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**FULL ARTICLE**

Does the geographical mobility of scientists shape their collaboration network? A panel approach of chemists' careers

Marine Bernard | Bastien Bernela  | Marie Ferru

CRIEF, University of Poitiers, Poitiers, France

CorrespondenceBastien Bernela, CRIEF, University of Poitiers,
2 rue Jean Carbonnier Bât.A1 BP623, Poitiers
86000, France.

Email: bastien.bernela@univ-poitiers.fr

Abstract

This study assesses the impact of geographical mobility of academic researchers on the formation and dynamics of their coauthorship network, through a bibliometric analysis. Based on 80 French chemists' careers (9310 publications and 14,783 coauthors), panel models point out first that coauthorship network features are independent of individual mobility: there is a stable volume of new coauthors and the researcher's lab colleagues per article, in all generations and career stages. Second, it highlights that mobility (i) allows network diversification but only in the short term and restricted to the new city attended and (ii) reduces the likelihood of sustaining collaborations with colleagues from the previously attended cities.

KEYWORDS

chemistry, collaboration patterns, geographical mobility, panel approach, scientific network

1 | INTRODUCTION

Literature interested in the geography of science has been developed in recent years to better understand the spatial distribution of scientific activities. Studies such as Livingstone (1995) and Eckert and Baron (2013) allow the mapping of the publication activity based notably on bibliometric data. Mobility has been studied as (i) a mechanism of reallocation of scientific people between regions and countries and (ii) a resource used by researchers to access instruments and infrastructures that are fixed, such as historical archives and heavy scientific machinery (Jöns, 2007). The mobility of scientists and inventors is considered essential for knowledge diffusion and



widely encouraged by public authorities, especially in the European Union, through various mobility programs (Morano-Foadi, 2005).

The underlying hypothesis behind the mobility–knowledge diffusion relationship is knowledge is attached to individuals (Cañibano, 2006), and therefore it travels with people who master it. In this context, it is logically assumed that by being mobile, researchers meet and collaborate with new researchers and exchange knowledge. This scientific network diversification driven by mobility would therefore be an indispensable element for the production and circulation of new knowledge across the world. In this paper, we propose to answer the question, “Should researchers move to extend their network?” Network extension could be understood in terms of persons and skills (e.g., new partners) and in terms of geographical locations (e.g., new cities). Researchers can indeed diversify their network by collaborating with new partners (i.e., social extension); they can also collaborate with new partners from changing geographical locations (i.e., spatial extension).

This approach suggests studying the formation and dynamics of personal scientific networks of researchers and identifying the contribution of researchers' geographical mobility to this dynamic. Although scientific network dynamics is largely studied in the framework of the geography of science into a macrolevel perspective (most often at the level of cities and countries), it is rarely considered at the microlevel of individual careers. Authors such as Bhagwati (1976) to Breschi, Lissoni, and Miguelez (2017) have mainly focused on the problem of “brain drain”: the question of mobility has been addressed through the analysis of migratory flows between territories, and nodes in networks are no longer individuals but organizations, cities, or countries. In parallel, some research has developed with a greater focus on individuals, testing mainly the impact of researchers' mobility on their performance (Hoisl, 2007; Lawson & Shibayama, 2015). More marginally, some authors have sought to account for the link between mobility and scientific network. Fontes, Videira, and Calapez (2013), based on the study of doctoral students' trajectories, shows that international mobility during the research work enriches the researcher knowledge network. Woolley, Turpin, Marceau, and Hill (2008) verify this result for the postdoctoral mobility of Asian researchers, and Melin (2004, 2005) nuances it (“the dark side of mobility”) through the study of Swedish researchers' mobility.

Our research is in line with these latter research topics. We seek to test the role of mobility in building and developing the scientific network by focusing at a microlevel: What is the impact of mobility on collaboration patterns? Under which conditions do scientists diversify their coauthorship, or do they tend to renew collaborations? To what extent is the geography of coauthorship sensitive to the spatial trajectories of chemists? Does mobility directly increase the number of new coauthors from attended cities? Does it also allow new partnerships from nonattended cities? Does mobility allow the continuation of partnerships with former and remote coauthors? We consider that mobility cannot be studied in isolation. It seems crucial to reintegrate the impact of mobility in the context of the ongoing career of the researchers. Therefore, to explain the scientific network diversification, we question the impact of career dynamics, including mobility, which has rarely been done earlier.

Empirically, we focus on scientific publications of researchers because they show a relevant indicator of successful collaborations even if they do not capture all researchers' collaborations. Such bibliometric data generally provide reliable information at the institutional (e.g., laboratory) scale; however, the data related to the individual scale of researchers remain unreliable. Being aware of these limitations, we use precise data at the individual level from a cohort of 80 chemists working in two French labs. We focus on chemistry as coauthorship in this field is particularly more because of the way research is being practiced (e.g., experimental dimension, need for technical skills, and importance of teams). However, the average number of coauthors by article (between 4 and 5) is less. The 80 studied chemists have published around 10,000 articles with 15,000 coauthors since the beginning of their career. To refine the bibliometric data, we notably have collected the affiliation and the location of each coauthor to understand the geography of coauthors. Thus, we can analyze the formation and dynamics of the scientific personal network and its evolving geography over time.

This paper is structured as follows. Section 2 provides a brief survey of the link between mobility and scientific networks. Section 3 describes the data and provides descriptive statistics. Section 4 presents the econometric



strategy used to assess the mobility impact on network dynamics. Section 5 summarizes the main empirical results. Section 6 discusses the findings and draws some conclusions.

2 | LITERATURE BACKGROUND ABOUT MOBILITY AND SCIENTIFIC NETWORKS

A major thesis considering scientists and inventors' mobility as crucial for knowledge diffusion has been developed. For many years, scientific mobility is acknowledged to be a key mechanism for the diffusion of knowledge that cannot be transferred without physical proximity (Collins, 1974). Nowadays, knowledge is considered to be attached to individuals (Cañibano, 2006), and individuals must move to transfer or to have access to knowledge. Considering this, mobility is a way to foster collaborations, and it helps build coauthorship networks (Moed, Aisati, & Plume, 2013; Scellato, Franzoni, & Stephan, 2015).

Public authorities seek to foster mobility through various mobility programs (Harfi & Mathieu, 2006): "European policy at the present time tends to conflate different forms of mobility and promotes the use of the concept as a proxy for internationalization, excellence and competitiveness. ... This implies both that 'excellence' is mobile (that 'excellent' scientists are equally footloose)" (Ackers, 2008, p. 413). They indeed associate mobility with the idea of excellence (Morano-Foadi, 2005; OECD, 2008), with emphasis at both micro- (e.g., productivity and career outcomes) and macrolevels (e.g., competitiveness of institutions and territories). In the context of low mobility of scientists in France, some criticisms arise considering that spatial inertia tends to generate cognitive inertia: if researchers do not move, science cannot spread through the network that mobility is supposed to generate. This implicit relationship must be empirically verified, leading us to the question, "should researchers move to diversify their network?"

The increasing availability of bibliometric data combined with the advanced techniques has given rise to various studies about researchers' mobility. Publication activity is a rich indicator for studying the scientific world: publishing is an indicator of production, copublishing is an indicator of collaboration, and quoting is an indicator of diffusion and research quality. Therefore, we have mainly focused on these two research paths (i.e., production and collaboration) that leave little room for studying the link between mobility and scientific networks.

The literature consists of two groups of studies; the first group of studies, based on a neoclassical view, considers mobility as a reallocation of knowledge or an allocative phenomenon that alters the level of inputs to production functions in different locations: the researcher chooses to carry out various experiments (e.g., training, professional activities, mobility) to accumulate skills, train his or her human capital, and increase his or her productivity. "In this approach, embodied knowledge travels automatically in the same direction than its human carrier and is automatically and efficiently used in its new destination" (Cañibano, 2017). Therefore, territories compete to attract and retain scientists and increase their human capital stock ("brain drain") (ibid.). A less binary approach to migration than the win-lose perspective has been developed by Saxenian (2002) who highlights the potential benefits of migration for both sending and receiving countries. These studies have mainly focused on mobility and researcher flows from a macroeconomic perspective. Breschi et al. (2017) show the effects of "diaspora" and "brain drain" for expatriate inventors and highlight the role of ethnic ties and country of origin in determining patent citations.

The second group of studies, focusing on mobility flows, analyzes the role of mobility at the individual level, highlighting, for instance, gender differences: Cañibano, Fox, and Otamendi (2016) show that more women researchers have experienced mobility but with a lower intensity, a shorter stay earlier in their careers, and to closer destinations. Mobility issues are viewed as a determinant that can explain productivity differentials. Empirical studies (Abramo, D'Angelo, & Di Costa, 2009; Landry, Traore, & Godin, 1996; Lee & Bozeman, 2005; Long, Allison, & McGinnis, 1993; Mairesse & Turner, 2005) tend to converge on the idea that being mobile has a positive effect on scientific productivity (e.g., publication and citations) (Aksnes, Rørstad, Piro, & Sivertsen, 2013; Hoisl, 2007) and on career advancement (Lawson & Shibayama, 2015). However, Aksnes et al. (2013)



emphasize the need to consider demographic factors, and Hoisl (2007) points out that increasing productivity leads to a decrease in the probability of mobility. Other researchers further qualify the positive role of mobility, showing not only its contrasting effect (Ackers, 2008) but also “the dark side of mobility” (Melin, 2005) and more particularly the difficulty of researchers to reintegrate with the university system upon their return to their country of origin (Morano-Foadi, 2005).

Although these studies are interesting for assessing the effects of mobility, they do not prove the idea that researchers' mobility promotes the dissemination of knowledge by allowing the formation of new scientific collaborations. Empirical work testing the link between the individual mobility of researchers and the collective scientific dynamics is rare, as Fontes et al. (2013, p. 442) recently underlined: “We still know very little about the role played by mobility on the creation of relationships.”

Some studies are exceptions and provide interesting insights. Cañibano, Otamendi, and Andújar (2008), through the analysis of 266 curriculum vitae (CVs) of Spanish PhD scholars, show that mobility promotes participation in international research projects, a result that Fontes et al. (2013) confirm from the analysis of more than 469 questionnaires and CVs of Portuguese researchers: mobile scientists are more likely to be associated with foreign organizations in their knowledge network. However, this study reveals the importance of other determinants in structuring the knowledge network: the personal characteristics of the researcher, his or her career and field, the period, the geographical distance, and the individual motivations for mobility. Agrawal, Cockburn, and McHale (2006) highlight the importance of past mobility and the persistence of former relationships: when researchers leave their workplaces, they maintain interpersonal links with their former colleagues, who could cite their work much later: “Once relationships are established, individuals can remain socially close even when they become geographically separated” (p. 589). Woolley and Turpin (2009) confirm this effect, described by Miguelez (2013) as “previous co-location premium” or “premium effect,” and show “the existence of personal relationships that endure beyond their tenure in particular places” (p. 145). The weight of past mobility is also observed by Baruffaldi and Landoni (2012), who underline the impact of links with the country of origin on the researcher's probability of return.

These studies, though rare, make real contributions through the study of large databases and the combination of quantitative and qualitative data to assess the impact of mobility on scientific networks. However, the authors point out the necessity to advance this analysis. A group of authors suggest integrating a dynamic perspective through longitudinal data (Scellato et al., 2015) not only to point out a short effect (Fontes et al., 2013) but also to integrate a researcher's career that can be particularly important in terms of the construction and development of his or her network. Cañibano et al. (2008) and Horta (2013) show the need for a dynamic analysis of researchers' careers, which can be particularly important for the construction of the scientific network (e.g., importance of the country of origin [Baruffaldi & Landoni, 2012]). Some recent works focus on coauthor careers, their continuance, disappearance, and reactivation (Cabanac, Hubert, & Milard, 2015) but have yet to investigate the role of mobility in these relationship dynamics.

We propose to follow these last suggestions and to test the impact of researchers' mobility within their academic career on the formation and development of their networks' dynamics and geography. To what extent does the geographical trajectory of researchers, characterized by greater or lesser mobility, contribute to the formation of coauthorship links? What does mobility do for relationship maintenance? Do new scientific ties lead to the abandoning of previous ones? Are there moments in researcher careers in which some kinds of relationships (new/former) are privileged? Are former colleagues significantly represented in?

3 | DATA AND DESCRIPTIVE STATISTICS

To fill the gap identified in Section 2, we choose to evaluate the career of 80 chemists and their scientific collaborations via coauthorship, using a bibliometric analysis at the microscale. We therefore analyze the social and geographic diversification of the coauthorship network of the studied researchers throughout their career.

**TABLE 1** Descriptive statistics of the population

		CNRS research director	Full professors	Total
IC2MP Poitiers	Male	6	26	32
	Female	3	3	6
	Total	9	29	38
LCC Toulouse	Male	14	12	26
	Female	12	4	16
	Total	26	16	42
Total	Male	20	38	58
	Female	15	7	22
	Total	35	45	80

IC2MP, Institute of Chemistry of Milieu and Materials; LCC, Laboratory of Coordination Chemistry.

3.1 | The case study of 80 chemists' careers

We selected 80 researchers from two French academic laboratories in chemistry, who were CNRS¹ research director or full professor in spring 2018 (Table 1). Hereafter, these positions will be referred to as "senior researchers" in this paper. This population was chosen for its comparability. It guarantees a certain professional experience and a minimum career longevity: all studied researchers are at an advanced stage of their careers and well established in their field.² In France, in 2012, the average age of recruitment for assistant professor in chemistry was around 31 years and that of full professor was around 42 years.³

The two studied labs are the Institute of Chemistry of Milieu and Materials (IC2MP) located in Poitiers and the Laboratory of Coordination Chemistry (LCC) located in Toulouse. These two laboratories share similarities. First, they both benefit from an old history and have acquired an international reputation in their respective scientific specialties. IC2MP resulted from the merger of five colocated, active, and historical laboratories in 2012. LCC was established in 1974 and has developed over decades without major organizational and scientific changes. Second, both labs are of equivalent size: each having around 250 members, including approximately 100 permanent ones. Although the number of senior researchers is almost the same in both labs (38 for IC2MP and 42 for LCC), their internal structure differs: IC2MP has a few teams but they are large (5 research teams with an average of 7.6 senior researchers), whereas LCC has many teams that they are small (16 research teams, with an average of 2.6 senior researchers). In addition, IC2MP is a joint research center (CNRS University), but LCC is a unit specific to the CNRS: this explains the overrepresentation of full professors in Poitiers (29 out of 38 senior researchers) and CNRS research directors in Toulouse (26 out of 42 senior researchers). In terms of gender, 72.5% are male, a percentage that appears consistent with the national distribution. In 2018, 62% of French academics in chemistry were men:⁴ this percentage ranges from 56% for assistant professors to 75% for full professors, highlighting the glass ceiling in academic careers (Sabatier, 2010).

¹French National Scientific Research Center (Centre National de la Recherche Scientifique).

²The French system can be characterized as a centralized and regulated labor market controlled by disciplines, close to the Italian and Spanish ones and very different from the USA (Pezzoni, Sterzi, & Lissoni, 2012). Academic careers in France can be divided into three main phases: (i) PhD thesis and postdoctoral positions (fixed-term positions); (ii) "Maître de Conférences" and "Chargé de Recherche CNRS," which correspond to "assistant professor" (access requires the person to hold a PhD); (iii) "Professeur des Universités" and "Directeur de Recherche CNRS," which correspond to "full professor" (access requires the person to hold a "Habilitation à Diriger des Recherches" [HDR]).

³According to the French Ministry of Higher Education and Research: https://cache.media.enseignementsup-recherche.gouv.fr/file/statistiques/05/3/orig2012_302053.pdf

⁴According to the French Ministry of Higher Education and Research: <http://www.enseignementsup-recherche.gouv.fr/cid129560/fiches-demographiques-des-sections-de-sciences-2017.html>



To capture the collaborative dimension of scientific activities, we collected all the publications (articles, reviews, letters, notes, and editorial materials⁵) of the 80 senior researchers from the Web of Science (WoS) Core Collection. It is widely accepted today in the literature on science that publication is a relevant indicator of academic practice and copublication of collaborative patterns. Although publication activity is not the only product of collaborative research (Katz & Martin, 1997),⁶ the bias introduced by a focus on publications is very limited in a discipline such as chemistry. The central place of publication activity in the form of English-written articles in peer-reviewed journals associated with the formal collaborative practice of research in such an experimental science ensures that copublications observed in the WoS are an excellent proxy for the collective activity of knowledge production in chemistry. Comparing researchers with similar career lengths, Jensen, Rouquier, and Croissant (2009) demonstrate that researchers do not share the same frequency of publication activity from one field to another: chemists published on average 58 publications during their career, whereas this figure was lower than 50 publications in all other fields. Chemistry is also a discipline where the differences in average frequency between subdisciplines is the lowest: each subdiscipline of chemistry is a representative of this high frequency of publication. Moreover, Vieira and Gomes (2010) clearly illustrate the higher level of the collaborative research in chemistry, showing “the average number of co-authors per document is the highest for Biology & Biochemistry (4.84) and almost the same for Chemistry and Physics (3.98 and 3.89, respectively). For Mathematics the average number found was 1.84 co-authors per document.” Finally, the publication process is quick in chemistry compared to, for example, the social sciences or mathematics so that it does not introduce a massive bias in publication lag. Discussion with some chemists in earlier surveys (Bernela, Bernard, & Ferru, 2018) revealed that it takes about 4 months from submission to publication.

Thomson Reuters' WoS is a well-known and reliable source, frequently used to collect copublication data. An initial screening was performed to avoid namesake bias: we kept 9310 publications, including 9206 copublications. Most of the variables in the publication database were left untouched (e.g., title, year, scientific journal, list of coauthors), and some other variables needed an in-depth screening, such as authors' location (see Section 3.2). From the publication list of each researcher, we split coauthored articles into coauthorship pairs (Melin & Person, 1996). As we stand on a personal network perspective, we are only interested in *ego-alter* relationships and do not consider relationships between *alter*: *ego* represents one of the 80 studied researchers and *alter* are all the coauthors. It is important to distinguish between cosignature (or collaboration) and coauthor: in cases where *ego* cosigns ten times with an *alter*, this relation equals one coauthor and ten cosignatures.

As we focus on the publication and collaboration dynamics, the career of each researcher is assumed to start on the year of his or her first publication. Although all the 80 senior researchers occupied the same position in spring 2018, they had unequal career length and did not start publishing at the same time: the longest career was 51 years and the shortest one was 12. We generated four cohorts of researchers that gather researchers by periods of 10 years according to their year of the first publication (1967–1976, 1977–1986, 1987–1996, and 1997–2006). This allows time to be integrated into two complementary ways:

1. The generation: Researchers who are currently in a senior position have experienced different contexts since the beginning of their career: the way research is conducted and the place of publication activity have hugely changed since the 1960s.
2. The career stage: Based on a panel approach, the career of each researcher is also sequenced in years (the first year of publication is considered as t_0 , the second year t_1 , etc.), considering that the propensity of a researcher to develop networks is not the same according to his or her career stage.

⁵Articles represent 99.4% of the total number of publications.

⁶As Katz and Martin (1997, pp. 2–3) underlined, “For decades the multiple-author publication, frequently referred to as a co-authored publication, has been used as a basic counting unit to measure collaborative activity. ... Bibliometric analysis ... can only be used to count collaborations where the collaborating participants have put their names on a joint paper.” “For co-authorship to be a truly accurate reflection of collaboration, it would require that, in all cases where the ‘level’ or intensity of joint work by collaborating researchers was above a certain minimum threshold, a jointly authored paper always resulted” (ibid., p. 11).



Table 2 details descriptive statistics regarding their publication activities and coauthorship: the 80 senior researchers copublished 9206 articles in which they cosigned 41,628 times with 14,783 different coauthors. At the individual scale, each senior researcher published on average 116 publications in his or her career and 3.78 publications per year. For each publication, a researcher collaborated on average with 4.52 coauthors, including 1.61 new coauthors. These descriptive statistics demonstrate a high frequency of publication activities and very collaborative research compared to other disciplines. In terms of volume, the majority of coauthors (58%) are “one-off” partners, that is, *alter* with whom *ego* collaborated only once. Bernela and Milard (2016) showed that these “one-off” coauthors often correspond to “second-rank” coauthors, that are often nonpermanent positions unknown by *ego*: the dominance of team level implies that some *alter* are involved in co-authored articles without any interaction with *ego*.

Figure 1 shows the dynamics of publication and collaboration patterns over the career and by generation. Figure 1a shows the average number of publications per year and generation of researchers. Although senior researchers did not start their career in the same historical context, all generations follow the same increasing frequency of annual publication in their career. The annual frequency of publication varies according to the career stage of the senior researcher and not according to the generation. However, we observe that in last years the most recent generation caught up with the old ones, reflecting strong publication requirements in the current scientific system. Figure 1b focuses on the average number of coauthors per article by generation of researchers. The collaborative dimension of publications depends on both the career stage and the generation of the senior researcher. Indeed, the average number of coauthors per publication increases throughout the career of each senior researcher. At the same time, the recent historical context encourages senior researchers to publish with more coauthors. For instance, in the 2000s, although the fourth generation just started to publish and the first generation started it more than 30 years ago, their publications had the same collaborative patterns.

3.2 | From spatial information in publication data to mobility patterns and the geography of coauthorship

To capture the impact of mobility on the scientific network of researchers, we must define both (i) the mobility patterns of the 80 senior researchers and (ii) the spatial distribution of their scientific network from the spatial information available in the WoS (through the location of their *alter*).

Before 2008, basic spatial information contained in WoS was a list of coauthors' addresses, without the possibility of identifying the location of each author. In some cases, several coauthors belong to the same team or some authors are from multiple affiliations, and thus the number of addresses does not necessarily correspond to the number of authors. Methodologically, this absence of author–location matching implies that most studies focus on the address level only—that is, how many cities collaborate in a publication—to provide an understanding of the geography of science (Grossetti et al., 2014; Maisonobe, 2015). It becomes a hindrance when studying geographical patterns of researchers' trajectories. In our case, we used search engines to collect all the locations of coauthors listed on a publication, at the scale of laboratory, city, and country. This represents a time-consuming task of disambiguation, standardization, and coding of the database, necessary to obtain reliable geographical information. To our knowledge, it is the only way to obtain the geography of collaborations of researchers at the microlevel and has not been done yet, except Bernela and Milard (2016).

Among the corpus of 9206 copublications, we resorted to manual web searches⁷ to obtain the location of *ego* and *alter* for the 5301 copublications made before 2008, as detailed in Figure 2. For each address, we distinguish three spatial scales: laboratory, city, and country. For laboratory, an important work of disambiguation appeared necessary: for instance, in the case of the Poitiers lab, “IC2MP” can also be registered as “UMR 7285” or the various

⁷A manual coding of each author–location couple was performed for publications prior to 2008 because of the nonmatching between the list of locations and the list of authors. It consisted in searching the articles by title and year: access to the PDF or to the notice of the article on the journal's website then made it possible to identify the affiliation of each coauthor.

**TABLE 2** Publication and collaboration patterns according to gender, position, and generation

	All researchers	Gender		Position		Generation			
		Male	Female	Full professors	Research directors	1967-1976	1977-1986	1987-1996	1997-2006
Number of researchers	80	58	22	45	35	18	28	21	
Average length of career (years)	31	31	29	30	31	37	28	19	
Number of publications	9310	7316	1994	4208	5102	2406	2634	1405	
Number of copublications	9206	7219	1987	4137	5069	2342	2634	1398	
Average number of publications per researcher	116	126	91	94	146	133	94	66	
Average number of publications per year and researcher	3.78	4.01	3.13	3.09	4.64	3.61	3.33	3.48	
Number of cosignatures	41,628	31,869	9759	18,181	23,447	9796	13,265	7410	
Average number of cosignatures per researcher	520	549	444	404	670	544	473	352	
Average number of cosignatures per copublication	4.52	4.41	4.89	4.39	4.63	4.18	5.04	5.3	
Number of coauthors	14,783	11,132	3651	6908	7875	3317	4880	2859	
Average number of coauthors per researcher	185	192	166	153	225	184	174	136	
Average number of new coauthors per copublication	1.61	1.54	1.84	1.67	1.55	1.42	1.85	2.05	
"One-off" coauthors	8574 (58%)	6361 (57%)	2213 (61%)	4033 (58%)	4541 (58%)	1899 (57%)	2822 (58%)	1706 (60%)	

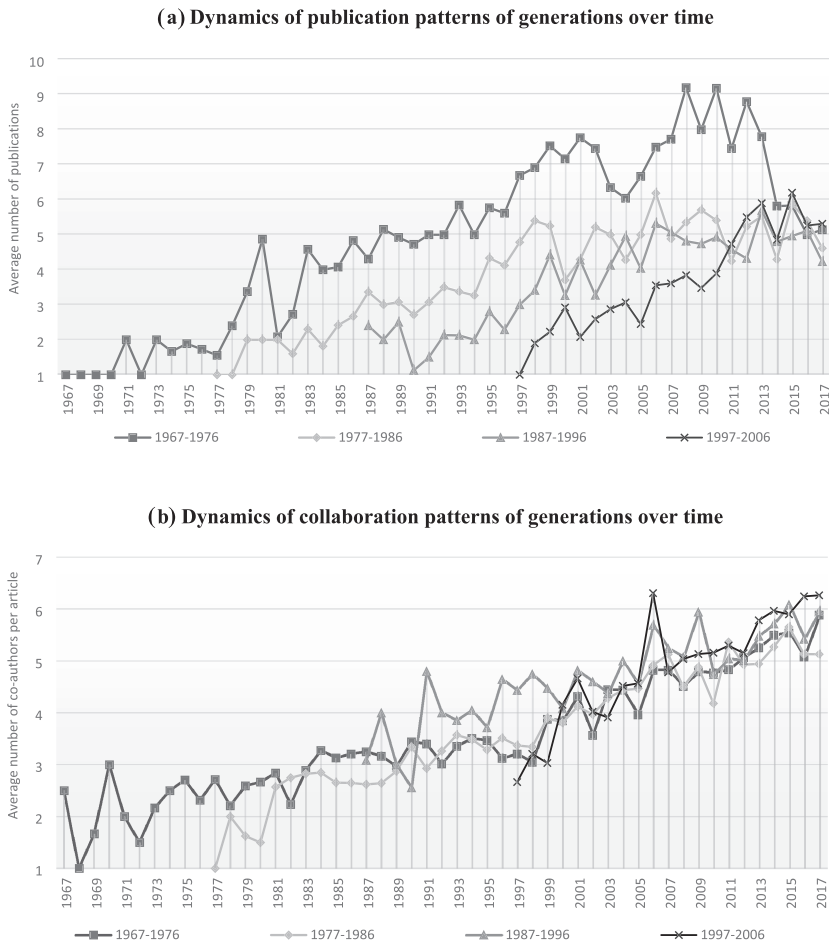


FIGURE 1 (a) Dynamics of publication patterns of generations over time and (b) dynamics of collaboration patterns of generations over time

names of old laboratories before the merger. Finally, we kept multi-affiliation cases, that is, when *ego* and/or *alter* is associated with different laboratories in the same publication.⁸

Once locations of *ego* and their coauthors are screened for each publication, we code the spatial distance between each pair of *ego*–*alter*. We break down this measure of distance into four increasing levels—lab, city, national, international—and can question, “Is *ego* located in the same laboratory, the same city, or the same country of *alter*?” This microscale collection of data, which involved the coding of the spatial distance between a researcher and his or her coauthors for each dyadic relationship, makes our database an original tool for the geography of science.

In this article mobility is considered as a change in *ego* affiliation from one year to another, at the city level.⁹ We identify the volume of mobility events along researchers' careers and distinguish between intranational and international mobilities. As outlined in Figure 3, 19 out of 80 researchers have never experienced mobility, whereas others

⁸A same *ego*–*alter* couple can be repeated several times for a publication but with a different geography, with an associated weight (ensuring that the sum is equal to 1 for each couple in the publication). For example, if *ego* is affiliated both in Paris and in London and cosigns with an *alter* affiliated in Berlin, we will have two pairs: *ego* (Paris)–*alter* (Berlin) and *ego* (London)–*alter* (Berlin), and each one weights 0.5.

⁹We do not observe institutional mobility within a same city, except changes in the lab name in the case of the merger in Poitiers.

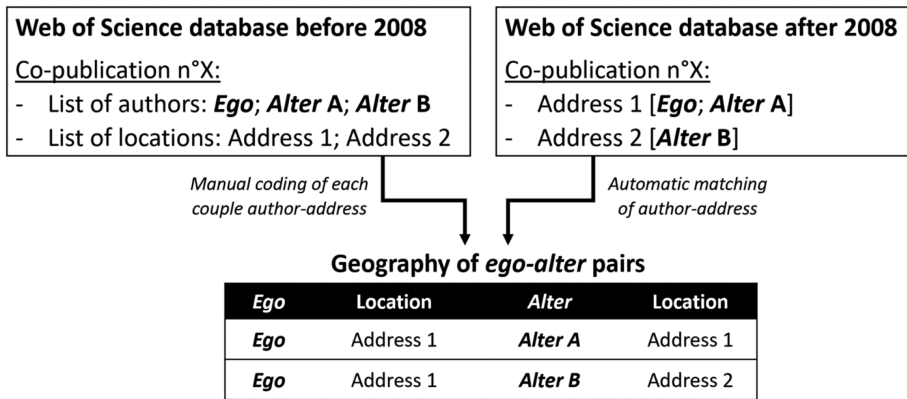


FIGURE 2 Geographic information at the individual scale

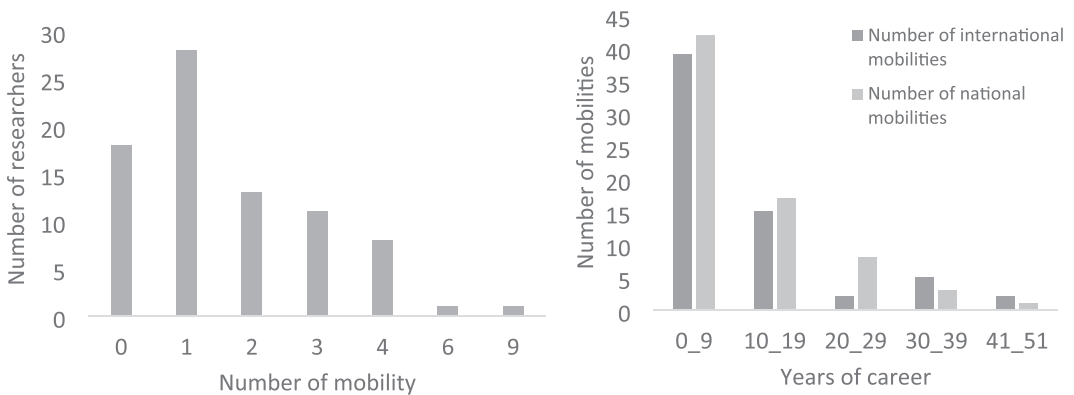


FIGURE 3 Volume of mobility events per researcher and during the career

have moved a lot over their career; this figure is higher than those observed in France for all disciplines (Bernela, Bouba-Olga, & Ferru, 2018). A binary categorization of mobile versus nonmobile scientists, as performed in many articles (Aksnes et al., 2013; Chinchilla-Rodriguez, Miao, Murray, Robinson-García, Costas, & Sugimoto, 2018; Franzoni, Scellato, & Stephan, 2014), would not be adequate regarding the diversity of the mobility profiles: there is a methodological opportunity to complexify mobility measures using bibliometric data (Robinson-Garcia et al., 2019).

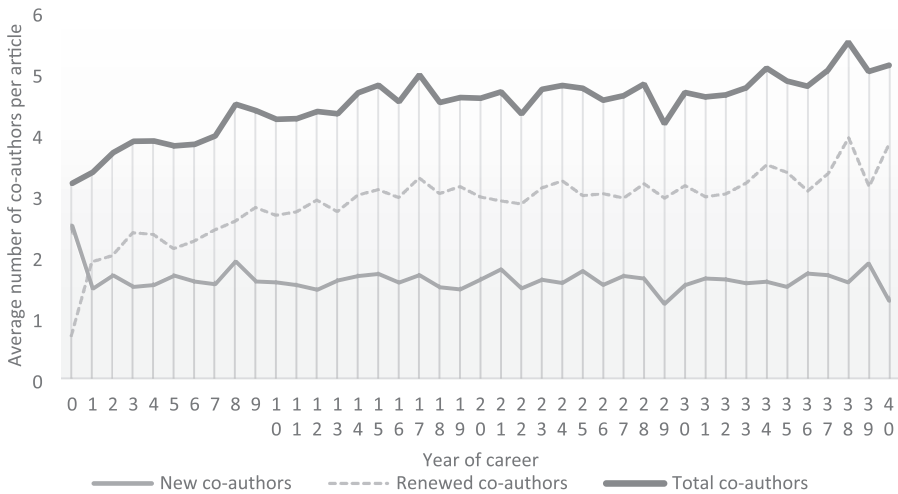
Figure 3 shows that there are as many international mobilities as national ones. Mobility generally occurs at the beginning of the career, highlighting the central role of postdoctoral positions in chemistry. Since even mobile people were sedentary before their first mobility, there is a need to contextualize these mobility events all along researchers' careers to properly evaluate the impact of mobility on the extension of the coauthorship network. Moreover, we identify and track the information about all the cities attended by *ego* in the past and are thus able to contextualize each publication (and coauthorship pair) in the geographic trajectory of the researcher. In a dynamic point of view, we can assess the continuance of relationships with *alter* from cities where *ego* was located before.

3.3 | Social and geographical dynamics of coauthorship over time

Independent of the mobility, we shed light on the social and geographical patterns of coauthorship over the career. Figure 4a shows the weight of new *alter* in comparison to the former ones (i.e., with whom *ego* renews cosignatures).



(a) Social decomposition of co-authorship throughout career (Renewal of co-authorship)



(b) Geographical decomposition of co-authorship throughout career (Distance between *ego* and *alter*)

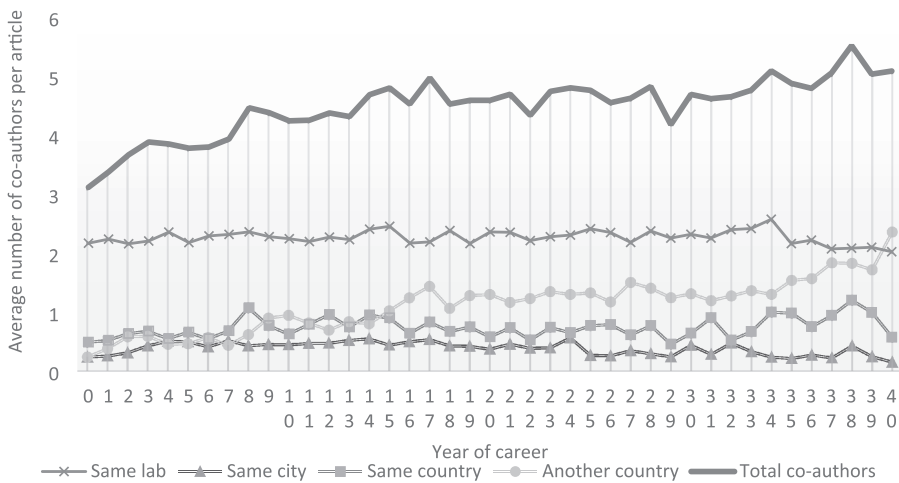


FIGURE 4 (a) Social decomposition of coauthorship throughout career (renewal of coauthorship) and (b) geographical decomposition of coauthorship throughout career (distance between *ego* and *alter*)

Figure 4b highlights the spatial distribution of *ego*–*alter* relationships. In both figures, the upper curve refers to the growing trend of coauthors per publication over the career (irrespective of the generations, as researchers advance their career, the number of coauthors per publication increases).

The increase in coauthors per article throughout career stages results from the continuance of relationships with former coauthors in addition to the stable number of new coauthors per article over the career (around 1.5). Therefore, when they pursue their career, researchers do not increasingly collaborate with new coauthors but mostly with former ones as already observed by Cabanac et al. (2015).

Concerning the spatial distribution of coauthors over the career and the distance that separates *ego* and *alter* (Figure 4b), we note the important and stable weight of the *ego*'s lab colleagues (2 per publication) in the publication activity in their career: local coauthors appear as central all along the career. Although nonlocal *alter* are a minority,



they are increasing throughout the career. We observe a progressive geographical openness in coauthorship and even more internationalization of the scientific network for all generations. The density of the network is continuing to build by both a reinforcement of lab colleagues' core and internationalization of coauthorship.

Table 3 presents the geography of coauthorship (i.e., *ego*–*alter* relationship) considering the spatial trajectory of *ego* (i.e., new coauthors located in current or attended or nonattended cities of *ego*).

On row (1), we note the importance of local partnerships as 32.6% of the new coauthors are from the same lab as *ego* and 42.6% of new collaborations occur with *alter* who was in the current city of *ego*. These first results underline the high “contribution” of local relationships in the network buildup. Regarding the total of cosignatures (and not only the new ones), we more generally observe that *ego* shared 58.5% of his or her cosignatures with *alter* he or she met in his or her lab or city. More precisely, *ego* shared 49.8% of his or her cosignatures with *alter* he or she met in his or her lab. In other words, local coauthors weight one-third of partners but half of the collaboration volume. It is an inverse trend for international coauthors who also weight one-third of partners but only one-quarter of total collaboration.

Table 3 reveals that only 3.1% of *alter* are located in a city that *ego* has frequented in the past. This means that, after mobility, *ego* maintains a very limited share of relationships with cities attended in the past: interpersonal relationships are hard to be maintained after a geographical move. In many cases (53.6% of coauthors and 37.6% of cosignatures), *ego* collaborates with *alter* from a city where he or she has never been affiliated before, suggesting mobility is far from being a prerequisite for opening the scientific network. Two crucial insights appear from Table 3: (i) we do not observe the *premium* effect of the mobility and (ii) mobility does not seem to be a prerequisite for opening the coauthorship network.

4 | ECONOMETRIC ESTIMATION

To capture the impact of mobility on the diversification of network, the panel approach seems to be the most appropriate way to study individual trajectories based on longitudinal data. Although many studies have focused on the ability of mobility to feed networks, we contribute to the literature by estimating the effects of mobility as a specific event in the career on both “births” and “deaths” of relationships within the *ego* network. In other words, we test whether the geographic mobility results in new collaborations and relationship breakdowns, and if so, to what extent.

We introduce an individual dimension that represents each *ego* ($i \in \mathbb{N} [0; 80]$) and a time dimension ($t \in \mathbb{N} [0; 51]$)¹⁰ that represents each year of career of *ego*. We adopt a fixed-individual effect model for two reasons. First, this method is more appropriate for our database: the unobserved heterogeneity could skew the results from random-effect models. Our Hausman test (1978) is significant: it supports that results from the estimation by fixed-individual effect are significantly different from those from the random-effect estimation. Second, this method is more appropriate to our issue because it focuses on the intraindividual variance instead of the interindividual one. Indeed, our approach involves diving into each career to test the impact of geographic mobility and not comparing careers of researchers. More precisely, using “within” model, we are free from the heterogeneity of publication and collaboration patterns between individuals: each variable is centered, and the impact of the geographic mobility is estimated relative to the average patterns of each individual (without comparing patterns between individuals). The choice of a fixed-individual effect model prevents us from using individual variables (e.g., as gender) to explain the dynamics of collaboration. Our strategy of panel econometrics favors the study of publication dynamics within an individual's career rather than comparing individuals with one another.

¹⁰The longest career is 51 years (between the first and the last publications in the career).

**TABLE 3** Geography of ego–alter relationships

	Distance between geography of ego–alter (%)				Location of alter compared to ego trajectory (%)						
	Same lab	Same city	Same country	Other country	Not found	Total	Current city	Attended city	Nonattended city	Not found	Total
New coauthors	32.6	9.9	22.8	34.0	0.7	100	42.6	3.1	53.6	0.7	100
Total cosignatures	49.8	8.7	16.1	25.1	0.3	100	58.5	3.3	37.9	0.3	100



To record the diversification of the coauthorship network, we measure annual flows of the new and outgoing coauthors in the network. These two complementary dimensions allow us to evaluate the potential “births” and “deaths” of relationships resulting from the mobility experience. Also, we chose to measure these flows with regard to the whole network of *ego* (all *alter*) and more specifically *alter* coming from nonattended cities by *ego*, to evaluate the impact of mobility on *alter* who were integrated through the geographic trajectory of *ego* or not.

We note

$y_{i,t}^{\text{entry}}$	The number of coauthors entering in the network of <i>ego</i> <i>i</i> in <i>t</i>
$y_{i,t}^{\text{entrynonatt}}$	The number of coauthors from cities nonattended by <i>ego</i> entering in the network of <i>ego</i> <i>i</i> in <i>t</i>
$y_{i,t}^{\text{exit}}$	The number of coauthors leaving the network of <i>ego</i> <i>i</i> in <i>t</i>
$y_{i,t}^{\text{exitnonatt}}$	The number of coauthors from cities nonattended by <i>ego</i> leaving the network of <i>ego</i> <i>i</i> in <i>t</i>

We construct two longitudinal explanatory variables to characterize the mobility of researchers all along their career, keeping in memory their past spatial trajectories. These two variables search to evaluate two complementary effects of mobility: immediate and delayed effects. They test the hypothesis that mobility can have a variable impact over time; the effect of mobility on the construction of the coauthorship network can take time or, on the contrary, have a short-term impact that then dissipates over time.

$x_{i,t}^{\text{mobnature}}$	The nature of mobility of <i>ego</i> <i>i</i> in <i>t</i> regarding <i>t</i> – 1 (no mobility, national, or international mobility)
$x_{i,t}^{\text{lastmob}}$	The number of years elapsed in <i>t</i> since last mobility of <i>ego</i> <i>i</i>

The general estimated equation model is given by

$$(Z_{i,t} - \bar{Z}_{i,t}) = \beta^{\text{mob}} (X_{i,t}^{\text{mob}} - \bar{X}_i^{\text{mob}}) + \beta^{\text{collab}} (X_{i,t}^{\text{collab}} - \bar{X}_i^{\text{collab}}) + (\varepsilon_{i,t} - \bar{\varepsilon}_i),$$

where $Z_{i,t}$ equals one of the four dependent variables $y_{i,t}^{\text{entry}}$, $y_{i,t}^{\text{entrynonatt}}$, $y_{i,t}^{\text{exit}}$, or $y_{i,t}^{\text{exitnonatt}}$ and $X_{i,t}^{\text{mob}}$ equals one of the mobility variables $x_{i,t}^{\text{mobnature}}$ or $x_{i,t}^{\text{lastmob}}$. $X_{i,t}^{\text{collab}}$ is a matrix of control variables dealing with publication and cosignature patterns concerning each *ego* *i* at each year *t*. $\varepsilon_{i,t}$ is the residual term. Finally, by combining the different dependent and explanatory variables, we estimate eight models, as detailed in Table 4. Table 5 provides descriptive statistics of the dependent, explanatory, and control variables.

TABLE 4 Synthesis of estimated models

		Dependent variables			
		Entry		Exit	
		All <i>alter</i> ($y_{i,t}^{\text{entry}}$)	<i>Alter</i> from nonattended cities ($y_{i,t}^{\text{entrynonatt}}$)	All <i>alter</i> ($y_{i,t}^{\text{exit}}$)	<i>Alter</i> from nonattended cities ($y_{i,t}^{\text{exitnonatt}}$)
Explanatory variables	The nature of the mobility ($x_{i,t}^{\text{mobnature}}$)	Model 1	Model 3	Model 5	Model 7
	The history of the mobility ($x_{i,t}^{\text{lastmob}}$)	Model 2	Model 4	Model 6	Model 8



5 | RESULTS

Table 6 describes results. Regarding model 1, mobility significantly increases the cosignatures with new *alter* at the publication scale, compared to years of nonmobility. Indeed, when mobility is assessed by distinguishing between national and international ones, we observe that the mobility experience has a significant and positive impact on the entry of *alter*. Being mobile stimulates the integration of new *alter* per publication in year t , and contrary to expectations, moving internationally has no greater effect than moving nationally. *Mobility encourages the creation of new coauthorship ties.*

By refining the measurement of mobility by taking into account that the experience is very recent (t or $t - 1$) or older ($t - 2$, $t - 3$, $t - 4$, $t - 5$, ...) in model 2, we observe that mobility has a significant and positive effect on the entry of an *alter* located in a city attended by *ego*. Nevertheless, mobility has a short-term effect because it increases the number of new coauthors only in the year in which the mobility experience occurs. Therefore, we do not observe the premium effect of mobility as in the previous studies (Jonkers & Tijssen, 2008). *The effect of mobility on the creation of ties is instantaneous.*

In addition, regarding flows of *alter* coming from nonattended city models 3, 4, 7, and 8, we note that mobility has no impact on entry and exit. The birth and death of relationships following a mobility only concern *alter* located in attended cities of *ego*. Thus, although mobility allows the diversification of the network, its geographical impact is relatively weak as it is limited to the attended cities of *ego*. Mobility has a direct effect only on the construction of the network because it does not allow the establishment of a coauthor with *alter* located in cities not frequented by *ego*. *Relationships out of the laboratory do not depend on mobility.*

In model 5, we observe that the experience of mobility significantly increases the probability of *alter* exits. The mobility weakens previous relationships, and this "exit" effect lasts longer than the "entry" one. *Mobility is therefore a synonym of both integration and destruction of relationships between ego and alter.*

Finally, we observe that independent of the mobility experience, the average number of cosignatures has a positive and significant effect on the entry and exit of coauthors, whereas the intensity of publications has a slightly negative effect.

6 | DISCUSSION AND CONCLUSIONS

The aim of this article was to evaluate the impact of mobility on the extension of the coauthorship network. We used 9206 publications of 80 chemists to analyze their 41,628 cosignatures with 14,783 coauthors, at the microscale. More precisely we tested the impact of changing city affiliation (mobility) on the entry and exit of coauthors in the network of researchers over their career.

Descriptive statistics suggested that the social and geographical patterns of coauthorship in chemistry were relatively stable whatever the individual trajectories. Although the number of coauthors by publication grew over the career, the volume of new coauthors (social opening) was stable and the volume of former coauthors (continuance of relationships) increased. Moreover, the weight of the *ego*'s lab colleagues (local coauthors) in the publication activity was central and all along the career. The densification of coauthorship proceeded with an internationalization process with career progress. However, mobility did not have a premium effect on the diversification of the network. The share of *alter* located in cities attended by *ego* in the past was very low (interpersonal relations were hard to maintain in an experimental practice of science), and mobility was not a prerequisite for internationalization of cosignatures. Researchers tended to maintain a relationship with local coauthors (in terms of cosignatures).

In the panel models, we evaluated the impact of mobility at the intraindividual scale. We found that the experience of mobility increased the integration of new coauthors per article. However, this effect was only instantaneous: we did not observe a *premium* effect of mobility over time (Jonkers & Tijssen, 2008). The effect of integration was also restricted to the cities attended by *ego*: there was no "bonus" openness linked to the arrival in a new city.

**TABLE 5** Descriptive statistics of dependent, explanatory, and control variables

Variables		<i>n</i>	Mean	Std. error	Min.	Max.
<i>Entry and exit (dependent variables)</i>						
$y_{i,t}^{\text{entry}}$	Entry (all <i>alter</i>)	2099 ^a	1.884	1.598	0	16
$y_{i,t}^{\text{entrynonatt}}$	Entry (<i>Alter</i> from nonattended cities)	2099	0.885	1.162	0	10
$y_{i,t}^{\text{exit}}$	Exit (all <i>alter</i>)	2099	1.880	1.914	0	18
$y_{i,t}^{\text{exitnonatt}}$	Exit (<i>Alter</i> from nonattended cities)	2099	0.865	1.245	0	15
<i>Mobility experience (explanatory variables)</i>						
$x_{i,t}^{\text{mobnat}}^{\text{ure}}$	<i>Not_mob</i>	Ego <i>i</i> kept the same city affiliation between (<i>t</i> – 1) and <i>t</i>	1965	0.94	0	1
	<i>National</i>	Ego <i>i</i> changes his or her city affiliation in <i>t</i> related to (<i>t</i> – 1)	71	0.03	0	1
	<i>Internat</i>	Ego <i>i</i> changes his or her country affiliation in <i>t</i> related to (<i>t</i> – 1)	63	0.03	0	1
$x_{i,t}^{\text{lastmob}}$	<i>Sedentary</i>	Ego <i>i</i> has never been mobile until <i>t</i>	801	0.38	0	1
	<i>This_year</i>	Ego <i>i</i> has been mobile in <i>t</i>	130	0.06	0	1
	<i>1_to_3</i>	Ego <i>i</i> has been mobile between (<i>t</i> – 1) and (<i>t</i> – 3)	271	0.13	0	1
	<i>4_to_6</i>	Ego <i>i</i> has been mobile between (<i>t</i> – 4) and (<i>t</i> – 6)	213	0.10	0	1
	<i>7_to_9</i>	Ego <i>i</i> has been mobile between (<i>t</i> – 7) and (<i>t</i> – 9)	173	0.08	0	1
	<i>10+</i>	Ego <i>i</i> has been mobile before (<i>t</i> – 10)	511	0.24	0	1
<i>Publication and collaboration patterns $x_{i,t}^{\text{collab}}$ (control variables)</i>						
$\text{Cosign}_{i,t}$	Moving average of cosignatures per article for ego <i>i</i> between (<i>t</i> – 1) and (<i>t</i> + 1)	2099	4.31	1.66	1	17
$\text{Publis}_{i,t}$	Moving average of articles per year for ego <i>i</i> between (<i>t</i> – 1) and (<i>t</i> + 1)	2099	4.27	3.67	0.33	24.67
$\text{Geo_net}_{i,t}$	Number of cities of <i>alter</i> with whom ego <i>i</i> has cosigned until (<i>t</i> – 1)	2099	17.26	18.16	0	116
Social_net_t	Number of <i>alter</i> with whom ego <i>i</i> has cosigned until (<i>t</i> – 1)	2099	81.19	93.77	0	673
$\text{Citat}_{i,t}^b$	Number of citations received by ego <i>i</i> until (<i>t</i> – 1)	2099	7038.19	19,274.17	0	2,267,733

^aIt corresponds to the total number of years observed in the 80 careers.

^bThis variable assumes a linear distribution of annual citations, from the stock of citations of each publication received in 2018.

**TABLE 6** Panel estimations (impact of mobility on entry/exit of alter in ego network)

Entry	Nonattended alter							
	(1)	(2)	(3)	(4)				
All alter								
(Intercept)	0.172 (-0.09)	*	0.15 (-0.09)	***	-0.442 (-0.08)	***	-0.444 (-0.08)	***
$X_{it}^{\text{mobnature}}$ (ref: Not_mob)								
National	0.627 (-0.15)	***			0.004 (-0.12)			
Internat	0.563 (-0.15)	***			0.053 (-0.13)			
X_{it}^{lastmob} (ref: sedentary)								
This_year			0.616 (-0.12)	***			0.022 (-0.1)	
1_to_3			0.108 (-0.09)				0.054 (-0.08)	
4_to_6			0.144 (-0.1)				-0.026 (-0.08)	
7_to_9			0.077 (-0.11)				-0.079 (-0.09)	
10+			-0.034 (-0.09)				-0.01 (-0.08)	
Cosign _{it}	0.438 (-0.02)	***	0.436 (-0.02)	***	0.3 (-0.02)	***	0.3 (-0.02)	***
Publis _{it}	-0.059 (-0.01)	***	-0.062 (-0.01)	***	-0.01 (-0.01)	***	-0.01 (-0.01)	***
Geo_net _{it}	0.004 (0.00)		0.005 (0.00)		0.012 (0.00)	**	0.012 (0.00)	**
Social_net _{it}	-0.002 (0.00)	*	-0.002 (0.00)		-0.002 (0.00)		-0.002 (0.00)	
Citat _{it}	0.00 (0.00)		0.00 (0.00)		0.00 (0.00)		0.00 (0.00)	

Note: * p<0.1; ** p<0.05; *** p<0.01 ; blank: non significant.



TABLE 6 Continued

	Exit	
	All alter (5)	Nonattended alter (7)
(Intercept)	-0.167 (-0.1)	-0.491 (-0.08)
$X_{i,t}^{\text{mobnature}}$ (ref: Not_mob)	-0.237 (-0.1)	-0.497 (-0.08)
National	0.206 (-0.16)	-0.036 (-0.12)
Internat	0.286 (-0.17)	-0.047 (-0.13)
$X_{i,t}^{\text{astmob}}$ (ref: sedentary)		
This_year	0.415 (-0.13)	-0.006 (-0.1)
1_to_3	0.408 (-0.1)	0.1 (-0.08)
4_to_6	0.135 (-0.11)	-0.033 (-0.09)
7_to_9	0.147 (-0.12)	-0.063 (-0.09)
10+	0.189 (-0.1)	0.087 (-0.08)
Cosign _{i,t}	0.452 (-0.02)	0.276 (0.00)
Publis _{i,t}	-0.159 (-0.01)	-0.049 (-0.01)
Geo_net _{i,t}	0.015 (0.00)	0.026 (0.00)
Social_net _{i,t}	0.004 (0.00)	-0.001 (0.00)
Citat _{i,t}	0.00 (0.00)	-0.000 (0.00)

Note: * p<0.1; ** p<0.05; *** p<0.01; blank: non significant.



Chinchilla-Rodriguez et al. (2018) showed that the international network of mobility was much lower than the international coauthorship network, suggesting that the international mobility of researchers was not solely responsible for their international cosignatures. The next effect was that mobility weakened previous relationships and the “exit” effect lasted longer than the “entry” one. These results are consistent with those of Bauder (2020) and Wang, Hooi, Li, and Chou (2019). Using interviews of Canadian and German mobile academics, Bauder (2020) showed that mobility may create social capital but may also lead to the loss of national social capital. Using a sample of highly mobile academics in Singapore, Wang et al. (2019) showed that research collaborations in the current host country increase sharply after a move, whereas collaborations with prior countries gradually fade out.

These effects must be taken into account when thinking about research policy and mobility incentives. Encouraging permanent/job-to-job mobility to expand the network of coauthorship seems counterproductive for two reasons. First, mobility had a significant effect on the network, on both entry and exit: it destroyed as many relationships as it created. Second, these effects on the network only concerned coauthors integrated into the geographic trajectory of the researcher. Integrating a new city, the researcher created only relationships with new lab colleagues and replaced the former ones. Ackers (2008) showed that in countries with high skilled scientists, mobility was considered as a sign of excellence only if the researcher had access to local skilled coauthors and had cosigned with them. However, the ability to collaborate with alter from various cities did not depend on the mobility of the researcher. Therefore, short-term mobility should be encouraged because it seemed so much powerful to create a link between scientists.

It is necessary to take precautions in the generalization of our results regarding the limited number of researchers studied and the heterogeneity of mobility patterns between groups of countries (Chinchilla-Rodriguez et al., 2018). Nevertheless, the alignment of modern research on chemistry publication practices (e.g., high frequency of publication, quick review process, and collaborative and international patterns) provided strong legitimacy to this case study. Our results more generally invite some avenues for future research. First, complementary data on careers could mitigate the bias of endogeneity: the experience of geographical mobility can depend on both professional and personal conditions that are missing in our models. Using CV and interviews could complete publication data with details about professional trajectory (e.g., job, promotion and teaching and administrative responsibilities) or personal trajectory (e.g., living place and matrimonial situation). Moreover, an analysis of the chemists' fields of research could help to understand reconfigurations of coauthorship: the entry and exit of coauthors in the network can be explained by thematic bifurcations, generated or not by city changes.

ORCID

Bastien Bernela  <https://orcid.org/0000-0002-2668-9606>

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