Studying co-authorship network dynamics throughout geographical trajectories of researchers: what part does mobility play?

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Abstract: The aim of this paper is to investigate the link between geographical mobility and co-authorship formation and dynamics. We propose a methodology based on matching bibliometric data and qualitative data recoded from CVs and semi-structured interviews. The case study of two prolific chemists (authors of 660 publications with 2,596 co-authors) located in the same laboratory shows that the difference in mobility behaviour does not have a strong incidence on the geography of their co-authorship.

Keywords: Mobility of researchers, co-authorship dynamics, collaboration network, linkage process, data matching.

1. Introduction

Public policies often associate mobility with the idea of excellence (CEC, 2001; MORANO-FOADI, 2005; OECD, 2008), with emphasis at both micro-level (productivity and career outcomes; see LEVIN and STEPHAN, 1991; LONG *et al.*, 1993) and macro-level (competitiveness of institutions and territories). Now taken for granted, the management of academic careers includes an expectation of mobility, especially in the early stages of careers (MUSSELIN, 2004). Mobility can also enhance competitiveness at territorial level since the circulation of scientists guarantees benefits for the host country or the home country in case of return mobility. Literature has progressively moved from a brain-drain to a brain circulation standpoint regarding the networking nature of the scientific profession and the ability of scientists to maintain relationships with previous co-located colleagues (CASEY *et al.*, 2001, MEYER, 2001). The movement of people and ideas represent a hymn for policies, expected to generate knowledge diffusion between partners across borders.

In parallel, scientific collaborations have been widely studied in recent literature, in the context of a growing trend. The emergence of collaborations has occurred with the development of information and communication technologies and a decline in transportation costs (KATZ and MARTIN, 1997; SONNENWALD, 2007), in a general context of internalisation

(GINGRAS, 2002). From a performance perspective, several national empirical studies (LANDRY *et al.*, 1996 for Quebec; LEE and BOZEMAN, 2005 for the US; MAIRESSE and TURNER, 2005 for France; ABRAMO *et al.*, 2009 for Italy) have shown a link between (international) collaborations and productivity at both individual and institutional levels, suggesting research policies should foster cross-border collaborations. Collaboration has progressively become a management tool in research policy, many funding targeted collaborative projects with international partners (SONNENWALD, 2007).

We consider that existing literature has largely focussed on the effect of mobility and collaborations on scientific productivity, but not sufficiently on the relationship between mobility and collaborations. Literature on collaboration has mainly focussed on the organisation of collaborative research and the coordination of the partners involved during projects - organisational patterns of collaborations (CHOMPALOV *et al.*, 2002), work styles (HARA *et al.*, 2003), interaction in cases of remote collaborations (CUMMINGS and KIESLER, 2007; STOKOLS *et al.*, 2008; TORRE, 2011) -, leaving out the genesis of collaborations and partner linkage issues. Few empirical studies have concerned the geography of scientific collaborations and their spatial determinants (MILARD, 2003; JÖNS, 2007). Literature focusses on the post-collaboration period, mostly through publications, but it does not take into account the formation stage (before) in any detail. Such an approach was taken regarding science-industry partnerships (GROSSETTI and BES, 2003; FERRU, 2014) and, like them, we consider that "the formation of the collaboration and notably the connection process of partners imply coordination problems that are necessarily prior to the exchange of knowledge and could also affect the spatial patterns of partnerships" (FERRU, 2014: 976).

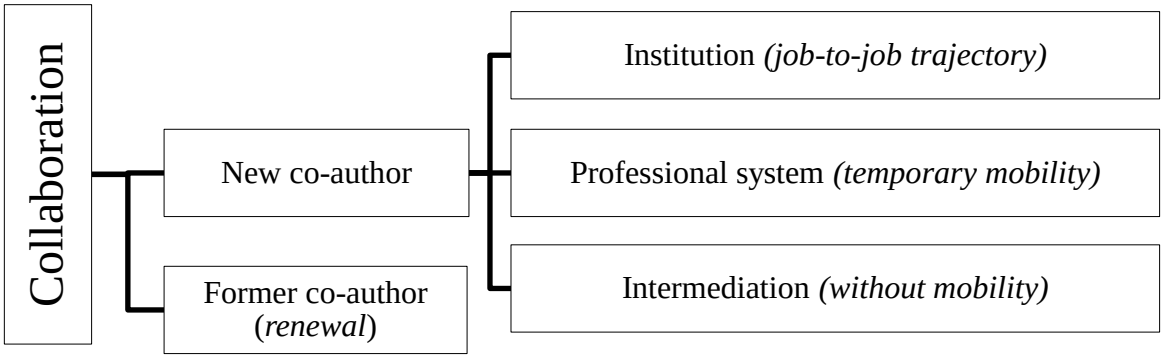
Our aim is to investigate collaboration formation and dynamics in the framework of career analysis. In science studies, literature has not yet permitted a clear identification of the contribution of scientist trajectories in the formation of co-authorship networks and the underlying mechanisms. As FONTES *et al.* (2013: 442) recently underlined, an empirical gap exists since "we still know very little about the role played by mobility on the creation of relationships". Some recent works focus on co-author careers, their continuance, their disappearance and their reactivation (CABANAC *et al.*, 2015), but have yet to investigate the role of mobility in these relationship dynamics. In a context of low scientist mobility in France, some criticisms emerge 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. However, to our knowledge there is no empirical evidence of this relationship.

This paper provides a methodological framework to better understand the formation, dynamics and geography of co-authorship throughout careers. Firstly, there is an overview of the way mobility can enhance co-authorship (section 2). Subsequently, we discuss the sources used to identify collaborations and mobility (section 3). We propose to match several sources of data (publications, *curriculum vitae*, interviews) to provide a quantitative and qualitative analysis of trajectories and collaborative dynamics of researchers (section 4). We then test this method on two cases of prolific chemists and submit empirical evidence on the link between geographical trajectory and collaboration dynamics (section 5). We conclude by discussing these preliminary results and formalising a research agenda on this subject area (section 6).

2. How can mobility contribute (or not) to co-authorship?

In order to understand the relationship between mobility and co-authorship, many scholars focus on the change in researchers' location, which is undoubtedly an important way to meet new co-authors. However, other opportunities to link exist besides institutional affiliation. We propose a typology of modalities of linkage (Figure 1) that also takes into account the role of temporary mobility and intermediation. CABANAC *et al.* (2015) have shown a strong tendency for collaboration renewal throughout careers that is also taken into consideration by this paper.

Figure 1. Typology of modalities of linkage



The role of institution in collaboration: being co-located and belonging to the same team

Several theoretical arguments tend to support the idea that geographical trajectory structures collaboration. The first commonly developed idea is that co-location of two parties (i.e. the existence of geographical proximity) facilitates collaboration and interaction. In the case of academia, it means that scientific collaboration is more likely to emerge between researchers located in close geographical proximity: belonging to the same institution guarantees both spatial and non-spatial proximity. According to the geography of innovation scholars (FELDMAN, 1999), geographical proximity is a way to exchange tacit knowledge and to develop other non-spatial proximity including social, cognitive and institutional, etc.

Mobility diversifies the places frequented during a career and can significantly augment the address book and relational circle. This idea fits with the concept of "scientific social capital", a part of scientific and technical human capital developed in BOZEMAN's work (BOZEMAN *et al.*, 2001; BOZEMAN and CORLEY, 2004). "A researcher's mobility, and his/her ability and opportunities to engage in research collaboration, are thus not only affected by their level of knowledge and scientific expertise, but also by his/her scientific social capital; the sum of his/her relationships to other scientists" (JONKERS and TIJSSEN, 2008: 313).

From a dynamic perspective, past trajectory continues to influence collaboration after mobility, with relationships being maintained. The hypothesis of "enduring social relationship" was confirmed by the empirical work of AGRAWAL *et al.* (2006:589): "once relationships are established, individuals can remain socially close even when they become geographically separated". Concepts of embeddedness (GRANOVETTER, 1985) and social

proximity between partners contribute to the explanation of the renewal of collaborations. "Researchers who move can be conceptualised as 'network builders', who establish social connections and personalised relationships that endure beyond their tenure in particular places" (WOOLLEY and TURPIN, 2009: 145). MIGUELEZ (2013) develops the idea of "previous co-location premium" that we intend to test empirically on scientific collaborations.

The networking nature of science: temporary mobility and interpersonal relations

On the other hand, some arguments suggest that collaboration networks can be established independently of the geographical job-to-job trajectory of scientists and that meetings are independent of the life of a laboratory.

Firstly, academia is characterised by its networking nature, organised as a professional system. AGRAWAL *et al.* (2006: 573) argue that "geography is likely to be less important in mediating social relationships between individuals in the same field since they have various alternative mechanisms through which to establish relationships. For example, individuals in the same community of practice or invisible college attend conferences and trade shows together, belong to common associations, and have other institutional settings in which to fraternise and share ideas". The temporary geographical trajectory of a scientist, built by participations to professional events - visiting scholar, conferences, member of a jury, etc. -, seem to be as much, if not more, important in terms of linkage opportunities and network formation. These events are characterised by a combination of organised proximity and temporary geographical proximity between non-co-located partners (TORRE, 2008, 2011), often leading to collaboration at a distance. Empirical evidence regarding the ability of parties to collaborate at a distance means that scientists can practice collaborative research independently of their permanent geographical location, temporary mobility and ubiquity being a way to meet new colleagues and then to manage long-distance partnerships.

Secondly, interpersonal mediation can allow access to resources and contacts without geographical movement. Individuals are embedded in networks of interpersonal relations and can put into contact some of their relationships. Intermediations can occur without a physical meeting between co-authors. They can also lead to mobility once contact is established (mostly mobility of precarious scientists in the framework of research stays).

The widespread view according to which international collaboration is a skill acquired by a scientific elite (LEYDESDORFF and WAGNER, 2008) suggests that, as the careers of researchers progress, geographical patterns are marked by an accumulation of international collaborations. This assumption suggests that an ongoing socialisation to international relationships, making senior researchers the best able to drive worldwide research, may be contradicted by the increasingly early stage at which young researchers have to move internationally, faced with precarious employment. However, we can wonder whether temporary foreign stays are associated to more international collaborations and, more generally, whether they condition coming collaborations. In other words, are former colleagues significantly represented in mobile researcher co-authorship? If so, it would

confirm the social capital accumulation assumption or, if not, it would reduce the bonus associated to geographical mobility in the development of professional relationships.

Furthermore, where do non-institutional relationships come from? If they are built up through conferences or other events of the scientific life of researchers, it underlines the importance of the circulation of researchers more than that of job changes. When collaborations are the result of interpersonal mediation, geographical mobility appears to no longer be necessary as the parties may never meet each other. Broadly speaking, we can question the link between mobility and collaboration continuation: 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? Investigating these issues should allow a better understanding of the nature of co-authoring teams that can be seen as a growing trend, but as yet little is known about modes of formation, renewing and continuation.

3. Sources for tracking collaboration and mobility: bibliographic data and CV

In the context of a significant increase in (international) collaborative science (LUUKKONEN *et al.*, 1992; WAGNER and LEYDESDORFF, 2005), many studies have concerned scientific collaboration dynamics. Since the seminal work of BEAVER and ROSEN (1978), specific research areas regarding scientific collaborations have developed as economics, sociology and geography of science, scientometrics, research evaluation and science policy studies. KATZ and MARTIN (1997: 7) define research collaboration as "the working together of researchers to achieve the common goal of producing new scientific knowledge". This notion of "production" has led to bibliometric analyses which consist of using co-publications as an indicator of collaboration.

MELIN and PERSSON (1996) and KATZ and MARTIN (1997) report the difficulty of identifying a precise perimeter of research collaboration and, even more, its measurement. Methodologically, a common way to identify researcher collaboration consists of retrieving the co-authors from a list of publications. "Bibliometric analysts recognise that co-publications constitute a partial indicator of (successful) research collaboration and collaborative networks because not all joint research is published and not all co-authors need to have contributed equally." (JONKERS and TIJSSEN, 2008: 312). BERNELA and LEVY (2015) discuss the validity of complete graph representation from innovation projects data and demonstrate that - although all partners in a project do not interact with the same intensity - this hypothesis is not so abusive and does not strongly modify network properties. Beyond the underlying limitations of using an indicator, co-publications seem to be the most satisfactory way, also chosen in this paper, to study scientific collaboration patterns.

Many empirical investigations use publications or patents data to study career paths, in line with JAFFE *et al.* (1993). They identify inventor and author affiliations at the different dates of patents/publications and deduce whether or not there was mobility by comparing the locations at these different events. This method has the advantage of providing a lot of peripheral information on mobility and allows the researcher to draw simultaneously from a single data

source: their spatial trajectory (through institutional affiliation), the collaborative processes involved (through co-productions) and networking effects (through citations and references).

We do not consider tracking mobility using only bibliographic data as a satisfactory method for three main reasons. Firstly, publication is a moment in a career and enables you to know the location for each moment identified, without the possibility of interpreting any changes occurring between two moments: it therefore obscures periods of "non-production" in the careers of individuals (DUBOIS *et al.*, 2014). Secondly, KATZ and MARTIN (1997) highlight problems related to researcher affiliation. Many of them have multi-affiliations and primary affiliation does not necessarily indicate the place where the article was produced. Moreover, depending on the publication time process, there can be a substantial gap in time between article production and publication, potentially generating a spatial gap between the two locations in case of mobility (FURUKAWA *et al.*, 2011). Lastly, publication data only allows the identification of job-to-job mobility and not temporary mobility, which can be equally important.

Considering the limitations of only using bibliometric data, CVs have progressively become a research tool to study scientists' trajectories (for a survey on the CV method in science policy, see notably CAÑIBANO and BOZEMAN, 2009). "In parallel with careers, CVs evolve over time capturing changes in interests, jobs and collaborations (DIETZ *et al.*, 2000). CVs reflect both, career trajectories and also the outcome and specific features of these careers." (CAÑIBANO *et al.*, 2008: 18-19). Although CVs have the intrinsic quality of collecting sufficiently accurate data on careers "rather than quantifying particular knowledge products at particular times" (CAÑIBANO *et al.*, 2011: 655), their collection and coding require a relatively large investment of time which can restrict the size of the population studied. This is the reason works that use CV data are often case studies. For example, SABATIER *et al.* (2006) have used the CVs of French life scientists to study the effect of gender on career advancement. FONTES (2007) uses CVs to obtain biographical information as a complement to a questionnaire about the repatriation of Portuguese scientists. To our knowledge, only JONKERS and TIJSSEN (2008) use CVs as a complement to bibliometric data in order to assess the links between the scientific mobility and co-authorship of Chinese researchers.

To delve deeper into the empirical gap regarding the role of the geographical trajectory of scientists in explaining the formation of collaborations, we propose an original methodology consisting of the use of several data sources that are rarely combined in science studies.

4. Combining publication data, CV coding and semi-structured interviews: a methodological framework

4.1. Publication data and bibliometric analyses: identifying collaboration networks

From the publication list of a scientist, we split co-authored articles into co-authorship pairs (MELIN and PERSSON, 1996) and we used these collaborative ties to generate an a-hierarchical and reciprocal network (MAGGIONI and UBERTI, 2011), as suggested in Figure 2.

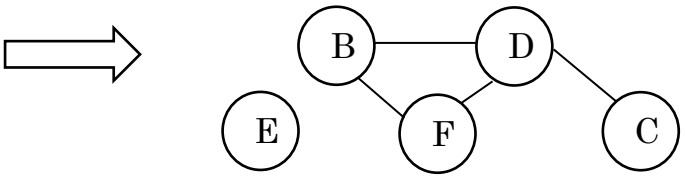
We put forth the use of Thomson Reuters' Web of Science to collect publications, which is a well-known and reliable source in science studies. Spatial information contained in this

database regards the affiliations of authors in the form of a list of addresses. However, the number of addresses does not often correspond to the number of authors (several co-authors belonging to the same team, multi-affiliations of an author, etc.) which prevents the identification of the address to which each author belongs. This methodological consideration implies that most studies focus on the address level only - 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 scientific trajectories. In our case, we used web search engines to collect all the locations of co-authors listed on a publication (laboratory, city and country of affiliation). This represents a time-consuming task of disambiguation, standardisation and coding of database, necessary to obtain reliable geographical information. We can also question the geography of collaborations (local/national/international) and see in which proportion pairs consisting of the researchers studied and their co-authors are characterised by geographical proximity.

Figure 2. From a list of publications to scientific co-authorship networks

List of publications of A

- Publication 1: A, B
- Publication 2: A, C, D
- Publication 3: A, E
- Publication 4: A, B, D, F



PERSSON *et al.* (2004) caution against an inflated use of bibliometric data and encourage coupling using more qualitative research. "We should use co-authorship data as a rough indicator of collaboration and also try to collect other kinds of data to reduce the various kinds of uncertainties involved" (MELIN and PERSSON, 1996: 364-365). That is why our approach is to match publication data and CVs.

4.2. CV collection and coding: reconstructing career paths and mobility

Methodologically speaking, we rebuild the trajectory of researchers from their CV (DIETZ *et al.*, 2000), which allows the identification of a researcher's professional trajectory, which in turn refers to their career advancement. Said professional trajectory can be translated institutionally and geographically. The institutional trajectory refers to all the laboratories in which scientists have exercised their research activity during their careers. The geographical trajectory refers to all the locations frequented. A change in trajectory, whatever its nature, corresponds to mobility. In this paper, we will especially focus on the geographical aspect of trajectories; mobility will refer to a change of location.

When analysing the spatial trajectories of scientists, it seems crucial to consider the "temporal quality of moves" (ACKERS, 2005). In a European context, the multiplication of short-term moves rather than longer-term ones promotes a reference to mobility rather than migration (WILLIAMS *et al.*, 2004). In reference to the traditional breakdown of geographical proximity operationalised by TORRE and RALLET (2005), it seems relevant to draw a distinction between permanent and temporary mobility (MORE, 2010; LAWSON and SHIBAYAMA, 2015). The

former – which we shall term job-to-job mobility - consists of a primary affiliation change and occurs systematically with institutional mobility. Postdoctoral positions are included in job-to-job mobility configurations. The latter refers to short-term moves without a change in primary affiliation (such as research visits, secondment, etc.). These temporary moves are characterised by a return to former locations/institutions, which is not necessarily the case after a post-doctoral fellowship, for instance. This last type of mobility is studied far less, because it is difficult to identify, and contributes to what MEYER *et al.* (2001) call "scientific nomadism", i.e. the ability of ubiquity of researchers. As JÖNS (2009: 317) mentioned, the reasons for so few studies on academic mobility include "a lack of data and its fleeting nature", particularly for temporal mobility, which is "less visible".

CV analysis also allows the consolidation of publication data and checking whether there are some missing co-authored publications. Last but not least, "the CV does allow one to go more deeply into acquaintance and common background and, as such, provides a useful complement to bibliometric data" (CAÑIBANO and BOZEMAN, 2009: 92-93): it constitutes a rich source of relational data about participation in juries, the supervision of PhDs and postdocs, participation in funded collaborative projects, etc.

4.3. Semi-structured interviews: questioning modalities of linkage

The development of bibliometric analyses has provided understanding about the collaborative dynamics of researchers through publications. However, the limited amount of information (a list of people and addresses) does not allow an examination of the nature of relationships between co-authors beyond quantitative indicators. To capture the relational aspect behind publication activity, we need to collect qualitative material by interacting directly with the parties, represented by the researchers themselves (MILARD, 2011). We therefore aim to combine current data with semi-structured interviews with researchers to examine the linkage processes between co-authors.

We have built a typology of modalities of linkage, presented in Figure 1, using theoretical frameworks in existing literature and material collected in interviews. This has allowed us to develop arguments suggesting that job-to-job trajectory can explain some collaboration, but is not sufficient to understand how researchers meet and work.

Regarding data consolidation, interviews have also been conducted to gather more qualitative information on careers: scientists developed the different sequences of their careers and the reasons for mobility. Then, from the chronological list of their publications, we looked at the genesis of the collaboration with each of their co-authors. Modalities of linkage have been coded from the typology reported in Figure 1 and has been refined following the interviews. The geography of linkage is also integrated in the interview since we are able to know where the meetings took place. Interviews are lengthy – around eight hours per researcher – as we have to address each case of collaboration. During interviews, we observed some cases in which several modalities of linkage operate together and it is difficult to isolate one. For example, some stays during PhD theses or postdoctoral positions are linked to a PhD supervisor's scientific contacts: in these cases, interpersonal relationships generate mobility,

which corresponds more to network consolidation than to network formation. It confirms the results of MELIN (2004), who demonstrates that most postdoc destinations rely on the existing scientific ties of a supervisor or colleagues.

Before moving to an in-depth case study of scientists, Table 1 summarises our methodological approach in studying the relationship between geographical trajectory and co-authorship network dynamics. Both primary and secondary data (MAGGIONI and UBERTI, 2011) are used to study careers, networks and their geography. At the end of the process, each node of the network is replaced in the career context. "Although temporal sequence analyses have been applied to the study of co-author networks (BARABASI *et al.*, 2002; PALLA *et al.*, 2007), analysis of the evolutionary mechanisms of the network whilst considering researcher mobility is yet to be conducted" (FURUKAWA *et al.*, 2011: 452).

Table 1. Synthesis of data collection and matching

Step 1: Publications	Identification of co-authors and renewal in time + co-authorship dynamics during the entire career
Step 2: CV	Identification of professional, institutional and geographical trajectory + relational information
Step 3: Interviews	Contextualisation of network formation + modalities of linkage with co-authors

5. The comparison of two prolific chemists

The two researchers studied in this paper, Sophie and Arnaud[1], were chosen for their uniqueness regarding our research subject and also for their comparability. They are both at an advanced stage in their careers and established in their scientific field. Besides the fact that Sophie is female and Arnaud is male, the former has never experienced mobility whereas the latter has moved a lot over the length of his career. This last difference is crucial for us: it does not allow generalisation in these two cases, but strongly conceptualises the issue of mobility in co-authorship dynamics thanks to a detailed analysis of these particular cases. For this purpose, and in accordance with a growing trend in social sciences, we chose to combine qualitative study with quantitative data. The analysis of Sophie and Arnaud's careers (from their first publication to 2012) led us to study their 660 publications and more than 2,500 co-authorship relationships.

5.1. Careers

Our approach is to apply our methodology to two researchers - Arnaud, university full professor, and Sophie, CNRS research director - both located in the same chemistry laboratory in Toulouse. They began their research activity around the same period; Arnaud earned his PhD in 1985 and Sophie in 1984. Their career paths, identified from CVs, are

[1] The first names of researchers have been changed.

represented in Figure 3. We observed a significant difference in job-to-job trajectory behaviour between the two researchers: Arnaud made several international moves (Italy, England, United States and France) while Sophie spent her entire career in Toulouse. Personal factors come into play when explaining this behaviour. Being responsible for the care of family members, Sophie was not really able to move. Arnaud had to leave Italy because of a shortage of academic positions and applied for French opportunities as his wife was French and wanted to return to her country.

There are descriptive statistics regarding their publication activities and co-authorship detailed in Table 2. Concerning the rhythm and quality of their publication activities, they more or less have the same score after thirty years of research - three hundred articles - with a large proportion published in prestigious chemistry journals, making their contribution to their field highly significant. The mean number of publications is higher for Sophie, but it should be remembered that she does not teach, unlike Arnaud. Sophie and Arnaud have both exercised very collaborative research. The mean of co-authors by publication is higher for Sophie than Arnaud (4.54 *versus* 3.27), but both increased over time, especially since the early 2000s (Figure 4a). Since the beginning of their careers, Sophie has co-signed 1574 times with 429 different co-authors, and Arnaud 1022 times with 325 co-authors. Many collaborations consist of bringing together different scientific expertise that is not all held by a single person or team. For example, they need partners to access some building blocks, technicians (crystallography, chromatography, spectroscopy, X-rays, etc.) and theorists for modelling.

Table 2. Descriptive statistics about co-authorship

	Sophie	**Arnaud**
Date of first publication	1983	1981
Number of publications	347	313
Average number of publications by year	11.6	9.8
Number of non-co-authored publications	0	14
Number of collaborations	1574	1022
Average number of co-authors by publication	4.5	3.3
Number of co-authors	429	325
Average number of new co-authors by publication	1.2	1.0
‘One-off’ co-authors	260 (61%)	181 (56%)

The first elements provided here indicate that, although Sophie and Arnaud have conducted very different careers geographically speaking, they are both confirmed scientists and have a high level of publication activity and a developed co-authorship. The contrast between these two geographical paths represents a great opportunity for understanding the role of mobility in collaboration dynamics. As both Arnaud and Sophie are recognised as excellent researchers in their fields, we neutralise performance issues and focus specifically on the role of mobility on co-authorship formation. Table 3 provides a general outlook of co-authorship geography on the entire career and we can underline five main results.

Figure 3. Career paths

Sophie	Year	Arnaud
PhD thesis, Toulouse (France)	1982	
	1983	PhD thesis, Pisa (Italy); student exchange fellowship during one year in London (UK)
	1984	
Postdoctoral position, Rueil Malmaison (France)	1985	
CNRS Researcher (CR2), Toulouse (France)	1986	Research associate, College Station (USA)
	1987	
	1988	Assistant professor, College Park (USA)
Postdoctoral position, Saarbrucken (Germany)	1989	
CNRS Researcher (CR1), Toulouse (France)	1990	
	1991	
	1992	
	1993	Associate professor, College Park (USA)
	1994	
	1995	
	1996	Full professor, College Park (USA)
CNRS Researcher (DR2), Toulouse (France)	1997	Full professor, Dijon (France)
	1998	
	1999	
	2000	
	2001	
	2002	
	2003	Secondment from Dijon to Toulouse (France)
	2004	
CNRS Researcher (DR1), Toulouse (France)	2005	Full professor, Toulouse (France)
	2006	
	2007	
	2008	
	2009	
	2010	
	2011	
	2012	

Firstly, given her geographical trajectory, the Sophie's co-authorship is significantly influenced by French collaborations, which represent 75% of co-signing (Table 3a). The locations of Arnaud's co-authors are more dispersed worldwide, with a three-thirds repartition between France, Europe and outside Europe, hiding local collaborations in each category, since Arnaud has worked in different countries (France, Italy and the United States).

Secondly, when looking at the geography of collaboration between partners (Table 3b), we observed that the highest share in total co-authorship corresponds to collaborations with co-authors belonging to the same team, both for Sophie (55.7%) and Arnaud (45.4%). The difference in this part for the two researchers is not negligible, but if we focus only on new collaborators (i.e. renewal of co-authorship), Arnaud's mobility generated just a little bit more new collaborations within his teams (29.1%), while he has belonged to several new laboratories. The renewal of laboratory co-authorship of Sophie, despite her lack of mobility, reaches 24.4%. This means that local collaborations can renew over time, even in the case of a local career.

Thirdly, collaborations with co-authors located in another laboratory in the same city (Table 3b) are relatively high for Sophie (16% of co-authors) and mainly correspond to interdisciplinary collaborations, namely with biologists and nanomaterials scientists. Sophie is rooted in Toulouse, where she grew up scientifically speaking; as reported in the interview, she has a perfect view of the local scientific system and the specialisation of laboratories, in which she has many contacts. In the case of Sophie's co-authorship, local intermediations have been very frequent. Given his mobility, Arnaud did not build his career on a spatially-bounded basis and did not collaborate a lot with other laboratories in the cities he frequented.

Fourth, Table 3c indicates that Arnaud maintains some relationships with former colleagues after moving: when looking dynamically at the geography of co-authorship, i.e. integrating the trajectory of the researcher, we observed that almost one tenth of his collaborations were conducted with former colleagues. When we add the share of 'current location' and 'past location' score for Arnaud, this almost matches the share of 'current location' for Sophie, confirming a similar role of institutional context in their scientific network. It confirms that the absence of mobility does not inhibit co-authorship renewal. The quasi-inexistence of 'future location' indicates that collaborations do not prefigure mobility: co-authorship and mobility seem to be two independent phenomena.

Fifth, Table 3d provides a precise understanding of Sophie and Arnaud's linkage processes with their co-authors. It confirms previous results as the comparable importance of institutional context in their co-authorship, even higher for Arnaud (32% of linkage), while Sophie (respectively 25%) has always worked in the same laboratory. Regarding laboratory co-authorships, the repartition between permanent and precarious co-authors is similar (precarious ones account for around twice the number of permanent ones). Non-institutional context is therefore the main way researchers meet. The professional system and temporary mobility represent 8% of linkage for Sophie and 17% for Arnaud. In addition to short-term moves, Arnaud met some of his co-authors through medium-term moves, more institutionalised as visits or secondment, which is not the case for Sophie, who cannot move for long periods of time. Concerning the role of relationships, it was soon apparent during

interviews that all interpersonal relationships do not lead to the same result: our intention is to distinguish between intermediation and second-rank. The former leads to a strong relationship between *ego* and the co-author, while second-rank co-authors are not well-known by *ego*, such as the following example: "It is a collaboration with the team conducted by Adrien, and the three other co-authors are in the team of Adrien, but I think I have not met any of them, there were probably Adrien's students or postdocs" (Sophie). Second-rank co-authors represent around half of the total number of collaborators and their incidence increases over a career. In 78 per cent of cases, they represent one-off collaborations.

When excluding second-rank ties in their co-authorship (see second column of Table 3d), we observed that, for non-institutional relationships, there is a strong difference in the way Sophie and Arnaud access their co-authors: professional system incidence is almost twice as high for Arnaud, and interpersonal relationships are more than twice as high for Sophie. In accordance with the fact that Sophie has not moved during her career, she does not meet her co-authors through the professional system, for which temporary mobility is necessary; however, this low mobility is largely compensated by the activation of a relational chain.

The analysis of collaboration as a stock shows how Arnaud's geographic mobility has configured his relations, which are more international and often associated to temporary moves. However, it does not seem that this mobility has boosted his co-authorship: Arnaud does not have significantly more new team collaborators than Sophie, even though he moved regularly from one laboratory to another. The total number of co-authors located in current and past laboratories is no higher than the number for a non-mobile researcher. Relationships from institutional contexts have the same incidence, while the high share of relationships due to temporary mobility can be largely compensated by intermediations to reach new co-authors. Although the career geographies are very different, co-authorships seem comparable and there is no evidence of a mobility premium.

Table 3. Descriptive statistics on co-authorship geography

		ego			
Data source		**Sophie**		**Arnaud**	
		New (n=429)	Total (n=1574)	New (n=325)	Total (n=1022)
	3a. Location of co-authors (%)				
Publications	France	63.3	75.4	23.5	33.2
	Europe	29.8	21.2	46.0	32.9
	Outside Europe	6.9	3.4	30.5	33.9
	3b. Geography of couples "*ego*-co-author" (%)				
	Same laboratory	24.4	55.7	29.1	45.4
Publications	Same city	16.0	9.7	1.2	0.8
	Same country	23.0	10.0	8.8	8.7

	Same continent	29.8	21.2	40.1	26.4
	Other continent	6.9	3.4	20.8	18.7
	3c. Geography of collaboration regarding *ego* trajectory (%)				
	Current location	40.3	65.4	30.3	46.2
+CV	Past location	0.5	0.1	5.4	9.5
	Future location	0.0	0.0	0.6	0.4
	Non-frequented location	59.2	34.5	63.7	43.9
	3d. Modalities of linkage between *ego* and co-authors (%)		*(Second-rank excluded)*		*(Second-rank excluded)*
	Institution	25.2	(*54.0*)	32.9	(*57.8*)
	Permanent	8.6	(*18.5*)	12.0	(*21.1*)
	Precarious	16.5	(*35.5*)	20.9	(*36.8*)
+Interviews	Professional system	7.9	(*17.0*)	17.2	(*30.3*)
	Medium-term	0.0	(*0.0*)	3.1	(*5.4*)
	Short-term	7.9	(*17.0*)	14.1	(*24.9*)
	Intermediation	66.9	(-)	49.9	(-)
	Interpersonal relation	*13.5*	*(29.0)*	6.8	(*11.9*)
	Second-rank	*53.4*	*(-)*	43.1	(-)

5.2. Trajectories

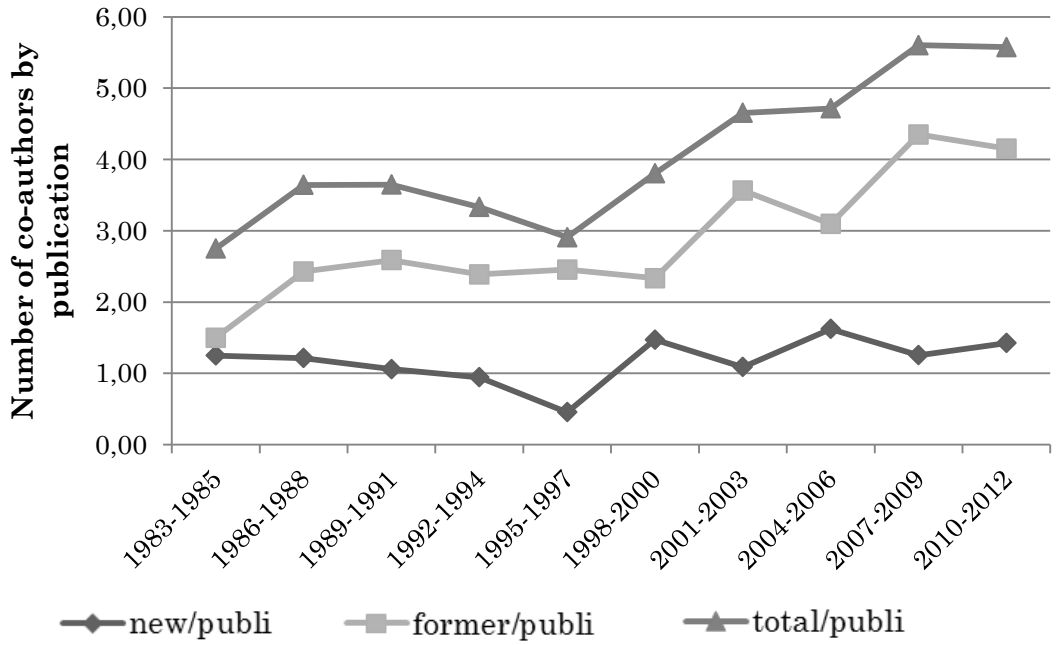
At the moment, the results on Sophie and Arnaud's co-authorship focussed on their whole careers and did not take into account their evolution over time. Figures 4 give a precise overview of the researchers' co-authorship dynamics, its renewal over time and its geography. Note that, in Figures 4a and 4b, co-authorship is normalised by publication: we calculate the mean of co-authors per article for each period. For example, Sophie published 53 articles between 2004 and 2006 and co-signed 250 times, with 86 new co-authors: in other words, during the period 2004-2006, Sophie mobilised an average of 4.7 co-authors by article, of which 1.6 were new co-authors and 3.1 previous co-authors.

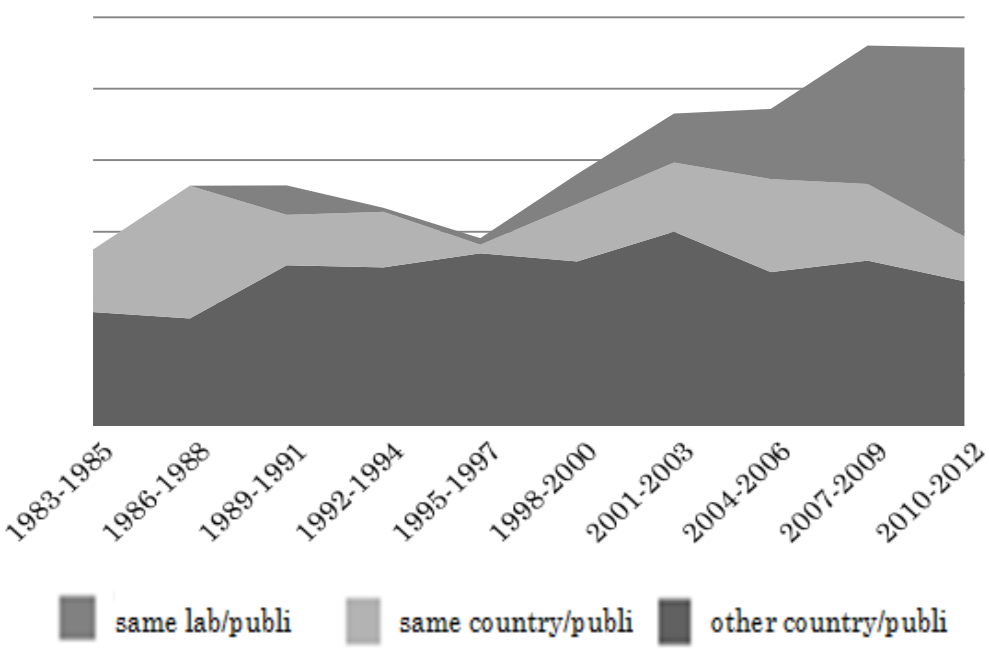
We can divide Sophie's career into two main periods of equal duration (1983-1997; 1998-2012). During the first period, Sophie was highly focussed on her team: the mobilisation of local colleagues was reinforced over time, notably through the recruitment of PhD students and postdoctoral fellows. Collaborations with other laboratories came essentially from the initiative of her colleagues. The continuity in her scientific subjects is striking: "Since my PhD, I have always worked in phosphorus chemistry" (Sophie) and 237 of her 347 publications contain "*phosp*-" in their title. In 1994, together with two team colleagues (a permanent and a PhD student) and a Parisian theorist, picked specifically for this initiative, she published a key article that marked the beginning of a research path for both Sophie and

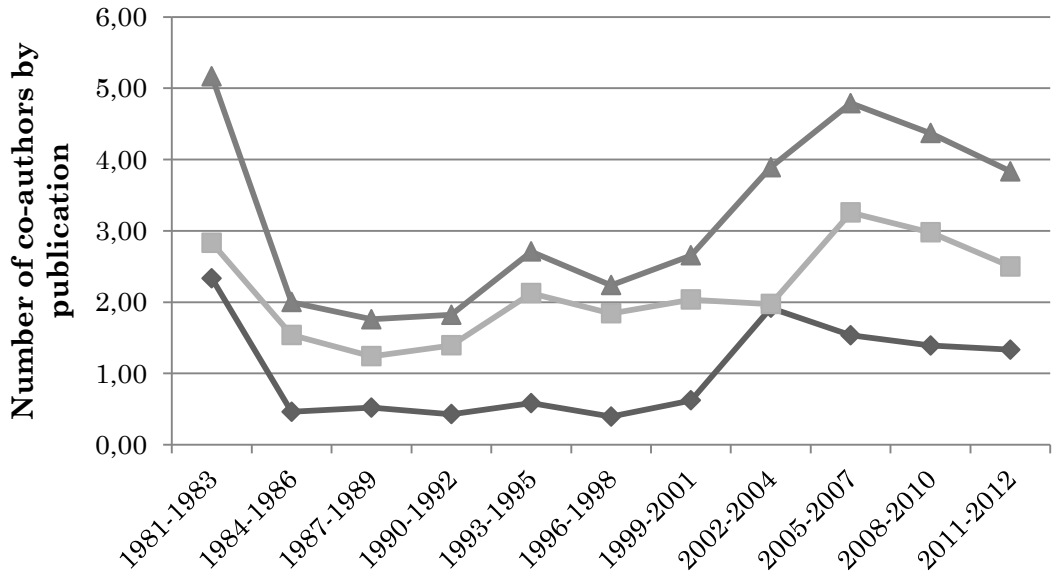
her team. During the next three years, Sophie invested intensively in this promising direction and published a lot of articles in high-ranking journals: we observed a severe refocussing on her team during this period (1994-1997) during which the creation of partnerships with other teams were almost inexistent (the share of her laboratory colleagues in the total number of collaborations reached 92% during this period). Drawing on the expertise developed, which was unique internationally speaking, Sophie became research director in 1997 and began a new phase of her career. Her research field increasingly influenced those in her team and she took the lead in 2006. From 1998, Figures 4a and 4b show a sharp acceleration in publication and collaboration rhythms, as well as an internationalisation of Sophie's co-authorship, highlighting scientific recognition mainly beyond the confines of Toulouse. The share (and not the number) of co-authors located in France significantly diminished while those of international collaborations rose from 3.8% in the period 1983-1997 to 29.3% in the period 1998-2012. This geographical expansion of co-authorship was partially based on European research program foundations, extra-European collaborations being rarer. For example, "this publication comes from collaboration with Spanish people in the framework of a European program. We are, with Spanish, Polish and Italian, the hard core teams of the network. Then, it allows meeting other teams we know less about, often partners of our partners" (Sophie). These research networks are an opportunity for many intermediations with remote partners.

Arnaud followed a radically different path, mobility having repeatedly cumulated and changed his scientific interests. The first period corresponds to his PhD thesis in Italy and is characterised by a dense co-authorship, which can be explained by a tradition of high labour division in that research system (several technicians do the experimental part of the work). The mean number of co-authors by publication dropped from 5 to 3 since Arnaud moved to the United States: "there were not technicians in the lab, each one did all the process himself" (Arnaud). In the 1993-1995 period, he hired his first students (PhD candidates and postdoctoral fellows) with whom he wrote many papers, explaining the peak of former co-authors. During the period in America, Arnaud's co-authorship was mainly local as resources were located in his laboratory, where he benefitted from a good level of funding. He subsequently moved back to France for personal reasons, taking a position in Dijon, before moving to Toulouse. In 2003-2004, he signed a secondment contract from Dijon to Toulouse during which he built up new collaborations with laboratory colleagues (a rise in new co-authors during the 2002-2004 period). During the next period, the share of new co-authors decreased, whereas those of former rose: Arnaud settled into the laboratory, became team leader and renewed collaborations started during secondment. The result suggests that medium-term mobility is an important modality of linkage; the mutation that followed did not bring new collaborations. In other words, temporary moves can be as "efficient", relationally speaking, as permanent job changes. Geographically, the arrival in Toulouse generated a reinforcement of local collaborations to the detriment of international ones (in terms of share, not volume): it revealed an anchoring dynamic in Arnaud's new laboratory, the inverse movement we observed for Sophie.

Figure 4a. Renewal of co-authors over time ***(Above: Sophie; Below: Arnaud)*** **Figure 4b. Evolution of co-authorship geography**







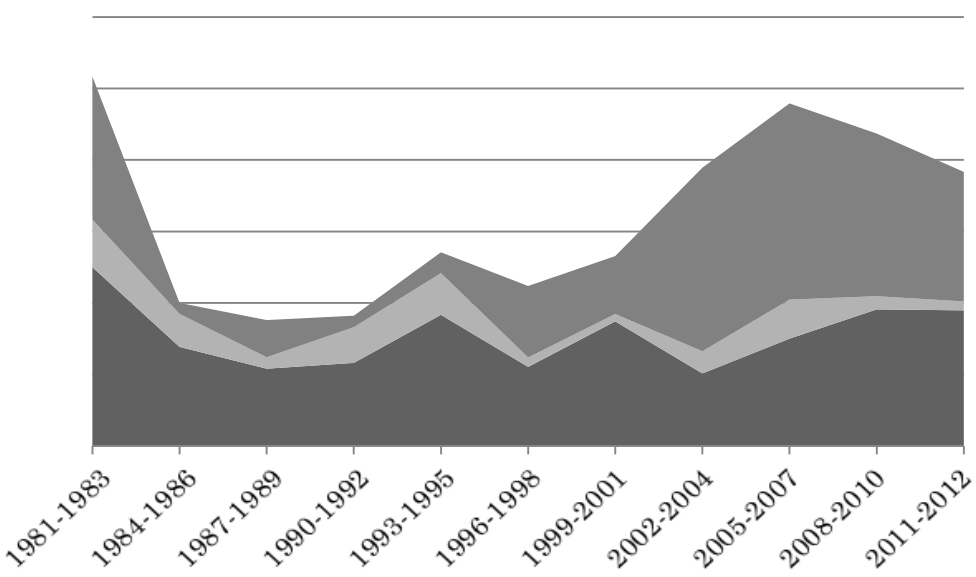
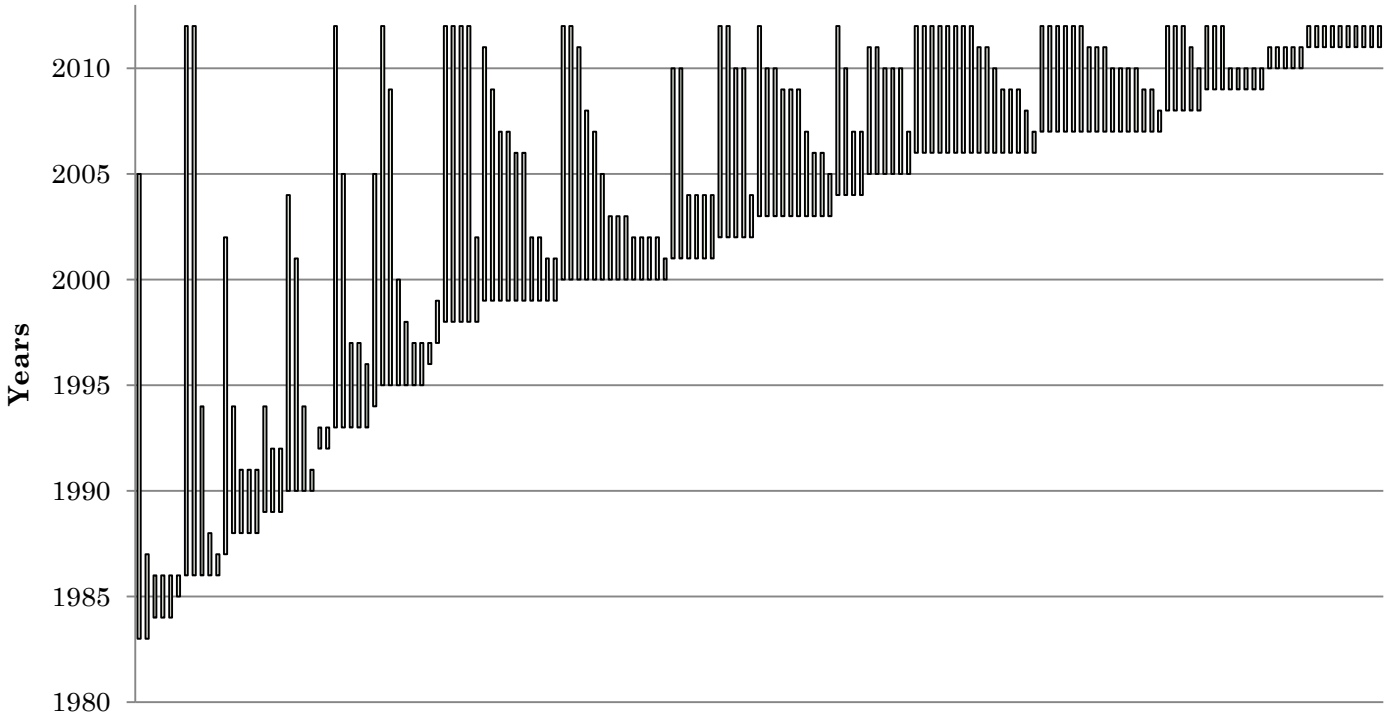
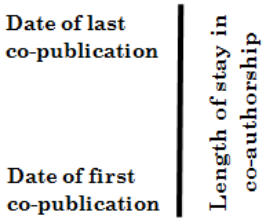
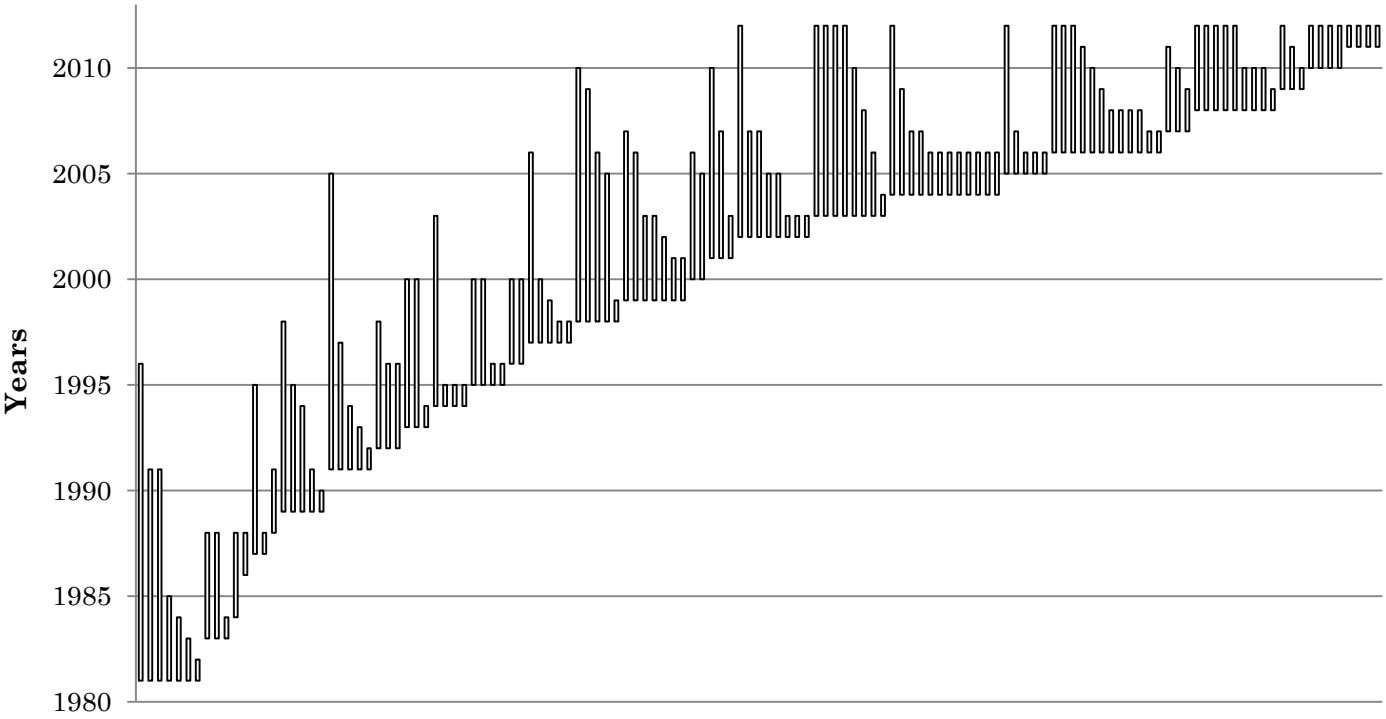


Figure 4c. Longevity of co-authorship relationships *(Above: Sophie; Below: Arnaud*)





In abscissa, co-authors are represented in the chronological order they appear in *ego* co-authorship. The length of a bar corresponds to the presence of a co-author in *ego* co-authorship. Co-authors publishing with *ego* during a single year are excluded from that figure.



Lastly, Figure 4c highlights that some relationships stand the test of time while others are ephemeral. We can see that the average length of stay in co-authorship is higher in Sophie's case (a mean of 6.1 years for Sophie compared to 5.0 for Arnaud). Since Sophie worked on the same subject and in the same location since the beginning of her career, the length of time during which she mobilised co-authors is higher than Arnaud's. We can assume that too much geographical job-to-job mobility weakens relationships, which are costly to maintain. The tendency of Arnaud to diversify scientific fields would also have to be taken into account in the dynamics of his co-authorship. However, we need to note that this trend is partly linked to Arnaud's need to adapt his scientific fields to his new team following a move.

Table 4. Evolution of modalities of linkage over a career (second-rank excluded)

	Doctoral and postdoctoral positions (*periods 1-2*)	**Junior/confirmed researcher (*periods 3-4-5*)**	**Senior researcher (*periods 6-7-8*)**	**Team leader (*periods 9-10-11*)**
Sophie				
Institution	12	27	45	24
Professional system	0	5	20	8
Intermediation	11	7	24	14
Arnaud				
Institution	7	23	27	45
Professional system	3	9	25	16
Intermediation	3	0	7	12

Table 4 details the evolution of the linkage process over their careers, without considering second-rank collaborations which are not proper relationships, but relationships of relationships. The table was completed using qualitative material gathered during interviews. We can notice the importance for the two researchers of the institutional context, the incidence of which is around half the co-authors in each period. The incidence of new relationships established through this channel was greater during the early stages of their careers (more than one third in the junior/confirmed researcher period), as if the period was not conducive to openness towards the outside world. Besides relationships within her laboratory, Sophie has always privileged intermediation during her career, mainly at the beginning (half of the linkage).

Tackling co-authorship issues through geographical trajectory does not allow taking into consideration the sum of new collaborations as a simple social capital accumulation. These two case studies show that scientific collaboration dynamics are marked by biographical, professional and personal elements and by geographical paths. Moreover, topic dynamics undoubtedly play a central role in co-authorship dynamics as some co-authors are mobilised

according to thematic areas: the renewal of co-authorship therefore depends on specialisation or diversification. The role of thematic trajectory may constitute a promising avenue for further research.

6. Conclusion

This aim of this article is to discuss the contribution of spatial trajectories in the formation, the dynamics and the geography of scientific collaboration networks: firstly, we developed an original methodology - based on publications, CVs and interviews - that we then applied to the cases of two prolific chemists. The objective was not to produce representative results, but to open a research program thanks to a method that could be reproduced. The study of two researchers provides new empirical evidence on the relationship between scientist trajectories and their collaborations. We have highlighted that co-authorship networks are composed of very heterogeneous relationships: some ties are strong and renewed over time, while others are weak and transient as a result of an intermediation. A large part of co-author linkage occurs in an institutional context, irrespective of the job-to-job mobility of researchers. When mobile, institutional collaborations are more spatially dispersed, but the incidence of the team remains equal.

The role of the team, particularly important in chemistry, raises a central issue: that of scales of analysis. In our view, the main challenge for further research is questioning and combining individual and organisational scales of analysis when studying scientific collaboration and linkage processes. When Sophie and Arnaud commented their publication histories, they mainly referred to the teams involved before individuals, identifying the number of teams and their geographic location: “this publication comes from collaboration between my team and the Belgium one” (Sophie). They then referred to the hierarchical position of each author within the teams: “Him, he is the leader, him, a technician, and they are postdocs or students” (Arnaud).

It would be interesting to extend the analysis of collaborations by taking into consideration the team level, which we began to do when integrating second-rank relationship in co-authorship. However, the initial analysis confirmed that publications are a reliable indicator of relational dynamics in scientific activity; associated to qualitative material (CVs, interviews), bibliometric data allows a robust analysis of the evolution of the personal networks of researchers.

By comparing the co-authorship of a hyper-mobile researcher with those of a rooted one, we demonstrated, by contrast, that geographical mobility is not more stimulating than other social experiences such as temporary mobility - even short-term moves - and the activation of relational chains. The result, which needs to be consolidated through the analysis of more cases, is of particular importance when we know the incentives for mobility emanating from research institutions and public policy, or at least when they consider mobility to be a condition for “excellence”. We do not wish to argue that mobility does not affect careers, but to underline that it does not necessarily make careers better, and there are different geographical ways to achieve a scientific career.

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