			
Biology	0.069	(0.076)	(0.107)
Biochemistry	0.091	(0.085)	(0.113)
Civil engineering	0.267	(0.074)	(0.102)
(intercept)	-0.004	(0.157)	(0.195)

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

AIC: 6474



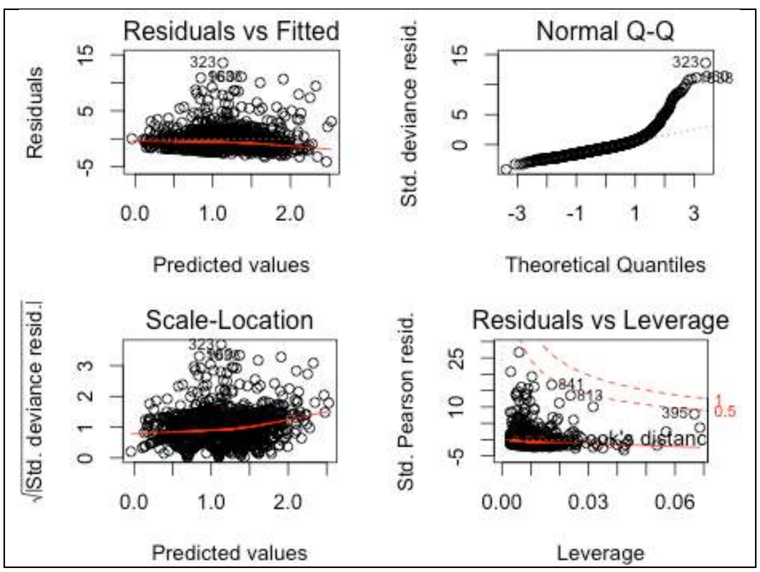
RESULTS:
Error terms are not normally distributed.

Poisson’s model

Appendix Table 8. Poisson’s model for the regression of publication productivity

	Publication count/year		
	coef.	**(se)**	**(rob.se)**
Foreign origin	0.196	(0.034)	(0.077)
Female	-0.170	(0.032)	(0.077)
Professional context			
Career length	0.036	(0.005)	(0.013)
Career length^2	0.000	(0.000)	(0.000)
Research hours weekly	0.021	(0.001)	(0.003)
US PhD	-0.037	(0.044)	(0.114)
Postdoctoral experience	0.106	(0.038)	(0.102)
Research extensive	0.069	(0.032)	(0.087)
Field			
Biology	0.048	(0.046)	(0.103)
Biochemistry	0.104	(0.051)	(0.110)
Civil engineering	0.301	(0.045)	(0.103)
(intercept)	-0.033	(0.094)	(0.213)

Signif. codes: ‘***’ 0.001; ‘**’ 0.01; ‘*’ 0.05; ‘.’ 0.1; ‘ ’ 1



RESULTS:
Error terms are not normally distributed.

Appendix D. Verification of the instrumental variable estimation for the publication productivity model

Sociability is used as the instrument for the professional network size in the regression of publication productivity. Testing of the model follows the standard protocol for verification of linear two-stage least-squares estimations:

1) verification of linear forms for both stages is done before and the results of the tests are in Appendices B and C. The 1st stage, regression of the professional network size on the instrument (sociability), is the same model as the one used for testing Hypothesis 1. The second stage regresses log-transformed publication productivity on foreign origin, professional network size, and control variables. The regression is similar to the one used for testing Hypothesis 2.

2) regression of the dependent variable on the instrument and in the presence of the endogenous explanatory variable

```
glm(formula = lhPubAvg ~ sociable)
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.10061    0.16056  13.083   <2e-16 ***
sociable     0.12188    0.05713   2.134   0.0331 *
AIC: 3423.4

glm(formula = lhPubAvg ~ sociable + Ties)
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.304416   0.142277   9.168   <2e-16 ***
sociable    0.076924   0.049588   1.551   0.1211
Ties        0.012193   0.004961   2.458   0.0141 *
AIC: 3038.6
```

Results of the regressions indicate that sociability might be a candidate for the instrument because it has a significant impact on publication productivity, but it is insignificant in the presence of the endogenous variable.

3) regression of the endogenous explanatory variable on the instrument and all other explanatory and control variables

```
glm(formula = Ties ~ foreignborn + female + sociable + CareerAge +
    CareerAgeSq + resHours + USphd + PostDoc + research1 + biology +
    biochem + civil)
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.8004065  0.9413573   4.037 5.69e-05 ***
foreignborn -2.4036221  0.2451650  -9.804  < 2e-16 ***
female       0.3923010  0.2248599   1.745 0.081256 .
sociable     1.1468439  0.2473273   4.637 3.85e-06 ***
CareerAge    0.1274631  0.0375849   3.391 0.000714 ***
CareerAgeSq -0.0024011  0.0008247  -2.912 0.003651 **
resHours     0.0199534  0.0083786   2.381 0.017371 *
USphd       -0.4850155  0.3558366  -1.363 0.173083
PostDoc      0.8278802  0.2660806   3.111 0.001898 **
research1    0.2579869  0.2277508   1.133 0.257501
biology      1.0498063  0.3168486   3.313 0.000945 ***
biochem      0.8395014  0.3628936   2.313 0.020841 *
civil        0.6971217  0.3148442   2.214 0.026970 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
AIC: 8277.4
```

The impact of sociability on the endogenous variable is significant, and it can be used as the instrument.

4) Results of the Durbin–Wu–Hausman test (F = -434.099, p = 1.379e-84) indicate that the OLS estimation is not consistent and the instrumental variables approach should be used.

Appendix E. Standardized regressions of the foreign and domestic social capital variables on foreign origin and US doctoral education in several populations

Foreign social capital: professional network size

Appendix Table 9. Standardized regressions of the foreign professional network size on foreign origin and US doctoral education in several populations

	Foreign professional network size								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs. US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				**.04**	**(.06)**		**.90**	**(.08)**	***
Female	-.14	(.08)	.	-.12	(.06)	*	-.03	(.06)	
Sociability	.18	(.09)	.	.13	(.06)	*	.13	(.06)	*
Professional context									
Career length	.00	(.01)		.02	(.01)	*	.02	(.01)	.
Career length^2	.00	(.00)		.00	(.00)	.	.00	(.00)	
Research hours weekly	.01	(.00)	*	.01	(.00)	***	.01	(.00)	***
US PhD	**-.78**	**(.09)**	***						
Postdoctoral experience	.02	(.09)		.29	(.07)	***	.23	(.07)	**
Research extensive	.10	(.08)		.15	(.06)	*	.06	(.06)	
Field									
Biology	-.03	(.11)		-.26	(.08)	**	-.17	(.09)	.
Biochemistry	-.23	(.13)	.	-.40	(.10)	***	-.26	(.10)	**
Civil engineering	-.42	(.10)	***	-.39	(.08)	***	-.26	(.09)	**
(intercept)	-.01	(.32)		-.82	(.22)	***	-.93	(.23)	***
	AIC: 1664.3 RESET = 1.5343, p-value = 0.2164 BP = 39.222, p-value = 4.86e-05			AIC: 3595.9 RESET = 2.9327, p-value = 0.0536 BP = 45.164 p-value = 4.54e-06			AIC: 2627.9 RESET = 2.7061 p-value = 0.0673 BP = 43.473, p-value = 8.984e-06		

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

Foreign social capital: ties that provide research-related resources

Appendix Table 10. Standardized regressions of foreign ties that provide research-related resources on foreign origin and US doctoral education in several populations

	Foreign ties that provide research-related resources								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs. US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				.06	(.06)		.56	(.08)	***
Female	-.14	(.09)	.	-.14	(.06)	*	-.06	(.06)	
Sociability	.18	(.10)	.	.13	(.06)	*	.14	(.07)	*
Professional context									
Career length	.00	(.01)		.02	(.01)	*	.01	(.01)	
Career length^2	.00	(.00)		.00	(.00)	.	.00	(.00)	
Research hours weekly	.01	(.00)	*	.01	(.00)	***	.01	(.00)	***
US PhD	-.43	(.09)	***						
Postdoctoral experience	.03	(.10)		.25	(.07)	***	.23	(.08)	**
Research extensive	.11	(.09)		.12	(.06)	*	.05	(.06)	
Field									
Biology	-.09	(.11)		-.20	(.08)	*	-.17	(.09)	.
Biochemistry	-.20	(.13)		-.36	(.10)	***	-.27	(.10)	**
Civil engineering	-.42	(.11)	***	-.35	(.08)	***	-.25	(.10)	*
(intercept)	-.31	(.34)		-.83	(.22)	***	-.89	(.23)	***
	AIC: 1732.4 RESET = 0.40981, p-value = 0.664 BP = 32.984 p-value = 0.000529			AIC: 3596.2 RESET = 2.6499, p-value = 0.07104 BP = 49.833, p-value = 6.707e-07			AIC: 2700.1 RESET = 3.0023, value = 0.0501 BP = 49.726, p-value = 7.01e-07		

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

Foreign social capital: research-related resources

Appendix Table 11. Standardized regressions of foreign research-related resources on foreign origin and US doctoral education in several populations

	Foreign research-related resources								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				**.08**	**(.06)**		**.35**	**(.09)**	***
Female	-.13	(.09)		-.10	(.06)	.	-.04	(.07)	
Sociability	.24	(.11)	*	.14	(.07)	*	.14	(.07)	*
Professional context									
Career length	-.01	(.02)		.01	(.01)		.01	(.01)	
Career length^2	.00	(.00)		.00	(.00)		.00	(.00)	
Research hours weekly	.00	(.00)		.01	(.00)	***	.01	(.00)	***
US PhD	**-.26**	**(.10)**	**						
Postdoctoral experience	.08	(.11)		.22	(.07)	**	.20	(.08)	*
Research extensive	.12	(.09)		.09	(.06)		.04	(.07)	
Field									
Biology	-.07	(.12)		-.07	(.09)		-.07	(.10)	
Biochemistry	-.11	(.14)		-.15	(.10)		-.15	(.11)	
Civil engineering	-.28	(.11)	*	-.18	(.08)	*	-.11	(.10)	
(intercept)	-.52	(.36)		-.84	(.23)	***	-.89	(.25)	***
	AIC: 1815.5			AIC: 3690.8			AIC: 2814.6		
	RESET = 1.6504, p-value = 0.1928			RESET = 1.6088, p-value = 0.2005			RESET = 0.22052, p-value = 0.8021		
	BP = 19.599, p-value = 0.05115			BP = 34.185, p-value = 0.000337			BP = 24.18, p-value = 0.012		
	Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1								

Domestic social capital: professional network size

Appendix Table 12. Standardized regressions of the domestic professional network size on foreign origin and US doctoral education in several populations

	Domestic professional network size								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs. US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				**-.61**	**(.06)**	***	**-.68**	**(.08)**	***
Female	.14	(.09)		.12	(.06)	*	.12	(.06)	.
Sociability	.28	(.10)	**	.24	(.06)	***	.24	(.07)	***
Professional context									
Career length	.02	(.01)		.02	(.01)	**	.04	(.01)	***
Career length^2	.00	(.00)		.00	(.00)	*	.00	(.00)	**
Research hours weekly	.00	(.00)		.00	(.00)		.01	(.00)	*
US PhD	**.08**	**(.10)**							
Postdoctoral experience	.14	(.10)		.16	(.07)	*	.18	(.08)	*
Research extensive	.10	(.09)		.02	(.06)		.01	(.07)	
Field									
Biology	.38	(.11)	**	.27	(.08)	***	.28	(.09)	**
Biochemistry	.49	(.13)	***	.20	(.09)	*	.25	(.10)	*
Civil engineering	.21	(.11)	.	.23	(.08)	**	.33	(.10)	***
(intercept)	-1.40	(.34)	***	-1.09	(.21)	***	-1.50	(.24)	***
	AIC: 1740.8 RESET = 0.19112, p-value = 0.8261 BP = 23.898, p-value = 0.01317			AIC: 3509 RESET = 0.50774, p-value = 0.602 BP = 37.088, p-value = 0.000111			AIC: 2758.5 RESET = 1.4759, p-value = 0.2291 BP = 30.411, p-value = 0.001365		

Signif. codes: ‘***’ 0.001; ‘**’ 0.01; ‘*’ 0.05; ‘.’ 0.1; ‘ ’ 1

Domestic social capital: ties that provide research-related resources

Appendix Table 13. Standardized regressions of domestic ties that provide research-related resources on foreign origin and US doctoral education in several populations

	Domestic ties that provide research-related resources								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				**-.46**	**(.06)**	***	**-.47**	**(.08)**	***
Female	-.01	(.09)		-.02	(.06)		.03	(.06)	
Sociability	.34	(.10)	***	.33	(.06)	***	.37	(.07)	***
Professional context									
Career length	.02	(.01)		.01	(.01)		.02	(.01)	*
Career length^2	.00	(.00)	*	.00	(.00)	*	.00	(.00)	**
Research hours weekly	.00	(.00)		.01	(.00)	***	.01	(.00)	***
US PhD	**.01**	**(.10)**							
Postdoctoral experience	.11	(.10)		.09	(.07)		.10	(.08)	
Research extensive	.11	(.09)		.04	(.06)		.03	(.07)	
Field									
Biology	.40	(.12)	***	.35	(.08)	***	.33	(.09)	***
Biochemistry	.37	(.13)	**	.22	(.09)	*	.25	(.11)	*
Civil engineering	.36	(.11)	***	.37	(.08)	***	.42	(.10)	***
(intercept)	-1.49	(.34)	***	-1.29	(.22)	***	-1.71	(.24)	***
	AIC: 1741.7 RESET = 0.63367, p-value = 0.531 BP = 15.03, p-value = 0.1811			AIC: 3578.3 RESET = 0.92667, p-value = 0.3961 BP = 31.62, p-value = 0.000878			AIC: 2774.9 RESET = 3.0165, p-value = 0.0494 BP = 27.653, p-value = 0.003657		
	Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1								

Domestic social capital: research-related resources

Appendix Table 14. Standardized regressions of domestic research-related resources on foreign origin and US doctoral education in several populations

	Domestic research-related resources								
	Among foreign-born scientists			Among scientists with the US education			Foreign-born with foreign education vs. US-born with US Ph.D.		
	StdY coef	**(se)**		**StdY coef**	**(se)**		**StdY coef**	**(se)**	
Foreign origin				**-.29**	**(.06)**	***	**-.34**	**(.09)**	***
Female	-.01	(.09)		-.06	(.06)		-.03	(.07)	
Sociability	.37	(.10)	***	.36	(.07)	***	.37	(.07)	***
Professional context									
Career length	.01	(.01)		.00	(.01)		.01	(.01)	
Career length^2	.00	(.00)	.	.00	(.00)		.00	(.00)	
Research hours weekly	.00	(.00)		.01	(.00)	***	.01	(.00)	***
US PhD	**.01**	**(.10)**							
Postdoctoral experience	.05	(.10)		.05	(.07)		.09	(.08)	
Research extensive	-.01	(.09)		-.07	(.06)		-.08	(.07)	
Field									
Biology	.38	(.12)	**	.37	(.08)	***	.41	(.10)	***
Biochemistry	.24	(.14)	.	.25	(.10)	**	.28	(.11)	**
Civil engineering	.46	(.11)	***	.46	(.08)	***	.50	(.10)	***
(intercept)	-1.45	(.36)	***	-1.32	(.22)	***	-1.53	(.25)	***
	AIC: 1785.6 RESET = 1.322, p-value = 0.2674 BP = 8.2974, p-value = 0.6864			AIC: 3644.5 RESET = 0.39674, p-value = 0.6726 BP = 21.112, p-value = 0.03223			AIC: 2818.6 RESET = 1.8618, p-value = 0.1559 BP = 27.367, p-value = 0.004043		

Signif. codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; ' ' 1

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