

# **Mobility of scientists and the development of international, interdisciplinary and intersectoral networks**

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## **Abstract**

This paper is a study of the development of international, interdisciplinary and intersectoral collaboration networks amongst internationally mobile scientists. Data is drawn from interviews with current and former Marie Curie Fellows who completed their fellowships under the European 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> Research Framework Programmes.

Based on semi-structured qualitative interviews, the paper examines the nature of collaboration networks that developed during the course of the Marie Curie Fellowships. It draws on social networks literature, notably Granovetter's work on strong and weak networks, and Burt's work on bridging and bonding networks. It is argued in this literature that strong networks facilitate information exchange but that weak networks are more likely to provide access to new ideas. The existence of structural holes or non-redundant ties enables actors to act as information brokers, combining information from different actors in a network.

In science, it is argued that interdisciplinary collaboration is increasing. A number of authors argue that scientists get their best ideas by collaborating with people from other disciplines. Scientists search for new ideas in a process described as 'bridging' or 'spanning' networks, and then go on to develop networks around these new ideas, in a process termed, 'building' networks. Interdisciplinary collaborations allow new research directions to develop. Diversity of collaboration partners implies increased intersectoral collaboration. University-industry links have also been shown to have increased in recent years. The development of interdisciplinary and intersectoral collaboration is facilitated by the international mobility of researchers.

The paper compares the development of new and the reinforcement of existing international, interdisciplinary and intersectoral networks during the course of Marie Curie Fellowships. The results demonstrated the two processes of bridging networks, where exposure to new approaches to research in different countries allowed new insights, and building networks, which is more likely to lead to incremental developments in the research field. New interdisciplinary networks developed as a result of a fellowship in a different country were most likely to produce novel ideas and allow the development of new research directions. This often also involved researchers increasing their knowledge of the application of their research in industry and other sectors. However, it was often not clear to what extent this new knowledge would be exploited in the longer term. On the other hand, the development of existing networks, although less likely to produce novel insights, was important for the building of a community around new ideas, and the consolidation of results, which might lead to the development of research disciplines over time.

## **Mobility of scientists and the development of international, interdisciplinary and intersectoral networks**

### **(1) Introduction**

In order to advance science, new collaborations are needed to generate knowledge. It is argued that collaboration in research is increasing (Chompalov et al 2001, Porac et al 2004). Collaboration in science is supported by mobility of researchers, mobility being regarded as a normal part of career progression in science (Mahroum, 2000, Meyer et al 2001, Schiller and Revilla Diez 2012). Mobility is promoted by mobility schemes. At the EU level, Framework Programmes have included mobility fellowships, Marie Curie Fellowships. Often, international mobility also implies interdisciplinary research and increasingly, intersectoral exchange has been a goal of mobility programmes. For example, EU funded Marie Curie fellowships under the 7<sup>th</sup> Framework Programme aim to develop intersectoral networks.

Mobility in science is based on the premise that developing new networks increases knowledge, in many cases increasing exposure to new, interdisciplinary knowledge. There is a large literature on social networks that discusses the extent to which diversity of networks promotes learning, which is useful for understanding science networks. It is argued that dense networks promote communications and learning but tend to result in incremental rather than discontinuous innovation. Many authors have argued for the benefits of diversity in terms of knowledge and learning. Granovetter (1973) argues for the strength inherent in weak ties that lies in the potential of occasional encounters for exposing individuals to new understanding. Burt (2004) argues that bridging networks, where there are structural holes, provide unique information. In science, it is recognised that new interdisciplinary and intersectoral networks can advance science through the development of new combinations. Porac et al (2004) point out that close relationships in science networks are more likely to lead to greater knowledge sharing but tend to lead to incremental rather than discontinuous knowledge production, whereas diverse alliances are more likely to generate discontinuous knowledge.

One idea that is not developed in the above is the changing and dynamic nature of networks. Science mobility (eg in the form of fellowships) tends to result in weak networks developing into strong networks. Typologies of organisational networks highlight the extent of commitment on which a network is based. A number of authors highlight 'hard' networks, based on joint activities (eg production or marketing) as opposed to 'soft' networks, based on information exchange. It is argued in organisational network literature and also in literature on science networks, that initial informal exchanges, can, if nurtured, lead to more formalized collaborations.

The link between interdisciplinarity, intersectoral exchange and international mobility in science has as yet not been explored to any great extent. Research on science collaborations is often based on bibliometric studies. Using qualitative interviews allows for more inductive, in-depth exploration of the nature of knowledge networks, that allows the range of outcomes to be examined, rather than purely focusing on one (eg publications). Since Marie Curie Fellowships involve taking up a fellowship in a different country with the aim of developing new collaborations, the programme is an excellent vehicle to study the link between international, interdisciplinary and intersectoral collaborations. Drawing on concepts of social networks, this paper seeks

to redress the gap in research, based on a number of qualitative, semi-structured interviews with Marie Curie Fellows. It examines the extent to which strong and weak networks developed and impacts that resulted from these different types of networks. The paper develops one part of a larger evaluation of the impact of the Marie Curie Fellowship Scheme commissioned by the European Commission (for further details see The Evaluation Partnership 2010).

The Conceptual Framework will next be outlined, focusing on strong and weak networks in science. The following Section will briefly describe Marie Curie Fellowships. The Methodology of the research will then be described. This will be followed by the Results and the Discussion.

## **(2) Conceptual Framework**

### **Strong and weak networks**

In recent years there has been extensive debate on the role of social capital or the goodwill resulting from social relations in several social science disciplines. There has been a divide between literature that stresses the benefits of strong and weak networks, also known as bridging and bonding capital. Whereas Coleman (1988, 1990) emphasises the social cohesiveness that provides stability and support in bonding capital, Burt (1992, 2004) talks of the benefits of bridging capital, which allows access to unique resources (Adler and Kwon 2002).

Granovetter's much cited work on social networks has had a significant impact on current debates. Granovetter describes tight communities that have efficient communication between members but little new information entering the community over time, and argues that individuals can maintain weak ties to communities different from those they interact with on a day-to-day basis. He argues that the strength inherent in weak ties lies in the potential of occasional encounters for exposing individuals to new ways of understanding (Granovetter 1973).

According to Burt (2004), whilst dense networks provide social support, they are less likely to provide access to new or unique resources because the high level of connectivity among network members implies few links to others outside the network. He argues that diversity of information and opportunities for brokerage are created by non-redundant ties, termed structural holes. Structural holes are links to actors who are unconnected to each other, which allows access to different information than would be available from actors connected to each other. The existence of structural holes enables actors to act as an information brokers, combining information from different actors in a network (Burt 2004).

In science, as will now be discussed, it is argued that, whereas communication is easier within cohesive networks, radical innovation is more likely to occur across networks.

### **Strong and weak networks in science**

It is argued that collaboration in science is increasing. According to Knorr-Cetina (1999), scientists within disciplines can communicate but may fail to collaborate across disciplines. Collaboration tends to be designed to develop new areas of interdisciplinary research, whereby collaborating with people with a different perspective aims to open up new research directions (Oliver 2004, Bozeman and Corley 2004). Burt points out that scientists get their best ideas by collaborating with people from outside their disciplines (2004). Research has established the importance of diverse inputs in the knowledge creation process. According to Hargadon, innovation is about the creative combination of ideas, people and objects from past technologies to start new technological revolutions in a process termed 'technology brokering' (Hargadon 2003). Hargadon describes the process, of recombining existing ideas by drawing from a range of disconnected worlds, in which existing ideas appear new to new audiences. He describes this as 'bridging', or 'spanning' communities to search for new ideas, and 'building' of new communities around these new ideas (Hargadon 2006). Similarly, Burt describes creativity of people connected to different groups as an 'import-export business'; an idea mundane in one group may be a valuable insight in another group (Burt 2004).

Oliver (2004) discusses the increasing interdisciplinarity of science generally, and also characterises some emerging areas of science as ones where interdisciplinarity and therefore collaborations are necessary to develop tacit knowledge. She focuses on collaboration in biotechnology, which she characterizes as a developing science, where the process is exploratory and heavily based on integrated teams of interdisciplinary experts, which she contrasts with developed sciences, such as chemistry. Porac et al (2004), compare outputs in two teams based on new interdisciplinary collaborations, that were recruited to advance the state of the art in computational modelling of astrophysical phenomena and computational modelling of ecosystems. The authors characterise the astrophysics team as '*a small, disciplinarily homogenous, and socially embedded team working in an academic field characterized by a strong theoretical paradigm*'. The ecology team is characterized as, '*a larger, more disciplinarily varied, and less socially embedded team working in a newly emerging field with a weak theoretical paradigm.*' Based on arguments made by Granovetter and others, that strong ties are more effective in sharing knowledge, but tend to limit to scope of knowledge, Porac et al found that, although new collaborations in both astrophysics and ecology resulted in new knowledge (measured by bibliometric methods), change was more significant in the ecology group, which brought together researchers from a greater variety of disciplines (Porac et al 2004).

Diversity of research partners implies carrying out research in collaboration with other sectors, notably with industry. Alongside the increase in collaboration, it is widely reported that there has been an increase in the commercialization of science and research in the form of university spin-offs, patenting and university-industry collaborations (Siegel et al 2007, Grimaldi et al 2011, Hunter et al 2011, Petruzzelli 2011). It is argued that growing interdisciplinarity, is linked to a growth in the number and importance of university-industry links (Oliver 2004, D'Este and Patel 2007, Etzkowitz and Viale 2010, Giuliani et al 2010). According to Giuliani et al., the growth in industry-academic links may be due to the increased transdisciplinarity of the knowledge production process, requiring continuous interaction between science and industry. It is argued that in emerging new fields, such as biotechnology and

nanotechnology, knowledge is often dispersed internationally and across different institutions, such as universities and industry (Oliver 2004, Pandza et al 2011). Etzkowitz and Viale (2010) go further, arguing that new knowledge occurs in polyvalent forms, having theoretical, practical and interdisciplinary implications. They argue that, the triple helix of university, industry and government model of knowledge creation is increasingly linked to the disappearance of traditional disciplinary boundaries.

Mobility in science is an important way of increasing networks and thereby expanding scientific horizons, often involving interdisciplinary and intersectoral collaboration. It is argued by Meyer (2001) that international science mobility is based on the principle that exposure to the latest knowledge worldwide necessitates mobility. Scientific communities are sustained through various forms of mobility, both short term, such as conferences, and longer-term through fellowships and other longer-term visits.

The above has described how networks are constantly evolving, involving recombination of networks to produce new knowledge, which may involve transforming networks from strong to weak networks. The following will therefore briefly examine types of networks based on more formal 'hard' networks versus networks based on knowledge exchange and outline the significance of this for science networks.

### **Types of networks**

Many authors writing on organizational networks make a distinction based on the level of commitment (eg Grandori and Soda 1995, Rosenfeld 1996, Hage and Alter 1997, Oliver and Ebers 1998). Rosenfeld distinguishes between 'hard' and 'soft' networks. Hard networks might encompass joint production or marketing whereas soft networks are likely to involve information exchange or training. These arguments are also relevant for science networks. According to Porac et al, *'Alliances such as joint marketing or manufacturing agreements, for example, involve knowledge that is already highly codified and operationalized. The purpose of these alliances is not so much the creative combination of partner knowledge stocks as it is the joint application of complementary routines that are already well understood. On the other hand, for research and development alliances, particularly inter-university scientific alliances, the knowledge sharing versus variety tradeoff seems more problematic.'* In scientific collaborations, although the aim is to combine knowledge from different partners, the extent to which scientific collaboration is based on exploration and exploitation may also vary and may change over time.

Huggins (2000) argues that formal groups offer the most potent form of networks, but are best facilitated initially by an informal structure. He suggests that 'soft' activities, such as information sharing are often the precursor to 'hard' activities and that it is important to nurture soft networks so that they may develop into hard networks. This also implies some movement from knowledge exploration to knowledge exploitation. Similarly, this argument is relevant in science. According to Bozeman and Corley (2004), it is widely agreed that many collaborations start with informal conversations, also arguing that spatial proximity is important to initiate these initial conversations.

Therefore mobility in the form of fellowships involves the development of networks

from some form of weak network, which may be based on informal conversations or knowledge of a researcher's publications, to more formalized collaborations. Mangematin and Robin (2003) discuss the role of early stage researchers in knowledge circulation and similarly, Almeida and Kogut (1999) and Agrawal et al (2003) show that the inter-organisational circulation of knowledge is based on the circulation of engineers from one firm to another. It is often early stage researchers, PhD students and postdocs, who take up fellowships in other countries. However, established academics may also take up a temporary fellowship in another country. The next Section will discuss the Marie Curie Fellowship scheme, which supports mobility at various career stages.

### (3) Marie Curie Fellowships

Marie Curie Fellowships are EU fellowships that provide funding for researchers to take up a placement in another country. They are funded as part of Framework Programmes for Research and Technological Development. They have developed over time with subsequent Framework Programmes. Under the current Framework Programme (FP7), they fall under the People part of the programmes, which is implemented through actions under five headings:

Table 1

<ul style="list-style-type: none"> <li>• <b>Initial Training</b> of researchers to improve mostly young researchers' career perspectives in both public and private sectors, by broadening their scientific and generic skills, including those related to technology transfer and entrepreneurship.</li> <li>• <b>Life-long training</b> to support experienced researchers in complementing or acquiring new skills and competencies or in enhancing inter/multidisciplinarity and/or intersectoral mobility, in resuming a research career after a break and in (re)integrating into a longer term research position in Europe after a trans-national mobility experience.</li> <li>• <b>Industry-academia pathways and partnerships'</b> to stimulate intersectoral mobility and increase knowledge sharing through joint research partnerships in longer term co-operation programmes between organisations from academia and industry, in particular SMEs and including traditional manufacturing industries.</li> <li>• <b>International dimension</b> to contribute to the life-long training and career development of EU-researchers, to attract research talent from outside Europe and to foster mutually beneficial research collaboration with research actors from outside Europe.</li> <li>• <b>Researchers' Night</b> s an event bringing together the public at large and researchers. It occurs annually on the fourth Friday of September all over Europe. Its main objective is to reveal scientists and science in a relaxed and friendly atmosphere.</li> </ul> <p>Source: <a href="http://cordis.europa.eu/fp7/people/home_en.html">http://cordis.europa.eu/fp7/people/home_en.html</a></p>
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The following are the types of fellowship available:

Table 2

<ul style="list-style-type: none"> <li>• Initial Training Networks</li> <li>• Intra-European Fellowships for Career Development</li> <li>• Career Integration Grants</li> <li>• Co-funding of Regional, National and International Programmes</li> <li>• Industry Academia Partnerships and Pathways</li> <li>• International Outgoing Fellowships</li> <li>• International Incoming Fellowships</li> <li>• International Research Staff Exchange Scheme</li> </ul> <p>Source: <a href="http://cordis.europa.eu/fp7/people/home_en.html">http://cordis.europa.eu/fp7/people/home_en.html</a></p>
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It can be seen from the above that the Marie Curie Actions provide funding for fellows at all career stages, PhD students (through the Initial Training Networks),

post-docs and experienced researchers. They are open both to researchers moving within the EU, to and from the EU and between third countries.

Interdisciplinary/multi-disciplinary and intersectoral mobility is emphasized in the case of experienced researchers. There are also specific programmes for cooperation with industry, including both for experienced researchers and for PhD researchers. The Marie Curie Schemes is therefore an interesting case study of the inter-section of international, interdisciplinary and intersectoral mobility. The Methodology will now be described.

#### **(4) Methodology**

The research was based on an online survey of all former Marie Curie Fellows under Framework Programmes 4 (FP4) and 5 (FP5) and former and current Fellows under Framework Programme 6 (FP6) followed up by a small number of qualitative interviews. This paper reports on the qualitative interviews (see The Evaluation Partnership 2010 for full results). The questionnaire and the interviews sought to gain information on the impact of the Marie Curie Fellowship on the career of the fellows. The aim of this paper is to analyse the way in which the fellowships impacted on the development of research networks of fellows in terms of developing new and exploiting existing international, interdisciplinary and intersectoral networks during the course of the fellowship.

The questionnaire was completed by a total of 4674 current and former Marie Curie Fellows and 1808 current or former supervisors. From these 6482 responses 22 people were selected with whom to complete an in-depth qualitative interview. 20 were current or former Marie Curie Fellows who had moved to a different country to take up the fellowship. The remaining two were supervisors of Marie Curie Fellows. They were selected based on the need to provide information related to the four key aspects of this part of the research (1) long-term career impacts of MCFs (2) extent to which brain drain and/or brain circulation occurred in relation to new member states (3) the extent and nature of interdisciplinary and intersectoral exchange (4) the effect of mobility on the need to reconcile work and family life in research. The selection criteria were based on this. This paper is concerned with the third question on interdisciplinary and intersectoral exchange. It does not discuss the other questions (reported in Final Report, The Evaluation Partnership 2010).

The following gives a brief overview of some of the characteristics of fellows interviewed.

Table 3

Frame-work	No. of fellows	Panel	No. of fellows	Home Country	No. of fellows	Career Stage	No. of fellows
FP4	6	Chemistry	5	EU (pre 2004)	14	Early	8
FP5	4	Engineering	3	<sup>1</sup> EU (post 2004)	5	Mid	10
FP6	12	Environmental sciences	1	Non EU	3	Senior	4
		Life sciences	7				
		Physics	2				
		Social&economic sciences	4				

The table shows that fellows were from all three Framework Programmes to investigate longer-term effects of the fellowship, although with more from the most recent Framework. They represented a range of disciplines ('Panels'). A slight majority of fellows (10) described themselves as mid-career at the time of the fellowship, with slightly less early career (8) and only 4 at senior level. The majority were from original EU member states, with a proportion from new members states from Central and Eastern Europe and from outside the EU<sup>2</sup>.

The interviews were semi-structured, the main themes being discussed being: the career history of the fellow, why they completed the Marie Curie Fellowship, benefits and outputs as a result of the fellowship (focusing on long-term impact), current position, interdisciplinary research, engagement with industry and how they managed to reconcile mobility with family life. The interviews were recorded, transcribed and entered into a qualitative analysis programme (NVivo). Factual information (eg age, gender, Framework Programme, panel) was coded, and the interviews were coded thematically based on the research questions identified above. The interplay between international, interdisciplinary and intersectoral exchange emerged as an interesting theme. Therefore the interviews were further coded under the themes of international, interdisciplinary and intersectoral exchange. A further distinction was discovered between new networks and existing networks. Therefore they were also coded based on this. The results are presented based on the development of new and existing international, interdisciplinary and intersectoral networks.

The next Section will consider the extent to which international, interdisciplinary and intersectoral networks developed during the Marie Curie Fellowship, comparing new and existing networks.

<sup>1</sup> Includes the Central and European countries that joined the EU in 2004: The Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia.

<sup>2</sup> The type of fellowship is not listed, because this was different for each Framework Programme, making it difficult to compare.



## **(5) Results**

### **New Networks**

#### International

For some researchers, the Marie Curie Fellowship provided the opportunity to access new networks, move into a different research area or change the geography of their networks. For early career researchers, in particular PhD students, the international networking was likely to be a new experience, as explained by the following PhD student *'INT: What would you say are the main benefits then from your Marie Curie Fellowship? RES: ... the networking part because I've been in touch with lots of institutions and senior researchers around Europe and also in Turkey and we have been able to be in different kind of conferences ... so in terms of social contacts it's been amazing, it's been great. I know that in the future I may apply for example for other projects with the same people.'* Another PhD student speaks of the impact of international networks: *'I probably got to know the people out in X a bit better because it's such a big group obviously you only really get to know the people that you directly work with. INT: And do you think you might continue with those kind of networks in future? RES: ..., Yeah, I mean it's like there are people that's like if you go up, they do generally meet, you know, out there for six months .. I've got to know them then you do tend to talk to them more and find out, ..., what they've been doing'.* In another case, a former Marie Curie Fellow describes how he has himself has now started a network that benefits students, *'I had some, some contacts to a group in Switzerland and Germany and so on, so we had this idea that we can build up this network and, there's a very good possibility for us to interact ... it's a very nice network and particularly the students benefit a lot from this.'* The experience of the PhD students of networking internationally was limited prior to their PhD and the fellowship is likely to have an important impact on their future career, as indicated by the Early Career Researchers interviewed.

For post docs, the Marie Curie fellowship tended to represent a change in direction rather than a completely new research career. Two researchers had returned from the US to Europe with a Marie Curie fellowship and they both explain that they have used the fellowships to reintegrate themselves in Europe and develop new research *'During that time I made also some contacts here and I could establish myself and, and also in the new research field ... the post doc I had done in the US was on a completely different field. ... INT: Were they mainly new [networks] or did they continue from the US at all or was it... ? RES: No, this was, this was completely new.'* Here, also the MCF allowed him to establish new research in Europe, although he had some experience already as a post doc in the USA. A second former fellow also explains that he had established new research in Europe following his post-doc in the US: *'Yeah [my networks are] mostly post-doc and from post-doc because most of these contacts are European contacts and my PhD was in the US.'* *'Yeah [my networks are] mostly post-doc and from post-doc because most of these contacts are European contacts and my PhD was in the US.'*

#### Interdisciplinary

The following researchers were exposed to different approaches to research as a result of their fellowship in another country in terms of approaches to theoretical and empirical work. The following two researchers were interested in learning more theoretical approaches to their work. The first works in archaeology: *'Archaeology*

*here is more theory-based than it ever was where I actually was in X, so I wanted to, to broaden my knowledge basically ... the learning curve was immense.*’ The second works in life sciences, *‘I really wanted to move more to theoretical biology and he’s one of the chief pioneers of theoretical biology.’* Another Marie Curie fellow speaks of developing her research away from theoretical philosophy towards more empirical work and collaborating with different disciplines, *‘I found a project that I was really interested in but it meant it was a much larger project than when I thought about it meant staying longer in the US and the only way I could do that project was through something like the Marie Curie grant ... So the focus of my research and its scope because now I began to work with 3 institutions and, instead of just ... theoretical biologists interested in evolution and most of my context now of my work now was ecologists and with biodiversity researchers ... Everything changed from, a small question that I worked on by reading other people’s papers, now I had contact, actual face-to – researchers to go out in the field so suddenly I didn’t only read papers, I went outdoors with biologists.*

The above researchers speak of learning and developing new approaches to their work. The final quote above is an example of learning which changed the researcher’s worldview as a result of being in a different country and being exposed to new, interdisciplinary approaches to her work. She had moved from Israel to the US, and spoke of the whole experience, both social and professional, as being completely new to her and her family. It was often such collaborations, where researchers found themselves in new, unfamiliar environments, and where the challenges were the greatest, where learning was greatest. Another excellent example came from a Marie Curie fellow who had moved a number of times between very different groups, which involved being in a completely new environment, difficult periods of adjustment and steep learning curves, which in the end produced novel ideas, *‘It was really challenging. I worked in a microtechnology institute – I knew a little bit about proteins but nothing about lasers and I was involved in a laser group and they were very good and it was really difficult for me at the beginning to learn about the laser and to know how to apply my experience to their activity, how to involve myself with my experience so I had to find new materials and ideas ... We made a paper and I presented this, research in [a conference] and we won two prizes there....It was the best X Journal prize for the research activity ... It was something you know, nobody tried to obtain something like this because maybe nobody had a chemist in the middle of the, of a laser group. This is the, an interesting point of view for Marie Curie fellowship...’* The above are examples of fellowships producing new networks and collaborations, which lead to new ideas. In these two cases, researchers speak of achieving good results by interacting with people from different disciplines, and becoming aware of or developing new areas of research by bridging networks.

In many cases, the extent and diversity of collaborations increased as a result of the Marie Curie fellowship, encompassing new academic and interdisciplinary collaborations and intersectoral exchanges. This fellow speaks of exposure to new disciplines and collaborations with applications in dentistry: *‘I got trained on basic cell culture techniques so I did a lot of things in UK that I couldn’t manage to do them in Italy let’s say like this ... for me it was a very good experience. ... because my field is materials science but because I work in let’s say in biomaterial topics that means that I need some biological background and for example in Italy we do everything in our materials department... In the UK my supervisor had a*

*collaboration with a professor from X Dental Institute and in this way I went to X Dental Institute and I was trained in basic cell culture so at the end I prepared all my samples at X University and I went to X so to X University because depends on that university and I did everything by own so all the experiments I did on my own'.*

The above interviews demonstrate how learning occurs at intersection between disciplines based on their experience in a different interdisciplinary group in a different country and thus illustrate well the inter-section between international and interdisciplinary mobility. They also indicate that researchers have become more aware of the applications of their work, in particular the final quote where the researcher's work has applications in dentistry. This will be developed further in the following discussion on intersectoral links.

#### Intersectoral

A number of fellows gained experience of developing links between academic and other sectors, notably with industry, as a result of their fellowships abroad. The following PhD student speaks of the many possibilities for spin-offs in particle physics *'With particle physics anyway, there's a lot of spin-offs into some areas ... I think I do a bit cos I wouldn't have gone to like this bit of technology cos I always wanted, well, for what I did to be ultimately useful in a way and not just for pure academic interest.'*

A supervisor of a postdoctoral fellow describes the interface between interdisciplinary and intersectoral collaboration, which resulted in a patent: *'During her PhD she was just doing synthetic chemistry and my group does much more biological chemistry so it basically expanded the area that she was working in into things that were more relevant maybe to biological systems and during the course of her research here we, we also produced the compound which has now been patented and licensed so she's had a, quite a lot of exposure to protecting intellectual property rights as well also developing her skills in more biological things.'* The same supervisor also describes the longer term impact international impact in terms of the fellow passing on knowledge to industry in her own country: *'They're trying to get companies to do chemical process in a more environmental way and so the idea is that she'd be one of the first people who'd go back to X trained in green chemistry concepts and principles so she'd then obviously pass them on to the companies there.'*

In another case a postdoctoral fellow was exposed to a new application whilst working with a company in green roof development in another country that she will be able to bring to her future work: *'The green roof thing is a new thing for me and actually I feel the quality and production and supply of seed is something that I've been introduced to because I've seen the difficulty in acquiring and processing large quantities of seed for sale so that's been a new thing for me and it's something that I can bring to, my future work.'*

It appears that the above fellows have gained new experience of the applications of their research in industry as a result of a fellowship in another country, which they can use in their work or develop in their country once they return. In these cases, the fellows were introduced to new interdisciplinary areas of research and new applications for their research as a result of a stay in a different country.

## **Existing networks**

### International

Experienced researchers were likely to strengthen existing networks rather than being introduced to new ones. It was common for fellows to know or know of the people they worked with in another country, but co-presence may be needed to develop knowledge or instigate joint projects. Ha of the 22 fellows already had networks with the institutions where they took up their fellowship. The following fellowships were undertaken within the context of existing networks, which were strengthened by the Marie Curie fellowship: *'I also applied to Marie Curie because from X. I knew some people from working here.'* Here she knew the colleagues she worked with for the MCF from meeting them whilst carrying out fieldwork, but benefited from spending time at the institute because of the vibrant research environment and because she was able to develop different kinds of knowledge.'

In a number of cases, the collaboration between the country of the Marie Curie fellow and the host institute already existed and strengthened as a result of the fellowship, such as the following cases. In these cases the former Marie Curie fellows have maintained their position in their own country but have spent periods abroad developing collaborations: *'In the past we have had contacts with the University of X and they were working more or less in the same research lines.'* Here the researcher had completed the fellowship around 10 years earlier, maintaining her previous post, and had kept the collaboration with the institute where she did her fellowship. The following two researchers had spent several previous periods of research at the MC host institute. The following was now completing a MCF with the intention of returning to his own country and maintaining the collaboration: *'There was a collaboration between the two centres but my supervisor kept on collaborating with people from, from here, this institute so there was a line of collaboration INT: And you've kind of strengthened that?'*. Again, the MC fellow had spent a number of periods in the host institute to strengthen the collaboration but was now back in his home institute: *'I kept collaborating with this professor from the University of X, so after being here some time in X I thought it actually would be very helpful for me to go again for two years and there was this a possibility and then I returned back here again, so now I'm in X [back home in his home country].'* These three fellows have a position in their home country, which has enabled them to continue their collaboration with the Marie Curie host institute. In the following case, the Marie Curie fellowship also strengthened an existing link but the future career path of the Marie Curie fellow was unknown at the time of the interview: *'That's now established a stronger link and that's why I was there a couple of weeks ago so I think that certainly having a person from there coming to my lab [has created] stronger links with that lab.'*

### Interdisciplinary

Some fellows did interdisciplinary research, but this was intrinsic to their research and did not change dramatically as a result of their Marie Curie Fellowship, as was the case in the discussion on new interdisciplinary networks. This was often the case for those working in medicine or related fields. For example the following researcher in brain research describes his research as interdisciplinary, which is fundamental to his research, rather than being a new insight from the Marie Curie Fellowship: *'I guess it is in the sense of, of applying different ideas of different disciplines to, for a specific problem ... it's always biologists and physicists, neurologists and psychologists ...'* Although medical researchers and others with a tradition of interdisciplinarity did not

explicitly say that interdisciplinary research was new to them, they did say that their networks had increased as a result of the Marie Curie Fellowship. Another researcher into the brain and speech said he worked with neurologists, linguists and computer scientists. He has more collaborations at the university in the UK where he was working at the time of the interview and found the research environment more vibrant than his previous institute in the USA. Others also spoke of the development of their collaborations in a new country with the implication of increased interdisciplinarity.

#### Intersectoral

As mentioned above, some applied areas of science have a long history of collaborating with industry and researchers have opportunities for working in collaboration with industry from early on in their career. For the Marie Curie fellows below, working in collaboration with industry was not new to at the time of his Marie Curie fellowship, but it is an activity they were able to develop during the fellowship.

The following PhD student, who is an automotive engineer had been seeking an opportunity to establish academic-industry collaborations for some years whilst working as an employee for a motor company, and had only recently found an effective partnership: *'We are 15 students from all over Europe ... and we are in different university institutions and we just met and we have already settled down to several meetings altogether with a co-ordinator of the project and so on with all the professors and the scientific leader of the project, and so is pretty much organised, I'm really in contact with several people even outside of Company X'*.

As mentioned above, several researchers in the medical field work with clinical applications, but this is intrinsic to their work rather than being a novel ideas as a result of a fellowship abroad, such as the following: *'We applied the same time as I applied for the fellowship [his supervisor] applied to, he got a big MRC translation grant for this kind of project. ... It means from very basic ideas on how consciousness works in theoretical cognitive sciences, from applications on consciousness, applications on people under anaesthesia or applications of sleep.'*

Another former Marie Curie fellow, as a result of a stay abroad, has an idea for setting up new systems in his own country: *'Yes exactly these political ideas that I got ..., I could see beyond the horizon as we say and now I looked at my own country and the situation here in a different way.'* He later goes on to explain how he was offered a new post in his home country a number of years later, which enabled him to set up similar systems: *'When I was in Sweden I was impressed by the way they handled data [in occupational health] ... I always wondered why we didn't have the same thing in Germany and ... I said ... I will take this post only if you would give me the space for, for putting up something similar and they thought it fit, it fit well to their current political thinking so, I said I could do it.'* He was not new to intersectoral collaborations with industry and policymakers at the time of his MCF, but his stay in another country gave him a new idea which he is now able to implement a number of years later.

#### **(6) Conclusions**

The results show that discontinuous learning often occurred at the intersection between different research disciplines. They further demonstrate how new combinations of knowledge are diffused as a result of international mobility,

highlighting the interplay between interdisciplinary, intersectoral and international mobility. They show how there is the potential to introduce new interdisciplinary combinations into countries where they were not yet developed. In some cases, the combination of knowledge in new ways could be seen, which is likely to produce completely new research directions. This often extends to increasing awareness of the applications of new technologies. Some fellows discovered how their research had been applied in other countries, giving them ideas how this might work in their own country. This shows how awareness of the applications of their research increased as a result of their stay abroad, allowing knowledge to be applied in industry or in policy.

Where networks already exist, learning appears to be incremental rather than discontinuous, and in these cases, exploitation is more likely to be an outcome. The integration of early career researchers (usually PhD students) into existing groups appears to allow circulation of knowledge that results in transfer or application of knowledge rather than radically new research directions.

Whereas more experienced researchers (often post-docs) might have new ideas from being introduced to new combinations of knowledge, the application of some of these ideas is likely to result from maintenance and development of these networks. This involves transforming weak networks into strong networks, which was seen in the discussion of strengthening existing networks. Whereas weak networks or bridging networks are important for having new ideas, their subsequent exploitation is contingent on the existence or development of strong or bonding networks. This is likely to take time. Outcomes such as papers, conferences papers, prizes and patents, sometimes emerged relatively soon after the fellowship in some cases. However other impacts can only be studied over time. This included career benefits mentioned by fellows, such as new networks of people to develop in future, or new job opportunities, which can take time to develop. This may depend on developing new lines of research in different countries or the political environment. This is likely to take time also because the fellow might need to obtain an established post, or obtain a position of seniority, which may take several years. Interviews with fellows who had recently completed their fellowship and those who had completed their fellowship years before showed how in some cases, the germ of an idea was sewn during the fellowship, that was exploited many years later.

The paper has produced some interesting results, which further knowledge on the inter-play between international, interdisciplinary and intersectoral collaborations in science, an area that has not been extensively researched. Marie Curie Fellowships, which involved placing a research fellow in a different country, have proved a useful vehicle to improve understanding of this inter-play. It was based on interviews, thus allowing fellows to elaborate and explain how their networks developed, and to understand the range of impacts from the point of view of the fellows (The full report describes the results from the survey with a brief summary of the results of the interviews, see The Evaluation Partnership 2010). However, the research does have some limitations, related mainly to the reliance on a small number of interviews. This presents several opportunities for further research.

Firstly, there is scope for large scale, multi-method research projects that focus on international, interdisciplinary and intersectoral learning and the impacts that

international collaborations have in terms of developing new knowledge. They might combine results of self-reported surveys and qualitative interviews with CVs, and also measures based on bibliometric analysis and patent data, to provide a more holistic picture of the impacts of international collaborations or mobility fellowships.

It would be particularly interesting to study the development of some of these new emerging research directions over time. Snapshots of instances of innovation could be fully understood only by completing longitudinal research, which study the development of innovations over time. This research had an element that sought to understand the long-term impact, and showed that the fellowships can have an impact many years after completion. Cohort studies, completing surveys or interviews with former fellows at various points in time would be a useful extension of this research. Single case studies of specific innovations would allow greater understanding of the development of innovations or of new research areas over time.

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