Chapter 6.

European Framework Programme collaborative research and the notion of critical mass

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6.1. Introduction

Since 2000, the basic idea underpinning European research policy is that of the European Research Area (ERA). [1] In that year, the Commission published a first Communication on the subject and launched it as the core concept on which to base Community research policy (EC, 2000). In a series of subsequent ERA Communications, the Commission identified three main weaknesses of the European research system:

1. insufficient funding;
2. lack of an environment to stimulate research and exploit results; and
3. the fragmented nature of activities and the dispersal of resources (EC, 2002).

In response to these weaknesses, the Commission proposed:

1. the creation of an "internal market" in research, *i.e.* an area of free movement of knowledge, researchers and technology, with the aim of increasing cooperation, stimulating competition and achieving a better allocation of resources;
2. a restructuring of the European research fabric, in particular by improved coordination of national research activities and policies, which account for most of the research carried out and financed in Europe; and
3. the development of a European research policy which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies (EC, 2002).

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[1] The views expressed are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

The ERA concerns both the Union and the Member States (Edler and Kuhlmann, 2005). At the level of the Union, a specifically designed new Community Framework Programme for Research and Technological Development (the 6th Framework Programme, FP6) was adopted in 2002 to help achieve the ERA. The key question posed by this paper is to what extent the FPs have contributed to the achievement of ERA. It will assess this by examining the characteristics of FP funded shared cost collaborative research projects and the networks they create.

The remainder of this chapter is organized as follows. Section 6.2 provides a brief overview of the FP and some core principles underpinning collaborative research. Section 6.3 discusses the collaborative research projects and the networks that have emerged from them. In section 6.4, the main findings are discussed.

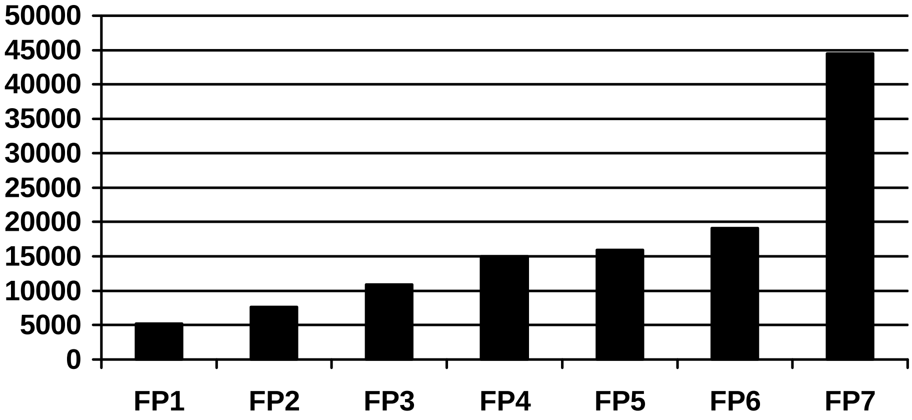
6.2. Framework Programme collaborative research

The stated objective of Community research policy is strengthening the scientific and technological bases of Community industry and encouraging it to become more competitive at international level (Treaty, Art. 163). This is a broad objective, which accommodates many possible approaches towards its achievement. The Community FPs, which are multi-annual programmes in support of European S&T and industrial competitiveness, have the same permissive objective. This has allowed the specific focus of each programme to evolve over time (EC, 2005c).

- The rationale for FP1 (1984-1987) was the perceived technology gap (Breshi and Cusmano, 2002).
- FP2 (1987-1991) was intended to strengthen the research base of European industry in response to fierce Japanese competition. Developing information and communication technologies was high on the political agenda.
- FP3 (1990-1994) was formulated within the context of efforts to integrate the European market.
- The conceptualisation of FP4 (1994-1998) took place during the period of the Maastricht Treaty (1992) and the White Paper on Growth, Competitiveness and Employment (1993).
- FP5 (1998-2002) put increased emphasis on socio-economic values.
- And FP6 (2002-2006) was designed to help build the ERA (EC, 2005b).

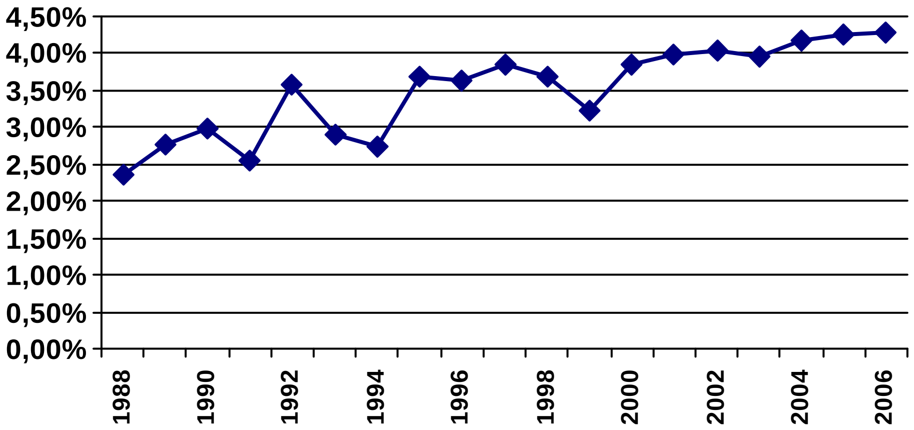
Other changes have marked the FP as well. Ever larger financial resources have been allocated to the FP (figure 6.1). Its budget reached about €19 billion (at 2004 prices) for the four-year period 2002-2006 under FP6 and FP7 will run from 2007 to 2013 with a budget of €44.5 billion (at 2004 prices). In 2006, research accounted for 4% of the EU budget (figure 6.2) (EC, 2006).[2] The FP also accounts for about 6% of EU-15 non-military governmental RTD expenditure, a share increasing to almost 25% when public support for research is more narrowly defined (Court of Auditors, 2004).

Figure 6.1. Evolution of the FP budget (€ million, 2004 prices)



Source: DG Research.

Figure 6.2. Share of the European Union's budget dedicated to research (%)



Source: DG Research.

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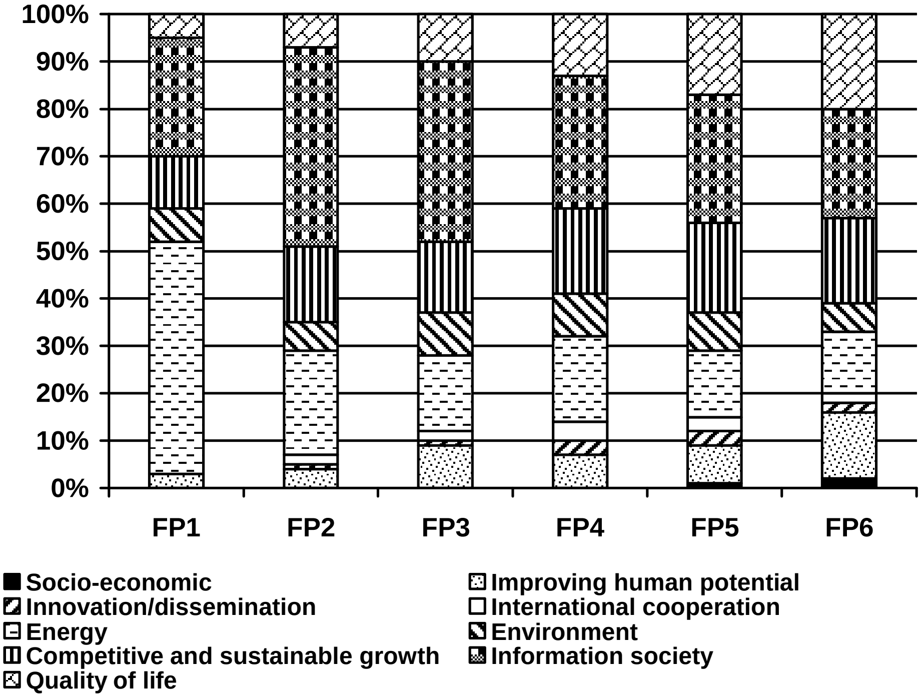
[2] Sum of commitment appropriations for 'Research' and for 'Research Framework Programme' under 'Enterprise', 'Energy and transport', 'Information society and media' and 'Direct research'.

The number and the content of the major components of the FPs, the so-called Specific Programmes, have also evolved. European FPs cover a wide range of activities. They contain schemes in support of pan-European researcher mobility. They facilitate the establishment of and access to large European research infrastructures. And they promote the coordination of national research programmes. Their mainstay, however, accounting for about 60% of the budget under FP6, is the provision of support to research projects by trans-national and mixed-actor (firms, universities, research institutes) consortia known as collaborative research. Such collaboration is at the heart of the Treaty articles on European research policy where it is said that the Community shall support the efforts of undertakings, including small and medium-sized undertakings, research centres and universities to cooperate with one another. Like the FP as a whole, collaborative research has benefited from a budget increasing across FPs. In addition, the number of thematic priorities has multiplied (figure 6.3). And new instruments, for instance, Networks of Excellence (NoEs) and Integrated Projects (IPs) under FP6, have been introduced.

Figure 6.3. Evolution of the FP priorities



Source: DG Research.

The core principle underpinning FP collaborative research is that of S&T collaboration. The importance of S&T collaboration is widely recognised in the academic literature. The literature on innovation systems emphasizes system-wide S&T connectivity and collaboration within the scope of a single economy. It describes an innovation system as the set of separate but interconnected public and private institutions and organisations and human resources which either individually or jointly and interactively create knowledge by financing and performing R&D, translate knowledge into innovations, and affect the diffusion of those innovations. What matters is the number and quality of systemic links. The innovation system also provides the framework within which government takes action in support of S&T. While national innovation systems are key, the international nature of innovation systems is increasingly acknowledged (Capron and Cincera, 1999; OECD, 2002). On the other hand, the literature on 'open innovation' observes that useful knowledge can be found everywhere and that firms should move from a closed innovation paradigm based on company control to one of open innovation under which they make optimal use of ideas generated elsewhere and make others use their internally generated ideas (Chesbrough, 2003).

Collaboration is a core element in the justification the Community has to provide of the added value of its research policy.[3] The argument made is that there are many instances in which there are benefits to intra-European cross-border and cross-sectoral S&T collaboration and that such collaboration is best organised at Community level rather than through a web of bilateral and multilateral S&T cooperation agreements at Member State level. Community-funded collaborative research projects allow for the EU-wide pooling of resources, whether funding, skills, data, etc. Examples include:

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[3] The concept of European added value underlies practically all policy areas and activities in which the EU is involved, and relates closely to the principle of 'subsidiarity', which is neatly expressed in the Treaty:

> *In areas which do not fall within its exclusive competence, the Community shall take action, in accordance with the principle of subsidiarity, only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the Member States and can therefore, by reason of the scale or effects of the proposed action, be better achieved by the Community.*

A protocol on subsidiarity and proportionality annexed to the Treaty of Amsterdam provides more precise guidelines for examining whether the subsidiarity condition is fulfilled. This can occur when

> *the issue under consideration has trans-national aspects which cannot be satisfactorily regulated by action by Member States; actions by Member States alone or lack of Community action would conflict with the requirements of the Treaty (such as the need to correct distortion of competition or avoid disguised restrictions on trade or strengthen economic and social cohesion) or would otherwise significantly damage Member States' interests; action at Community level would produce clear benefits by reason of its scale or effects compared with action at the level of the Member States.*

- indivisible 'big science' research projects of such scale and complexity that no single Member State can provide the necessary critical mass of financial or personnel resources;
- research on rare diseases affecting a small number of people in each Member State where scattered evidence and expertise needs to be put together to develop new diagnostic methods and treatments;
- research on pan-European and even global public policy challenges (climate change, food safety, public health) – which can be faced only on the basis of a common scientific endeavour – and in support of European policies; and
- research where it is useful to take a comparative approach.

FP funded collaborative research projects reduce commercial risk because involving key EU industry players helps ensure that research results and solutions are applicable across Europe and beyond, enables the development of EU- and world-wide standards and interoperable solutions, and offers the potential for exploitation in a market of 450 million people. Finally, Community level collaborative research projects ensure dissemination to users, industries, firms (SMEs in particular), citizens, etc. more efficiently than at Member State level, leading to a better exploitation of research, with a larger impact.

A key selection criterion in the evaluation of collaborative research project proposals is scientific excellence. The Treaty articles on research and technological development emphasize the need for the Community to support research and technological development activities of high quality (Treaty, Art. 163). That objective appears to have been met as past ex-post evaluations of the FP have indeed found EU-supported collaborative research to be of high quality (EC, 2005c). Industrial participants have reported that FP projects are of relatively high scientific and technological complexity, while university participants have identified major benefits in the form of knowledge enhancement (EC, 2005b). Yet in spite of this early call for scientific excellence, the emphasis on excellence has clearly increased across FPs. In this regard, FP6 constituted a clear turning point. The "scientific and technological excellence and the degree of innovation" was the first of a number of evaluation criteria common to all the programmes of FP6 and set out in the European Parliament and Council Regulations on the Rules for Participation (Article 10). In addition, a higher threshold score was assigned to S&T excellence than to other criteria in the evaluation of collaborative STREP and IP proposals, while in the evaluation of NoE proposals, excellence was the keyword throughout.

Another notion increasingly emphasized across FPs is that of critical mass. Critical mass remains an as yet poorly defined notion (EC, 2004a; DTI, 2004). Yet the Commission appears to have interpreted critical mass mainly as bringing together more and more players and pooling their resources (EC, 2004a). At the level of the European research effort as a whole, the 2000 Commission Communication on ERA called for more coherence between measures taken at different policy levels since

> *a configuration of this kind would make for the essential "critical mass" in the major areas of progress in knowledge* (EC, 2000).

At the project level, the 2002 follow-up Commission Communication on ERA described how FP6 was specifically designed and formulated to help achieve the ERA, and how this had been done through, among other things,

> *new support instruments which will make it possible to build up critical masses of resources (NoEs and IPs)* (EC, 2002).

The aim of the new instruments was to establish self-organised, large-scale and long-term cooperation (Edler and Kuhlmann, 2005). IPs were designed to create the knowledge required to implement the priority thematic areas of FP6, by integrating a critical mass of activities (research, demonstration, training, innovation, management) and resources (staff, skills, competences, finances, infrastructure, equipment etc.). NoEs are instruments for directly tackling the fragmentation of research activities in Europe in a given thematic area. The notion of critical mass has been even more important in FP7. The concept was widely used in the 2004 Commission Communication on future European research policy. It stated that the Community could encourage companies to invest more in research in Europe through the creation of "centres of excellence" of critical mass. It pointed to the need to rationalise and regroup – to form a coherent whole with a critical mass – the Community activities:

- to support research in SMEs and for their benefit;
- for the development of risk-capital funds, science parks, incubators, and regional innovation policies; and
- for technology transfer, and the management of intellectual property and patents.

And it described how "technology platforms" were being set up bringing together companies, research institutions, the financial world and regulatory authorities at European level to define a common research agenda which should mobilise a critical mass of national and European public and private resources (EC, 2004b).

6.3. Collaborative research projects and the networks created by them

Collaboration, scientific excellence and critical mass are core principles underpinning FP collaborative research. But how have these principles been translated into action? How have the characteristics of FP collaborative research projects and participations, and the networks established through them, evolved from one FP to the next? These questions can be answered through two complementary kinds of analyses presented in this section. In a traditional analysis of FP participation data, basic parameters like the number of projects and participations, the average number of participations and different Member States per project, and the average EU funding per project and participation are traced and this at both the aggregate and the instrument level. This can be complemented with an analysis of the number of participations per type of institution or region/country. In addition, the overall number and the distribution of links created through collaborative research projects are calculated. Such a traditional analysis of FP participation data can be complemented with network analysis, a fast developing tool quickly gaining in importance for research evaluation since it can provide an insight into issues such as the efficiency of operations and knowledge dissemination, the role of different players, the openness of networks to new members, etc. Knowing what networks look like, and how they have formed and evolved in response to external stimuli is of great importance for the design, implementation and assessment of new policy measures that aim at creating and deepening the ERA (Roediger-Schluga and Barber, 2006). Recent work of Breschi and Cusmano (2002), Cowan and Jonard (2004), Wagner *et al*. (2005), Barber *et al*. (2006), Roediger-Schluga and Barber (2006), Roediger-Schluga and Dachs (2006) has started using this technique to measure and examine the structure and composition of the research networks that have emerged in the FPs.

6.3.1. Towards bigger projects

The aforementioned growth in the overall FP and collaborative research budgets (figure 6.1) has been accompanied by an increase in the number of collaborative research projects and participations (table 6.1). Since FP2, the number of projects went up by about 140% to reach 6,712 in FP5. Likewise the number of participations surged to 44,000 in FP5, representing an increase of about 240% over FP2. Interim data show that, in line with the critical mass objective, FP6 is successful in funding decisively larger projects. It brings together more participants per project and awards more funding to each project and participation. The average number of participations per project has more than doubled to 14.4, while the average EU funding per project has almost tripled to €3.9 million and the average EU funding per participation has increased from €196,000 to €298,000. In addition, FP6 collaborative projects run over a longer period of time. The average duration has increased with about seven months compared to FP5, from 31.7 to 38.8 months.

Table 6.1. Changing features of shared-cost research actions across FPs

Indicators	FP2-EU12	FP3-EU15	FP4-EU15	FP5-EU15	FP5-EU25	FP6-EU25
N° of projects	2 779	3 292	2 949	6 709	6 712	2 130
N° of participations (000)	13	18	21	41	44	27
Average n° of participations per project	4.7	5.6	7.0	6.2	6.5	14.4
Average n° of different Member States per project	3.0	3.5	4.2	3.7	4.0	6.3
Average EU funding per project (€ 000)	1 202	1 218	1 160	1 405	1 405	3 941
Average EU funding per participation (€ 000)	256	218	165	200	196	298

Note: FP2, FP3, FP5 – definitive data. FP4 and FP6 – partial data (respectively: 01.01.1994 – 31.12.1996; to 01.09.2006). FP6 – interim data (first calls). Average EU funding per participation under FP6 calculated by summing the EC contributions of all projects and dividing by the number of participations.
Source: DG Research.

This important change in basic FP characteristics between FP5 and FP6 is clearly due to the introduction in FP6 of new instruments (IPs, NoEs). When IPs and NoEs are compared with the more traditional Specific Targeted Research Project (STREP) collaborative research instrument, it is clear that the former succeed in setting up large-scale, long-term cooperation (table 6.2).[4] While STREPs have an average number of nine participations per project, IPs and NoEs arrive at an average of 24 and 29 respectively. New instrument projects are also longer on average (47 months for IPs and 51 months for NoEs, compared to only 35 months for STREP) and receive more EU funding per project (€9.5 million for IPs and €7.1 million for NoEs, compared to only €2.0 million for STREPs). At the participation level, IPs receive almost twice the funding received by STREPS: €443,000 compared to €241,000.

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[4] Specific Targeted Research Projects are an evolved form of the shared-cost RTD projects and demonstration projects used in FP5. Their purpose is to support research, technological development and demonstration or innovation activities of a more limited scope and ambition, particularly for smaller research actors and participants from candidate countries. http://cordis.europa.eu/fp6/instr_strp.htm

A third new instrument allows the application of Article 169 in the Treaty that enables the Community to participate in research programmes undertaken jointly by several Member States. This instrument requires co-operation at the level of national governments. It aims at integrating whole national or regional programmes on a particular topic by their joint implementation, e.g. through harmonised work programmes and common, joint or co-ordinated calls for proposals. http://cordis.europa.eu/fp6/instr_169.htm

Table 6.2. Features of shared-cost research actions within FP6

Indicators	STREP	IP	NOE
N° of projects	1458	522	150
N° of participations	11901	11144	3942
Average n° of participations per project	9.40	23.95	29.38
Average n° of different Member States per project	5.10	8.40	10.69
Average EU funding per project (€ 000)	1964	9465	7131
Average EU funding per participation (€ 000)	241	443	**
Average duration per project (months)	34.65	47.01	50.99

Note: FP6 Data Partial (to 01.09.2006); Average EU funding per participation under FP6 calculated by summing the EC contributions of all projects and dividing by the number of participations
Source: DG Research.

6.3.2. Towards increased connectivity

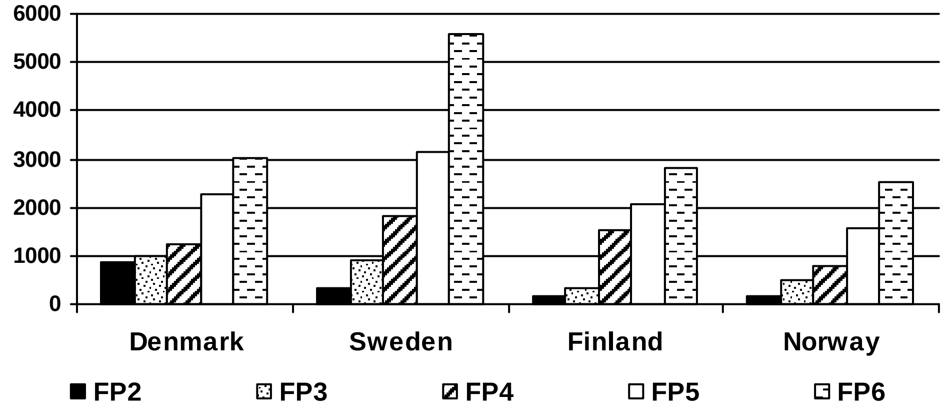
The overall number of links established between Member State participants in FP collaborative research projects has increased substantially from around 40,000 in FP2 to over 180,000 in FP5. Interim data for FP6 point to a marked increase in the number of links compared to FP5. Before the end of the programme, the number of links has already reached almost 275,000. Relative to the number of participations, FP6 establishes more collaborative links than FP5 and can therefore be considered as more tightly interconnected. This connectivity offers possibilities for access to many other actors across the FP (and ERA) conducting similar or complementary research (Wagner *et al*., 2005).

This increased connectivity under FP6 is due to a changing dynamic at the project level. As mentioned above, collaborative research projects bring together more participants per project under FP6 than under FP5. But more than under FP5 these participants also come from a higher number of different Member States (6.3 under FP6 compared to 4.0 under FP5). Breaking down the FP6 interim data by instrument, there are clear indications that IPs and NoEs are responsible for this leap. They bring together 10.7 (NoEs) and 8.4 (IPs) different Member States per project on average respectively, whereas STREPs only reach an average of 5.1. In addition, Wagner *et al*. (2005) found that FP6 projects were more likely to show linkages among different research sectors than was the case in FP5.

In addition to the intensity of collaboration, the geography of collaboration is changing. The intra-European North-South and East-West divides are becoming less deep (see also Sharp, 1998), and extra-European collaboration is increasing. Between FP2 and FP5, the number of collaborative links between Northern

(Denmark, Finland, Norway and Sweden) and Southern (Spain, Greece, Portugal, Italy) European countries increased twice as fast as the total number of links.[5] FP6 interim-data show a further intensification of the collaboration between Northern and Southern Europe (figure 6.4). The cooperation between the fifteen 'old' and the ten 'new' Member States has intensified as well.[6] The number of collaborative links between those two groups of countries increased from around 18,000 under FP5 to more than 35,000 under FP6, their share in the total increasing from 9.7 to 12.9%. Compared to FP5, EU-25 countries collaborate to a greater extent with non-European countries under FP6. The number of non-European collaborative links almost doubled from 32,392 under FP5 to 62,535 under FP6, their share in the total rising from 14.92 to 18.58%.

Figure 6.4. Collaborative links between northern and southern European countries



Source: DG Research.

6.3.3. The networks created by collaborative research projects are complex

6.3.3.1. Repeat participation by knowledge leaders

The FPs are tilted in terms of their participation structure. A comparatively small number of organisations participate in many projects within and across calls, and across FPs, and rake up most participations and funding. Often, but not always, they act as consortium coordinators. Geuna (1995) found on the basis of FP1, FP2 and FP3 data that the distribution of FP university participations is skewed. Many institutions are present in the system only one or a few times, but

[5] Collaborative links calculated for EU-15.
[6] BG and RO not included in the analysis.

a small number of universities achieve a high number of participations. Breschi and Cusmano (2002) found an average of just 2.79 participations per participant, but also a very wide spread. 91% of all organisations participated less than 5 times, and 68% just once. On the other hand, there were 39 organisations that participated between 50 and 100 times, and 10 organisations that participated more than 100 times. A recent summary of a series of FP ex-post evaluations concluded that many organisations' participation in the FP is short lived, but there is a core of frequent participants (EC, 2005c). The Five-Year Assessment 1999-2003, which focused mainly on FP5, discovered a relatively small core of organisations participating multiple times and across several FPs, often as consortium coordinators, and estimated that these organisations accounted for about 20% of all participants (EC, 2005b). Roediger-Schluga and Barber (2006) found on the basis of data covering FPs 1 to 5 that until FP4 the share of actors participating in the preceding FP was larger than that of new actors, with the majority of universities and research organisations overlapping between FPs and new actors being mainly firms. In FP5, more than two thirds of the participants were new, partially because of increased participation by the ten countries acceding to the EU in 2004. One third of the actors taking part in each of the preceding FPs also participated in FP5. A survey among FP5 participants on participation in FP3 through FP6 found that 21.4% had participated in four FPs, 27.9% in three FPs, 26.6% in two FPs, and 24.1% in just one FP (EC, 2005a).

The most frequent participants in the FP are usually so-called knowledge leaders. Breschi and Cusmano (2002) found that the few organisations participating extensively and continuously in shared-cost actions were mainly large firms and universities. Roediger-Schluga and Barber (2006) found that the most active organisations were predominantly large research centres (e.g. CNRS, TNO), a number of large industrial firms (e.g. Fiat, Siemens, DaimlerChrysler), and the natural science and engineering faculties of some of the best known universities in Europe (e.g. Imperial College London, Oxford, Cambridge). Wagner *et al*. (2005) consider larger organisations as "gatekeepers" to FP participation, providing stability over time.

6.3.3.2. Stable networks built around core participants

In addition to repeat participation by knowledge leaders, the FP is characterised by stable networks. FP funded collaborative research networks are relatively stable within and across calls, and across FPs. The Five-Year Assessment 1995-99 found evidence to suggest that many of the links formed between academic and industrial researchers persist beyond initial projects (EC, 2001). The Five-Year Assessment panel 1999-2003 took the view that the FPs have played an important part in the formation and reinforcement of inter-organisational networks (EC, 2005b). A recent summary of FP ex-post evaluations concluded that the FP does not generate wholly new R&D networks, but causes network extension. In other words, the basic networks remain stable but they are able to absorb new participants (EC, 2005c). A survey among FP5 participants found that 81% had worked with some (74%) or all (9%) of their partners before, and 97% expected to work with some (72%) or all (25%) of their partners in the future (EC, 2005a).

These stable networks are built among and around so-called core participants, a subset of the frequent participants. Breschi and Cusmano (2002) identified on the basis of FP3 and FP4 data a large 'oligarchic core', the centrality and connectivity of which strengthened over programmes. And Roediger-Schluga and Barber (2006) found a stable core of interlinked actors since the early FPs with integration increasing over time. Finally, a recent network analysis of partial FP6 data (Wagner *et al*., 2005) found skewed distributions of connectedness, with a central core of highly linked organisations and a periphery of less well-connected entities. The same study found that the type of organisations dominating the networks differed across the FP6 instruments.

The structure and topology of collaborative research networks is also affected by technology. Roediger-Schluga and Dachs (2006) found systematic differences (number of partners, funding and type of prominent actors) between networks in telecommunications and the agro-industry in two specific programmes of FP4. The variation was ascribed to differences in the underlying knowledge base, the research trajectories pursued in EU funded R&D and the organisation of knowledge production in the two industries.

6.3.3.3. The networks resulting from the FPs: Complex, and with small world properties

The networks created by the FPs are complex and carry the "small world" mark. Such networks are considered to be conducive to collective knowledge creation and knowledge transmission (Roediger-Schluga and Barber, 2006; Cowan and Jonard, 2004). The "small world" mark implies the presence of centrally located hubs and highly interconnected actors that may considerably affect the way a network operates (scale-free degree distributions). The maximum distance between two actors is small. Short path-lengths increase the diffusion power of the system: knowledge moves among actors in the network more quickly, and degrades less. At the same time, scale-free networks are quite dense locally, and actors tend to be connected with many of their direct neighbours (cliquishness) (Roediger-Schluga and Barber, 2006; Cowan and Jonard, 2004).[7]

[7] Although there appears to be a tension between cliquishness and short path lengths, small world networks have advantages of both. Because of relative short path lengths, they enjoy a fast diffusion of knowledge in the early periods and, because they are locally structured, the trade or collaboration continues longer than in random networks (Cowan and Jonard, 2004).

6.4. Discussion

A first question raised by the identification of a stable core of FP collaborative research participants is why such a core emerged, and did so at an early stage, and how it was able to survive within the context of a programme marked by substantial change. As has been mentioned before, the specific focus, the budget, and some of the major components of the FP have changed. So have the budget, thematic priorities and instruments of collaborative research. Yet, as Roediger-Schluga and Barber (2006) observe, in spite of changes in programme governance rules, basic network formation mechanisms have remained unchanged. Crucial in this respect appears to be the fact that the FP proposal evaluation system is and has always been based on peer review. The literature identifies a number of factors which promote a certain degree of concentration of participation in (internationally collaborative) research programmes (Geuna, 1999). Large institutions are more likely to apply multiple times to research programs as they have more staff, and to internationally collaborative research programmes as they are more likely to have prior experience with international research collaboration. Large, well-known institutions are better placed than small, lesser-known ones to put together research consortia. And more than small institutions, large organizations have the institutional capacity to handle complex application and project management procedures, and to do so multiple times. Yet in peer review based programmes, research project proposals submitted by consortia involving a large, well-known institution with a well-established research reputation are also more likely to get selected. A lock-in effect then ensues (Breshi and Cusmano, 2002). This results first of all from the fact that successful applicants can familiarise themselves even more with complex application and project management procedures, which remain stable to a certain extent over time (learning effect). This facilitates later applications. Although the FP has changed substantially over time, the application process has remained sufficiently constant to allow for the existence of a learning curve and benefiting from past experience (Geuna, 1999). Successful participation, on the basis of which scientific and technological outputs can be produced, further consolidates the participant's scientific reputation and reinforces the information signalling effect to both potential consortia participants and proposal evaluators at the occasion of a next application. In the literature, this phenomenon is referred to as the 'Matthew effect' and cumulative and self-reinforcement phenomena (Merton, 1968, 1988; Geuna, 2001).

Other questions concern the impact of the persistence of a stable core of FP participants on patterns of knowledge production and dissemination. There are clear potential benefits to having such a stable core of FP participants in terms of achieving critical mass at the project level and across projects, and in terms of reducing overall research fragmentation. It is self-evident that an individual collaborative research project involving one or more European knowledge leaders is better able to pool many and high quality financial and knowledge resources so as to pack punch and achieve critical mass. At the same time, a stable core of FP participants writing up research proposals and pulling projects can ensure the achievement of critical mass through a series of successive research projects by making sure that each project builds nicely on the results of the previous one. It enables actors to deepen a current topic and increase the value of current science (Geuna, 1999). Since these core participants can be conceived of as steering the overall research agenda in a particular field, they are also well-positioned to avoid overlap and gaps. What this shows is that the stable core of FP participants is a strong force for European research integration and that at least some of the concern underlying the 2000 ERA communication about a lack of critical mass and fragmentation was unwarranted since a spontaneous transformation was already in operation.

On the other hand, it is clear that the presence of a stable core of FP participants can also have negative effects on knowledge production and dissemination. Everything depends on the degree of concentration and cliquishness. Excessive concentration in terms of FP participations and funding persisting across calls and FPs raises the question of input additionality: is the FP funding new research that would not be possible without FP funding? Or is it merely funding research that would be carried out anyway in the absence of FP funding? The persistence of networks across calls and FPs also raises the question of behavioural additionality: if Europe's knowledge leaders were already collaborating with each other since the first few FPs, then what was and is the added value of the NoE and (to a lesser extent) IP instruments? Excessive cliquishness also increases the strategic vulnerability of the network since the removal of a key player can have major repercussions. The network rigidity associated with excessive cliquishness also prevents the break-in of new, often smaller and nimbler players with new topics, approaches, etc. (Breshi and Cusmano, 2002). A large portion of organisations with unsuccessful attempts will not submit again as this requires too much resources and effort compared to the chance of getting funding (i.e. negative learning effect) (Geuna, 1999). It also hampers the dissemination of knowledge. Highly cliquish networks are very conducive to idea creation, but appear to suffer from poor diffusion properties (Cowan and Jonard, 2004).

As yet, the FP does not seem to be characterised by excessive cliquishness. But the degree of the cliquishness of the FP network is clearly something that needs monitoring (Cowan and Jonard, 2004). In fact it is clear that the integrated analysis of the characteristics of the FP network and its implications should become part and parcel of regular FP monitoring and ex-post evaluation exercises. That requires something of a paradigm shift for the European Commission. The focus of EC policy so far has been on the quality of research, and on the size of the network carrying out that research. It has never been on the nature and quality of *the network*, i.e. on whether each network involves the pivotal partners and whether the network formation is favourable for knowledge creation and diffusion. From a network perspective, an organisation is important if it occupies a central position. Participating in many projects is not a sufficient condition; centrality depends on whom actors are connected to. Centrality is theoretically the appropriate measure to identify main actors and the assumption is that central actors have a stronger influence on other network members (Roediger-Schluga and Barber, 2006). They serve to organise research and to facilitate exchange of knowledge among more peripheral actors (Wagner *et al*., 2005).

Monitoring the FP network and its impacts is all the more important since there is evidence that increasing the scale of the network and raising the quality of the network may not be compatible (Roediger-Schluga and Barber, 2006; EC, 2004a).[8] Only weak associations were found between the size and the centrality of projects, suggesting that different types of projects attract different groups of players. In particular, large projects appear to have included few of the pivotal actors in the networks studied, implying that large projects include a fair number of peripheral actors. FP ex-post evaluation studies have also found that larger project size under FP6 has not had the expected impacts on efficiency and effectiveness (EC, 2004a, 2005c). While large project size may have a positive effect on knowledge dissemination, the evidence suggests that to create pivotal nodes, it is at least as important to assemble well-connected actors as it is to assemble many actors (Roediger-Schluga and Barber, 2006).

6.5. Conclusion

Since the very first Framework Programmes (FPs), a stable core of participants has formed, which has solidified over time. These participate frequently, sit at the heart of FP networks, collaborate with each other, and do so ever more intensively. The existence of such a core has important policy implications, especially for achieving critical mass at programme and project level, and creating and diffusing knowledge, which are key for the knowledge economy (Cowan and Jonard, 2004). Innovation depends critically on collaborative networks involving

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8 *Unexpectedly we find only weak association between central projects and project size, suggesting that different types of projects attract different groups of actors. In particular, large projects appear to have included few of the pivotal actors in the networks studied.* (…) *This suggests that a policy of creating larger projects may not be fully appropriate to foster networking and the connectivity of R&D collaboration networks in Europe. Rather, projects need to include pivotal actors, which seems to have been the case only partially in the first five Framework Programmes* (Roediger-Schluga and Barber, 2006, 36-37).

academic institutions, research centres and business enterprises (EC, 2005b). By influencing the structure of the network, a policy maker might be able to influence not just the knowledge flows, but also ultimately the capacity of actors and regions to innovate (Singh, 2005).

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