Study on Network Analysis of the 7th Framework Programme Participation

Final Report

EN

Research and Innovation

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Final Report

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OXFORD RESEARCH

Directorate-General for Research and Innovation
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ABSTRACT

This report examines the effectiveness of FP7's network approach in achieving EU research policy objectives and fostering Europe's international competitiveness in S&T. In investigating the potentials and limits of this approach, the study examines the effects of multidisciplinary, interdisciplinary, intersectoral and international collaborations on achieving the positive outcomes sought in FP7.

The study's methods included a network analysis, a survey, case studies including in-depth interviews, a representative stakeholder workshop and regression analyses. The key findings reveal benefits from the continuity of research from FP6 to FP7. However, despite these demonstrated benefits and the increase in participants overall for FP7, the study also found a high attrition rate of organisations from FP6 to FP7.

The report's six recommendations include allowing existing networks to continue research in successive calls, while ascertaining that new members are included, as this has a positive impact upon innovation. Clear guidelines outlining selection criteria expectations for the multidisciplinarity or interdisciplinarity and intersectorality of participants and the number of participating organisations, regions or countries in a project are recommended, and it is also recommended the European Commission investigate why 65% of the organisations present in FP6 did not participate in FP7.

EXECUTIVE SUMMARY

Objectives

The objective of this study was to assess the contribution of networks to the effective delivery of EU research policy and to provide lessons for the future. This is one of several preparatory studies for the overall ex-post evaluation of FP7 and it was carried out from November 2013 to February 2015 by Science-Metrix in consortium with Fraunhofer ISI and Oxford Research.

The overarching questions to be addressed through the study were:

- How far did the network approach, promoted and implemented by FP7, contribute to the achievement of EU Research Policy objectives?
  - What are the effects of networks on strengthening the overall innovation capabilities at local, regional and national levels?
  - How have the networks contributed to the improvement of the competitiveness of national economies?
- What are the potentials and limits of this approach?

In addition, the study addressed eight specific questions about framework programme networks, based upon certain assumptions.

Methodological approach and limitations

In preparing this study, analytical approaches included desk research and a literature review, a social network analysis, a survey of FP7 participants, a regression analysis, case studies including interviews, and a workshop with representative stakeholders. A logic model was developed to address the questions raised in the terms of reference and to assess whether FP7's network approach contributed to achieving the EU's research policy objectives.

One noteworthy limitation for the study is that at the time it was undertaken only approximately 40% of FP7-funded projects had been completed. This had an impact in terms of the availability of intermediate and longer-term measurable outcomes such as collaborative publications and innovations reaching the market. It also presented challenges for comparisons between FP6 and FP7, since one programme was complete and the other was not.

Key policy findings and recommendations

This report delivers 46 findings on networks at the organisational, regional and national levels under FP7, as well as six recommendations for capitalising on networks in future framework programmes.

1. Collaborative research network structure, structural holes and the beneficiaries of the current network structure

One of the most striking aspects of FP7 networks in comparison to FP6 was the increase in participant numbers. The number of participating organisations grew from 20,794 to 26,014 and there were 450,000 new collaborations recorded for FP7. Furthermore, 18,654, or 72%, of the organisations participating in FP7 were new to the network, having not participated in FP6.

This study found a strong core-periphery network structure across both FP6 and FP7, and at the organisational, regional and national levels. At the organisational level of both framework programmes, universities and research organisations dominated the core of the co-participation network while the private sector, small and medium-sized enterprises (SMEs) and public bodies populated the network periphery, surrounded by the network's structural holes and with fewer direct links between them than the organisations at the network core.

2. Continuity and knowledge transfer between FPs

A number of the strongest findings relate to the beneficial effects of network continuity: grounding FP7 projects in work conducted in FP6 lead to well-organised and well-planned research producing more beneficial outputs or outcomes in the longer term and fostering scientific excellence.

The study has also shown that continuity increased the breadth of knowledge and the number of tools created in research projects, and increased knowledge transfer to business and society.

The experience in framework programmes and in collaborative research in general shows that past collaborative experiences, particularly when they involved successful projects, have a positive effect on subsequent network performance.

In light of the observed benefits of continuity, the present study's first recommendation is that the European Commission allows existing networks to receive additional funding in successive calls provided they demonstrate excellence and secure approval in peer reviews.

Considering the benefits of research continuity from one framework programme to the next, this draws into question why 13,434 organisations that participated in FP6, or 65% of the total, did not continue on to participate in FP7. It is recommended that the European Commission perform an in-depth study to explain why nearly two thirds of the organisations in FP6 did not participate in FP7 and investigate the reasons why many organisations will not participate in Horizon 2020.

3. Effects of new organisations and new collaborations on innovation

As a general finding, the regression analysis of projects revealed that the share of new partners involved in a collaborative project had a notable positive effect on both the innovations triggered and the breadth of knowledge created: new partners help strengthen networks and promote innovation.

The study has shown that the benefits of incorporating new members do not lie solely in innovation. New entrants into the framework programmes that partner with more experienced participants were able to gain experience in international collaboration, further their research capabilities, and develop and strengthen their own networks.

It is therefore recommended that in the case that an established network is supported in successive calls, the Commission ascertain that new members are present.

4. Multidisciplinarity and intersectorality effects

At the disciplinary level, the study has found that FP7 linked researchers and projects from fields of science that do not otherwise frequently exchange knowledge.

The study also found that while the majority of the research projects in FP7 were quite multidisciplinary and involved new lines of research, the multidisciplinary research formally supported by the programme does not appear to have been a prerequisite to starting these new lines of research. At the same time, based on a regression analysis having innovation as the dependent variable, multidisciplinary research was not shown to exert a significant effect on triggering innovation in the form of new products or processes. The evidence also did not demonstrate that there was an ideal level of multidisciplinarity to obtain the outcomes sought in FP7.

At the sectoral level, the study has shown that FP6 and FP7 have successfully promoted intersectoral collaborations. The integration of business enterprises, including SMEs, in intersectoral partnerships was found to foster innovation. Bibliometric and survey data revealed that knowledge transfer from research to market and the propensity of projects to introduce innovation in the form of new products or processes were both significantly increased when SMEs were involved in projects in all specific programmes where such activity could be measured. Furthermore, innovations were triggered in almost 61% of all FP7 projects studied, whether or not SMEs were involved.

However, no clear evidence came to light suggesting an ideal number of sectors in a project in order to achieve the outcomes sought in FP7. Extensive intersectoral links could have a possible adverse effect on innovation. Project management difficulties can also be incurred by increased multidisciplinarity and interdisciplinarity, and largely multisectoral projects can bring specific management challenges. Therefore this study recommends that interdisciplinarity and intersectorality should not become mandatory elements in framework programme calls.

5. Contribution to integration of ERA regions and to international research relations

The study demonstrated that both FP6 and FP7 clearly contributed to fostering inter-regional research relationships within the ERA, averaging close to nine participating regions per project. An increase of 93 participating NUTS 3 regions was also observed from FP6 to FP7, and participation intensity also increased, growing from 42 projects per NUTS 3 level region in FP6 to 72 projects per NUTS 3 region on average during FP7. The number of NUTS 3 regions in a project appears to relate significantly and positively with the volume of new knowledge produced through the project. By producing the positive outcomes sought by FP7, regional cooperation within the ERA was found to contribute to raising the international competitiveness of European countries.

As regards the effects on international research relations with countries outside the ERA, the study demonstrated that the contribution of the framework programmes is relatively moderate even if the number of these countries increased from 113 in FP6 to 135 in FP7. The large majority of participants surveyed indicated that the share of international, non-European partners in their projects amounted to less than 5%, and the presence or absence of non-ERA countries does not appear to have had an impact on the production of the positive outcomes sought in FP7. However, the cross-case analysis revealed one of the potentially many mechanisms through which FP7 successfully enhanced international research relations by promoting international cooperation—namely, by increasing the cross-country mobility of researchers.

6. Project management challenges and optimal project size

A cross-case analysis confirmed that a strong and transparent management structure is critical when dealing with international research, most especially because of potential management issues that may arise from cultural differences, geographical distances and language barriers. Therefore <u>the study recommends</u> the Commission require that coordinators have demonstrated project management skills and networks have a clearly stated project management approach.

As regards the effects of size of networks on the results, this study has not been able to confirm the existence of optimally shaped collaborative research networks. Finding an ideal number of participants, disciplines, sectors, NUTS 3 regions or countries is elusive. Based on these findings <u>the study recommends</u> that the Commission produce clear guidelines for calls that mention the Commission's expectations and absence thereof regarding selection criteria, such as number of participating organisations, level of multi/interdisciplinarity, level of intersectorality, and number of regions and countries, wherever relevant.

RÉSUMÉ

Ce rapport examine l'efficacité de l'approche en réseau du 7e PC dans l'atteinte des objectifs en matière de politiques de recherche de l'UE et dans la promotion de la compétitivité internationale de l'Europe en S-T. En explorant le potentiel et les limites de cette approche, la présente étude examine les effets des collaborations multidisciplinaires, interdisciplinaires, intersectorielles et internationales dans l'atteinte des résultats positifs recherchés par le 7e PC.

Les méthodes utilisées dans le cadre de la présente étude comprennent une analyse de réseau, un sondage, des études de cas incluant des entretiens approfondis, un atelier avec des parties prenantes représentatives et des analyses de régression. Les principales constatations révèlent les bénéfices de la continuité de la recherche entre le 6e et le 7e PC. Cependant, malgré ces bénéfices démontrés et l'augmentation de la participation totale dans le 7e PC, l'étude a aussi indiqué un taux d'abandon élevé des organisations entre le 6e et le 7e PC.

Les six recommandations de ce rapport portent entre autres sur le fait d'autoriser les réseaux existants à continuer leur recherche dans les appels successifs tout en s'assurant d'inclure de nouveaux membres, puisque ceci a un effet positif sur l'innovation. Elles portent également sur l'élaboration de lignes directrices claires expliquant les critères de sélection quant à la multidisciplinarité, l'interdisciplinarité et l'intersectorialité des participants ainsi que le nombre d'organisations, de régions et de pays participants. Le rapport recommande également que la Commission européenne enquête sur les raisons qui ont mené 65 % des organisations ayant participé au 6e PC à ne pas participer au 7e PC.

SOMMAIRE EXÉCUTIF

Objectifs

Le but de la présente étude était d'évaluer la contribution des réseaux à la mise en œuvre efficace des politiques de recherche de l'UE et de fournir des leçons pour le futur. Il s'agit d'une des nombreuses études préparatoires à l'évaluation ex post globale du 7e PC. Elle a été réalisée de novembre 2013 à février 2015 par Science-Metrix en consortium avec Fraunhofer ISI et Oxford Research.

L'étude visait à répondre aux questions générales suivantes :

- À quel point l'approche en réseau, promue et implémentée par le 7e PC, a-t-elle contribué à la réalisation des objectifs de la politique de recherche de l'UE?
  - Quels sont les effets des réseaux sur le renforcement des capacités d'innovation générales aux plans local, régional et national?
  - Comment les réseaux ont-ils contribué à l'amélioration de la compétitivité des économies nationales?
- Quels sont le potentiel et les limites de cette approche?

L'étude visait également à répondre, sur la base de certaines hypothèses, à huit questions précises sur les réseaux du programme-cadre.

Approche méthodologique et limitations

Les méthodes analytiques utilisées dans la préparation de la présente étude incluent la recherche documentaire et une revue de la littérature, une analyse des réseaux sociaux, un sondage des participants au 7e PC, une analyse de régression, des études de cas incluant des entretiens ainsi qu'un atelier avec des parties prenantes représentatives. Un modèle logique a été élaboré afin d'aborder les questions soulevées dans le mandat et de décider si l'approche en réseau du 7e PC a contribué à l'atteinte des objectifs en matière de politique de recherche de l'UE.

Une importante limitation de l'étude est que, au moment où elle a été effectuée, seulement environ 40 % des projets financés dans le cadre du 7e PC avaient été complétés. Ceci s'est répercuté sur la disponibilité des résultats mesurables à moyen et à long terme, tels que les publications collaboratives et l'entrée sur le marché des innovations. Cette limitation a aussi posé un défi quant à la comparaison entre le 6e et le 7e PC, puisque le premier programme était complété alors que ce n'était pas le cas pour le second.

Principales conclusions et recommandations en matière de politique

Ce rapport présente 46 conclusions portant sur les réseaux aux niveaux organisationnel, régional et national sous le 7e PC, ainsi que six recommandations visant à tirer parti du potentiel des réseaux dans les programmes-cadres futurs.

1. La structure des réseaux collaboratifs de recherche, les trous structuraux et les bénéficiaires de la structure de réseau actuelle

Un des aspects les plus marquants des réseaux du 7e PC, comparé au 6e PC, a été l'augmentation du nombre de participants. Le nombre d'organisations participantes a augmenté de 20 794 à 26 014, et 450 000 nouvelles collaborations ont été enregistrées pour le 7e PC. De plus, 18 654 organisations parmi celles participant au 7e PC, soit 72 %, étaient nouvelles dans le réseau, n'ayant pas participé au 6e PC.

L'étude a permis d'observer une forte structure de réseau centre-périphérie à la fois dans le 6e et le 7e PC, ainsi qu'aux niveaux organisationnel, régional et national. Au niveau organisationnel des deux programmes-cadres, les universités et les organisations de recherche dominaient le cœur du réseau de coparticipation, alors que le secteur privé, les petites et moyennes entreprises (PME) et les organismes publics peuplaient la périphérie du réseau, entourés par les trous structuraux de celui-ci, et avec moins de liens directs entre eux que les organisations occupant le cœur du réseau.

2. Continuité et transfert de connaissances entre les PC

Parmi les constatations les plus solides, un certain nombre portent sur l'effet bénéfique de la continuité du réseau : le fait de baser les projets du 7e PC sur le travail effectué durant le 6e PC a permis d'améliorer l'organisation et la planification de la recherche et de produire plus de résultats bénéfiques à long terme, tout en favorisant l'excellence scientifique.

L'étude a également montré que la continuité permettait d'accroître l'étendue des connaissances ainsi que le nombre d'outils créés dans les projets de recherche, et favorisait le transfert de connaissances vers les entreprises et la société.

L'expérience des programmes-cadres et de la recherche collaborative en général démontrent que le fait d'avoir eu des expériences collaboratives dans le passé, surtout si elles impliquaient des projets fructueux, avait un effet positif sur la performance ultérieure du réseau.

À la lumière des bénéfices observés de la continuité, la première recommandation de la présente étude est que la Commission européenne permette aux réseaux existants de recevoir du financement additionnel dans les appels successifs à condition que l'excellence de leurs travaux soit démontrée et que ceux-ci soient approuvés par les pairs.

Compte tenu des bénéfices de la continuité de la recherche d'un programme-cadre à un autre, il est important de se demander pourquoi 13 434 organisations, parmi celles ayant participé au 6e PC, ce qui représente 65 % du total, n'ont pas poursuivi leur participation dans le 7e PC. L'étude recommande que la Commission européenne procède à une étude approfondie afin de déterminer les raisons pour lesquelles près des deux tiers des organisations du 6e PC n'ont pas participé au 7e PC, et pourquoi également de nombreuses organisations ne participeront pas à Horizon 2020.

3. Effets des nouvelles organisations et des nouvelles collaborations sur l'innovation

Un constat général de l'analyse de régression des projets est que la proportion de nouveaux partenaires impliqués dans des projets collaboratifs avait un effet positif notable à la fois sur la stimulation de l'innovation et sur l'ampleur des connaissances générées. Ainsi, les nouveaux partenaires aident à renforcer le réseau et à promouvoir l'innovation.

L'étude a montré que les bénéfices d'incorporer de nouveaux membres dans un réseau ne se limitent pas à l'innovation. Les nouveaux entrants aux programmes-cadres qui s'associent avec des participants ayant davantage d'expérience sont en mesure d'acquérir de l'expérience en collaboration internationale, de faire avancer leurs capacités de recherche et de développer et renforcer leurs propres réseaux.

L'étude recommande donc que, pour les cas où un réseau établi reçoit du financement dans des appels successifs, la Commission s'assure qu'il contient aussi de nouveaux membres.

4. Effets de la multidisciplinarité et de l'interdisciplinarité

Sur le plan des disciplines scientifiques, l'étude a montré que le 7e PC a mené à l'établissement de liens entre des chercheurs et des projets provenant de domaines de la science qui n'échangent habituellement pas souvent leurs connaissances.

L'étude a également démontré que même si la majorité des projets de recherche du 7e PC étaient très multidisciplinaires et impliquaient de nouveaux axes de recherche, la recherche multidisciplinaire formellement appuyée par le programme ne semblait pas être un prérequis pour démarrer ces nouveaux axes de recherche. De plus, selon une analyse de régression prenant l'innovation comme variable dépendante, la recherche multidisciplinaire n'a pas semblé exercer un effet significatif sur l'incitation à l'innovation sous la forme de nouveaux produits ou procédés. L'existence d'un niveau idéal de multidisciplinarité permettant d'obtenir les résultats recherchés par le 7e PC n'a pas été démontrée non plus.

Sur le plan sectoriel, l'étude a révélé que le 6e et le 7e PC ont réussi à promouvoir les collaborations intersectorielles. Elle a également montré que l'intégration des entreprises, incluant les PME, dans les partenariats intersectoriels favorisait l'innovation. Les données bibliométriques et de sondage ont démontré que le transfert des connaissances de la recherche jusqu'au marché et la tendance des projets à introduire l'innovation sous la forme de nouveaux produits ou procédés augmentaient de façon importante lorsque les PME étaient impliquées dans les projets de tous les programmes spécifiques où de telles activités ont pu être mesurées. De plus, presque 61 % de tous les projets du 7e PC à l'étude ont engendré des innovations, indépendamment de la présence de PME.

Toutefois, il n'a pas été possible de trouver des preuves claires suggérant un nombre idéal de secteurs à inclure dans un projet afin d'atteindre les résultats recherchés par le 7e PC. Le fait d'avoir un grand nombre de liens intersectoriels pourrait entraîner un effet négatif sur l'innovation. Une augmentation de la multidisciplinarité et de l'interdisciplinarité des projets peut engendrer des difficultés sur le plan de la gestion des projets. La présente étude recommande donc que l'interdisciplinarité et l'intersectorialité ne deviennent pas des éléments obligatoires des appels des programmes-cadres.

5. Contribution à l'intégration des régions de l'EER et aux relations internationales de recherche

L'étude a démontré que le 6e et le 7e PC ont tous deux manifestement contribué à favoriser les relations de recherche inter-régionales à l'intérieur de l'EER, avec une moyenne de presque neuf régions participantes par projet. On remarque aussi une augmentation de 93 régions NUTS 3 participantes entre le 6e et le 7e PC, ainsi qu'une croissance dans l'intensité de participation. Celle-ci est en effet passée de 42 projets par région NUTS 3 dans le 6e PC à 72 projets par région NUTS 3 dans le 7e PC. Le nombre de régions NUTS 3 participant à un projet semble avoir une corrélation significative et positive avec le volume de nouvelles connaissances produites par le projet. Il a été démontré qu'en produisant les résultats positifs recherchés par le 7e PC, la coopération régionale à l'intérieur de l'EER a contribué à l'augmentation de la compétitivité internationale des pays européens.

En ce qui concerne les effets sur les relations internationales de recherche avec les pays extérieurs à l'EER, l'étude a montré que la contribution des programmes-cadres est relativement modérée, même si le nombre de ces pays est passé de 113 dans le 6^{e} PC à 135 dans le 7^{e} PC. La grande majorité des participants sondés ont indiqué que moins de 5 % de leurs partenaires de projet provenaient de pays non européens et la présence ou l'absence de ces pays ne semble pas avoir eu d'effet sur l'atteinte des résultats positifs recherchés par le 7^{e} PC. Cependant, l'analyse transversale des études de cas a révélé un des nombreux mécanismes potentiels à travers lesquels le 7^{e} PC a réussi à augmenter les relations de recherche internationales en encourageant la coopération internationale : l'augmentation de la mobilité transfrontalière des chercheurs.

6. Défis liés à la gestion des projets et taille optimale des projets

Une analyse transversale des études de cas a confirmé qu'une structure de gestion rigoureuse et transparente est essentielle en recherche internationale, surtout à cause des problèmes potentiels causés par les différences culturelles, la distance géographique et les barrières linguistiques. En conséquence, la présente étude recommande que la Commission exige que les coordonnateurs aient des compétences éprouvées en gestion de projet et que les réseaux aient une méthode de gestion de projet clairement établie.

En ce qui a trait aux effets de la taille des réseaux sur les résultats, l'étude n'a pu confirmer l'existence de formes optimales de réseaux collaboratifs de recherche. Il semble improbable d'arriver à déterminer un nombre idéal de participants, de secteurs, de régions NUTS 3 ou de pays. Compte tenu de ces résultats, l'étude recommande d'inclure des lignes directrices claires quant aux attentes de la Commission ou l'absence de celles-ci concernant les critères de sélection tels que le nombre d'organisations participantes, le niveau de multidisciplinarité ou d'interdisciplinarité, le niveau d'intersectorialité et le nombre de régions et de pays, lorsque cela est pertinent.

FINDINGS

RECOMMENDATIONS

1 INTRODUCTION

The willingness to increase Europe's competitiveness by strengthening the scientific and technological bases of industry whilst closing the 'technology gap' with the US and later with Japan played an important part in the setting up of a multiannual Framework Programme for Research, Technological Development and Development Activities (Muldur, 2001; Peterson, 1991). From the First Framework Programme (FP1) initiated in 1984, to Horizon 2020, which was launched in 2014, the framework programmes have been among the EU's main instruments for funding research and innovation in Europe (European Commission, 1995; European Policy Evaluation Consortium, 2011). While the role of the framework programmes has developed over time, two strategic objectives were common to each of them: 'to strengthen the scientific and technological basis of European industry and to encourage it to become more competitive at international level' (European Parliament, 2014).

As the latest of the framework programmes prior to Horizon 2020, the Seventh Framework Programme (FP7) was promoted as a key tool to respond to Europe's needs in terms of jobs and competitiveness, and to maintain leadership in the global knowledge economy (European Commission, 2006). The stated overriding aim of FP7 was 'to contribute to the Union becoming the world's leading research area. This requires the Framework Programme to be strongly focused on promoting and investing in world-class state-of-the-art research based primarily upon the principal of excellence in research' (European Parliament, 2006).

Grants were meant to fund actors all over Europe and beyond, to co-finance research, technological development and demonstration projects. Activities funded under FP7 were required to include 'European added value'. One key aspect of this is transnationality and mobility over national borders—that is, research projects carried out by consortia that include participants from different European (and other) countries (European Commission, 2007).

Framework programmes have also played a role in the promotion of common technical standards, enhanced sharing of costs and risks inherent in new technology development, and substantial intangible or indirect effects regarding technological learning or acquisition of new skills and knowledge (Caloghirou, Ioannides & Vonortas, 2004; Luukkonen, 1998; Polt, Vonortas & Fisher, 2008).

Simultaneously instruments of policy intervention and key results of framework programmes, cooperation and networking have contributed greatly to the construction of the European Research Area (ERA) and analysing them is essential to explaining both the strengths and the limits of framework programmes.

1.1 Role of networking and the construction of the ERA

Since the implementation of FP1, European collaboration has increased substantially. On average, 35% of the publications produced by ERA countries (between 2008 and 2011) result from cross-country co-authorships within the ERA and 22% of the publications produced by ERA countries (between 2008 and 2011) result from cross-country co-authorships involving at least one country beyond the ERA (Campbell, Roberge, Haustein & Archambault, 2013).

A 2009 report found that the Sixth Framework Programme (FP6) made a 'significant contribution to an increased emphasis on the value of networking as a general method to generate innovation, to utilise resources and to complement competencies—in the context of FP6 but also broader in the context of national research programmes' (Rønnest, 2009). Indeed, since the start of the framework programmes, the nurturing of networks has become an important point on the regional, national and supranational science, technology and innovation (STI) policy agenda of the EU Member States.

Research shows that the widespread promotion of the networking approach has not been without difficulties. Networking raises challenges, notably regarding the effective coordination of research activities among heterogeneous partners in research networks. Frenken, Hoekman, and Van Oort (2007), for example, concluded that it remains unclear whether the ERA, 'as defined as an area in which research activities at the national and EU levels are well integrated', is sufficiently integrated and coordinated, and that the 'European Union has not yet succeeded in creating a European Research Area and that its present efforts to do so are apparently well justified'.

Some criticism has also been levelled at how the European funding mechanisms used in the framework programmes have placed too much emphasis on various types of networking, stating that the widespread requirement for collaboration has led to unbalanced and incompatible partnerships, or that excellence has been the price of increasing participation (Royal Society, 2011). Other studies suggested that the funding instruments in FP6 may have resulted in 'artificially "too large" research consortia' and the existence of decreasing marginal returns to an increase in the size of consortia (Breschi & Malerba, 2011).

One of the most comprehensive analyses to date of collaborative networks under the framework programmes was conducted by Heller-Schuh et al. (2011). The authors observed extensive instrumental and structural change over time, concluding that the networks have 'increased in size and have become more cohesive as collaboration has evolved with time'. Others have found that the structure of networks based on framework programme supported mechanisms tends to align with those of other large, complex social networks (Paier & Scherngell, 2011) and tends to retain a similar shape and structure across framework programmes regardless of the level of analysis (Ploszaj & Wojnar, 2009). This indicates that similar network formation mechanisms are in place despite changes in governance rules (Roediger-Schluga & Barber, 2007).

Yet, to date, no comprehensive ex-post evaluation of FP7 has been undertaken. An ex-post evaluation is required not only for legal purposes but also to better understand the effects networks and cooperation have on the strengthening of capabilities at local, regional, and national levels and the ways they have contributed to the improvement of the competitiveness of national economies. The ex-post evaluation will consider inputs from several specific studies on key aspects of FP7. In particular, there is a need to specifically assess how far networks and cooperation have been supported through the different specific programmes. In addition to nuclear research, FP7 was structured around four specific programmes outlined in the Decision No. 1982/2006/EC of the European Parliament and of the Council of 18 December 2006:

- **Cooperation**: With a budget of €32.4 billion (2007–2013), Cooperation provided support to international cooperation projects across the European Union and beyond. The programme aimed to promote progress in knowledge and technology to address European social, economic, environmental, public health and industrial challenges, serve the public good and support developing countries. Cooperation supported research actions in the following thematic areas:

  - Health
  - Food, Agriculture and Fisheries, Biotechnology
  - Information and Communication Technologies
  - Nanosciences, Nanotechnologies, Materials and New Production Technologies
  - Energy
  - Environment (including Climate Change)
  - Transport (including Aeronautics)
  - Socio-economic Sciences and Humanities
  - Space
  - Security

- **Ideas**: With a budget of €7.5 billion, the Ideas programme was implemented through the European Research Council (ERC) to boost Europe's competitiveness by helping to attract and retain the most-talented scientists, support risk-taking and high-impact research, and promote world-class scientific research in new, fast-emerging-fields activities. In contrast with Cooperation, which aimed to support cooperation and networking among organisations, the locus of support of Ideas was the individual researcher. Projects were funded on the basis of proposals presented by researchers both from the private and public sectors on subjects of their choice and evaluated on the sole criterion of excellence as judged by peer review. Two types of the ERC grant were available, both operating on a 'bottom-up' basis without predetermined priorities, across all fields of research:
  - The ERC Starting Independent Researcher Grants (ERC Starting Grants) provided support to the independent careers of outstanding researchers located in or moving to the EU and Associated Countries and who were at the stage of establishing their first research team or programme, whatever their nationality.
  - The ERC Advanced Investigator Grants (ERC Advanced Grants) supported excellent frontier research projects by leading established researchers across the EU Member States and Associated Countries, whatever their nationality.
- **People**: With a budget of €4.75 billion, People built on experience with the Marie Curie Actions under previous framework programmes and it covered all stages of a researcher's professional life from initial training to lifelong learning and career development. It encouraged individuals to enter the researcher profession, structured the research training offer and options, encouraged European researchers to stay in or return to Europe, attracted researchers from all over the world to Europe, and encouraged intersectoral mobility.
- **Capacities**: With a budget of €4.1 billion, Capacities aimed to optimise the use and development of research infrastructures while enhancing the innovative capacities of SMEs to benefit from research. The programme aimed to support regional research-driven clusters and to unlock the research potential in the EU's convergence and outermost regions. Support was provided for horizontal actions and measures underlining international cooperation. Capacities operated in seven broad areas:
  - Research infrastructures
  - Research for the benefit of small and medium-sized enterprises (SMEs)

- Regions of knowledge
- Research potential
- Science in society
- Support for the coherent development of research policies
- Activities of international cooperation

The networking approach was supported differently across the specific programmes and could take different forms depending on the objectives of each programme and the characteristics of funding schemes. This implies that research networks funded under FP7 are diverse, ranging from ad hoc or established R&D consortia to mobility grants between research institutions.

1.2 Study questions

This report commissioned by the European Commission (EC) summarises the findings of an in-depth analysis of FP7 participation in research networks. This is one of several preparatory studies for the overall ex-post evaluation of FP7, which is to be carried out over two years following completion of the Programme. The specific contribution of this report is to address the two following overarching questions:

- (FQ1) How far did the network approach, promoted and implemented by FP7, contribute to the achievement of EU Research Policy objectives?
  - What are the effects of networks on strengthening the overall innovation capabilities at local, regional and national levels?
  - How have the networks contributed to the improvement of the competitiveness of national economies?
- (FQ2) What are the potentials and limits of this approach?

In addition to these fundamental questions, the terms of reference for the present project also required the study to address the following specific questions (SQ1 to SQ8):

Table I Specific questions of the project terms of reference

Question Report section	**Assumption, question and hypothesis**
SQ1 Section 7	Based on the assumption that innovation demands recombination of existing knowledge and new and scientific perspectives: to what extent does the FP link separate fields of knowledge, bridge different field of science, and facilitate new scientific disciplines? Hypothesis: High diversity of linked knowledge increases the probability of the emergence of innovation.
SQ2 Section 8	Based on the assumption that success of innovation depends on the link between basic research, applied research, and business/industry: to what extent does the FP link different types of organisations (universities, industry, SME, etc.) and bridge the flow of innovation ideas between them? Hypothesis: Links between different types of organisations foster success of innovation.
SQ3 Section 6	Based on the assumption that high density networks are fostering competitiveness of EU research: to what extent has the FP contributed to new collaboration and integration of new organisations? How many new collaborations emerged due to the FP? Hypothesis: New organisations in the network and new links

Question Report section	Assumption, question and hypothesis
	between existing organisations in the network indicate a way to a common ERA.
SQ4 Section 9	Based on the assumption that research collaboration is the core idea of ERA bringing competitive advantage: where are the structural holes (missing links) in the structure of the FP network, and who benefits from them? Hypothesis: By identifying and bridging structural holes ERA will be more integrated and EU research more competitive.
SQ5 Section 5	Based on the assumption that scientific innovations are based on the accumulation of knowledge, and looking at network dynamic over time, to what extent are FP project results used as an input for new FP projects, and to what extent knowledge generated in previous FPs has been transformed into new knowledge? Hypothesis: Chaining the scientific outcomes gives good indications that ERA is working in the long-term and is well organised and planned.
SQ6 Section 11	Based on the assumption that openness to international knowledge sharing is important for innovations and competitiveness of the EU: to what extent does the FP contribute to international research relations between the EU and third countries (patterns by countries and specific research areas)?
SQ7 Section 10	Based on the assumption that FPs should play a proactive role in developing excellence across all countries and regions in the ERA: to what extent FPs contribute to integrate countries and regions and foster a wider participation of relevant actors and stakeholders?
SQ8 Sections 4 & 5–11	Where applicable and feasible the contractor will analyse the trends and developments and compare with the situation in the previous Framework Programme (FP6). Note that this question is addressed as part of each of the questions above, whenever relevant.

1.3 Research methods

The present study examines the effects and outcomes of networking at the macro level through network analysis and at the micro level through a survey and case studies that comprised in-depth interviews. Regression analyses were instrumental in connecting data obtained from E-CORDA (the European Commission's External Common Research Data Warehouse, hereafter referred to as CORDA), bibliometric evidence, and the survey.

A workshop with representative stakeholders (project participants and EC representatives) served to validate preliminary findings and was instrumental in articulating the policy conclusions of the present report.

It is worth noting that at the time the present study was undertaken, approximately 40% of FP7-funded projects had been completed. This presents a limitation for the study, particularly in terms of measurable outcomes such as collaborative publications. It also presents challenges for comparisons between FP6 and FP7. The completed projects are, however, a fair representative sample of all FP7 projects, and there is no expectation of wide divergence from the observations made in the existing data.

The main analytical instruments used for the study were as follows. Note that a more detailed description of the methods is presented in an accompanying Methodological Annex.

Desk research and literature review: An extensive review of the literature was conducted with two principal angles. The first angle consisted of examining the scientific literature on research collaboration and networks. This review was useful in anchoring the present study in current best practices in Social Network Analysis (SNA), in addition to providing external evidence to contextualise the study's finding. The second angle consisted of examining official documentation from the EC, in addition to specific studies on collaboration and networking as spurred by EC policies and programmes. The principal use of these documents was to understand the 'programme theory' underlying current and past EC intervention in support of research networks, in addition to helping produce the logic model presented in Section 3.

Social network analysis: The SNA aimed to provide a broad view of networking activities that took place in FP7 and its different specific programmes and underlying thematic areas using CORDA data as well as bibliographic data on the scientific outputs resulting from FP7 projects. Network indicators and analyses were computed using the information on all participants in each FP7 project contained in CORDA. In addition, some bibliometric data from the Web of Science (WoS) database was used to determine the level of interdisciplinarity of projects and to provide data on scientific collaboration between countries.

Survey of FP7 participants: The survey aimed to fill gaps in the SNA. The overall survey sample of around 8,000 potential respondents was compiled based on the full set of raw CORDA data provided by the European Commission's services. This selective approach was adopted in line with the tender specifications to prevent an undue burden on FP7 participants, who were also approached by other evaluation projects conducted in parallel at the time of this study. The survey questionnaire was approved by the European Commission and pretested. The survey was then implemented following a protocol presented in greater detail in the Methodological Annex. The 25.4% completion rate obtained constitutes a substantially above-average achievement when compared to similar surveys.

Regression analysis: Using data gathered from both the SNA and the survey, a number of regressions integrating both SNA and survey variables were performed to assess their impact on a set of targeted positive outputs/outcomes identified for each of the SQs. Measures of these positive outputs/outcomes came from both a bibliometric analysis quantifying the scientific production resulting from FP7 projects and from answers to the survey. Because People and Ideas did not directly support networked research projects, unless otherwise explicitly stated the findings based on the regression analyses pertain to the Cooperation and Capacities specific programmes only.

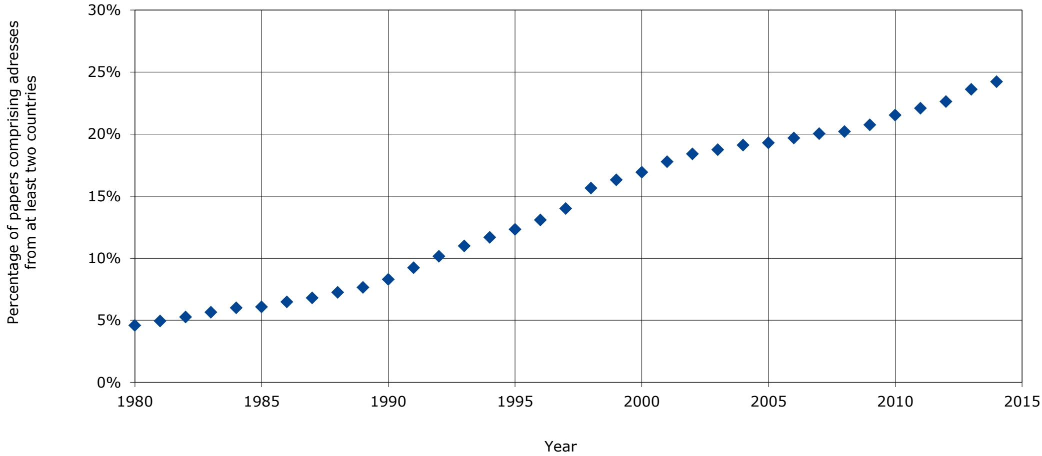
Case studies including interviews: Case studies were used to confirm the preliminary findings from the SNA and the survey, as well as to examine the many factors that can either hinder or foster the achievement of desired outputs/outcomes. Twelve case studies were performed to cover varying levels of achievement for both networking activities and production of positive outputs/outcomes. For each case, desk research was conducted in addition to interviews with the project coordinators and partners. In total, 55 semi-structured interviews were completed.

Workshop with representative stakeholders: A workshop with about 15 participants (academics, practitioners and representatives of the EC Directorate-General for Research and Innovation) was held to validate preliminary findings. Discussions, questions and presentations were addressed in three different sessions. Meeting minutes were provided to all participants for review. The results of the workshop are integrated into the conclusions and recommendations presented in this report.

2 COLLABORATIVE RESEARCH NETWORKS: KEY CONCEPTS AND DEFINITIONS

One of the most striking trends in scientific production over the last several decades has been its increasingly collaborative nature. Whereas fewer than 5% of the papers in 1980 comprised authors’ addresses from at least two countries, this figure is now closer to 25%, a remarkable fivefold growth in 35 years (Figure 1).

Figure 1 Growth of international co-authorship of scientific papers, 1980–2014



Source: Computed by Science-Metrix using Web of Science (Thomson Reuters) data

Several empirical studies have underlined the growing importance of research collaboration within and across fields of science and technology (Cummings & Kiesler, 2005; Porter & Rafols, 2009; Van Rijnsoever & Hessels, 2011), institutional sectors (e.g. higher education, industry) (European Commission, 2013; National Science Board, 2014), geographic areas, including regions (Hoekman, Frenken & Tijssen, 2010; Kroll & Stahlecker, 2012) and countries (Guellec & Van Pottelsberghe de la Potterie, 2001; Adams, Black, Clemmons & Stephan, 2005; European Commission, 2013; Leydesdorff, Wagner, Park & Adams, 2013; National Science Board, 2014). The rise in collaboration has not been restricted to bilateral and trilateral relationships but has resulted in the emergence of collaborative research networks encompassing several actors across national borders (Wagner & Leydesdorff, 2005; Adams, 2012). Research collaboration is sought after given its potential to address complex problems and ultimately to contribute to sustaining broader social, economic, and political objectives (Sonnenwald, 2007).

The evidence obtained so far suggests that productivity gains vary considerably across disciplines (Abramo, D’Angelo & Di Costa, 2009). The effect of collaboration on scientific productivity should be measured carefully; it has been suggested that fractional counting methods preferably be used to avoid the obvious effects of multiple counting (Aksnes, Rørstad, Sivertsen & Piro, 2010; Archambault & Larivière, 2011; Braun, Glänzel & Schubert, 2001).

There is ample evidence that scientific collaboration—more particularly international collaboration—translates into greater scientific quality (Presser, 1980), visibility (Beaver & Rosen, 1979; Bordons, Gomez, Fernandez, Zulueta & Mendez, 1996), and impact (Frenken, Holzl & de Vora, 2005; Glänzel & Schubert 2001; Narin, Stevens & Whitlow, 1991; Smart & Bayer, 1986), and that international collaboration presents particular benefits to less-developed countries (Glänzel, Schubert & Czerwon, 1999).

A plurality of concepts and terminology has been used to define research collaboration and collaborative research networks, making their investigation challenging (Katz & Martin, 1997; Sonnenwald, 2007; Bozeman, Fay & Slade, 2013). Section 2.1 examines key concepts, while Section 2.2 examines the principal dimensions that have been used in studies of research collaboration and networks.

2.1 Collaboration and networking key concepts

Note that in the current report, cooperation and collaboration are used interchangeably. Also, collaboration network—or simply network—in the context of the present report refers to collaborative research networks.

2.1.1 Research collaboration

Currently, there is simply no common definition of 'collaboration', and research collaboration in particular remains a fuzzy concept, largely because it takes place at multiple levels including between individuals, groups, departments, institutions, sectors and countries. The line separating informal links between scientists and more formal collaboration is also blurry (Katz & Martin, 1997). Many broad definitions of research collaboration have been presented, such as Smith and Katz's 'working with someone else for a special purpose' (2000). Likewise, definitions of 'collaborator' tend to simply refer to those who provide input into a particular piece of research and contribute 'directly to all the main research tasks over the duration of the project' (Fraunhofer ISI, Idea Consult & SPRU, 2009). Probably the simplest form of collaboration is that established by a single mobile researcher, such as a visiting scientist or a researcher in residence, who links knowledge of several organisations in one or more countries (see Katz & Martin, 1997), though collaboration is usually understood as meaning that at least two individuals are involved.

Research collaboration can be examined in terms of the human capital involved, as in Bozeman et al. (2013), who define it as 'social processes whereby human beings pool their human capital for the objective of producing knowledge'. Clark (2009) notes that research collaboration studies tend to focus on 'substantive collaboration' between individuals, meaning that they have taken roles that are active and meaningful. Substantive collaboration is further separated into three types: additive (characterised by divisions of labour), exponential (resulting in the creation of knowledge that grows exponentially due to the presence of multiple actors), and conceptual (building off of the creativity of others).

2.1.2 Research networks

An important distinction should be made between research collaboration and networks. While collaboration is often characterised as individual interactions taking place between two or more researchers, networks are larger-scale, usually more complex, multi-faceted interactions between entities. Newman (2004) defined the network (specifically, the social network) as a 'set of people or groups each of which has connections of some kind to some or all of the others'. The Royal Society (2011) characterised them simply as 'networks of individuals, mostly self-organised but sometimes orchestrated', which can take numerous shapes such as diaspora communities, virtual global networks and professional communities of shared interests. Rogers, Bozeman, and Chompalov (2001) define them:

> as guiding metaphors for conceptualizing the relationships between actors and as techniques to measure structural properties of the ensemble. It has been claimed that all network studies share the assumption that the ties between the actors,

which connect them into a system, are more important than their individual attributes.

In the context of research, networks provide a structure that enables entities to collaborate towards the achievement of common or compatible research objectives. A complex social phenomenon, the mechanisms behind scientific collaboration networks involve several types of formal contracts between researchers, as well as informal knowledge exchange. Mali, Kronegger, Doreian, and Ferligoj (2012) argue that networks represent accurate depictions of the structure of science, which does not operate as a single community of hundreds of thousands of individual scientists. Instead, science is 'organized by many different networks that cut across the formal boundaries dividing science with regard to disciplinary, sectoral, and geographical levels' (Mali et al., 2012). Those engaged in networks benefit from timely access to expertise and knowledge that they would not have had otherwise, and they are better able to monitor and control fast-moving developments in their fields (Breschi & Malerba, 2009).

In a global environment characterised by complex technologies and rapid technological advances, science, technology and innovation networks are considered to be an emerging organisational mode that serves as a 'locus for innovation' (Cassi, Corrocher, Malerba & Vonortas, 2008b). Science and technology networks, based on collaboration in research, may be differentiated from the innovation network, which is considered to be an organisational phenomenon focused on economic development and growth in novel and complex technologies, products, and services and the exploration of new market opportunities (Powell & Giannella, 2010; Borrás & Haakonsson, 2012).

2.2 Taxonomy of research collaboration and networks

Research collaboration and networking take form in several dimensions. Help in their characterisation comes from examining disciplinary, sectoral, geographical, type of research (such as basic, applied), and type of interaction dimensions. These analytical dimensions can be used simultaneously, as a collaborative research network could include, for example, interdisciplinary research between enterprises and universities located in different countries with researchers specialised in different scientific disciplines.

2.2.1 Disciplines

The disciplinary dimension comprises the inclusion and interplay between disciplines within a particular collaboration or collaborative network. Research has empirically shown a slow upward trend towards a mode of research joining together several disciplines, at least in certain fields of science and technology (Porter & Rafols, 2009). The measurement of this new mode of research is still challenging (Wagner et al., 2011).

Several scholars have suggested that this mode of research can have positive effects on the generation of new knowledge (Gibbons et al., 1994), while policymakers, including at the EU level, have increasingly supported this mode of research through various R&D funding programmes (Van Rijnsoever & Hessels, 2011) such as FP7 (e.g. Cooperation, Ideas).

Subdimensions reported in the literature to characterise this dimension include intradisciplinary, multidisciplinary, cross-disciplinary, interdisciplinary, and transdisciplinary collaboration (Stokols et al., 2003; National Research Council, 2004; Sonnenwald, 2007; Stock & Burton, 2011; Wagner et al., 2011). The definition of these subdimensions is not without difficulty as the terminology used to categorise research collaboration into the disciplinary dimension is sometimes blurred in the scholarly literature as some researchers use the terms ‘multi-’, ‘cross-’, and ‘interdisciplinary’ collaboration synonymously (Sonnenwald, 2007).

Sonnenwald (2007) defines intradisciplinary collaboration as a collaboration in which a researcher performs his or her research using knowledge from the discipline he or she belongs to and produces new knowledge in that discipline. This can also be simply called disciplinary research.

Multidisciplinary collaboration involves more than a single discipline and each discipline makes a separate contribution. In this type of collaboration, researchers may share data, facilities, materials, databases, and research approaches and knowledge in the course of their collaboration, but they perform research separately by exploring different facets of a problem to solve (National Research Council, 2004; Breschi & Malerba, 2009). Multidisciplinary research has been defined as ‘a mode of research that involves more than a single discipline in which each discipline makes a separate contribution’. Investigators may share facilities and research approaches while working separately on distinct aspects of a problem.

Interdisciplinary collaboration also involves more than one discipline, but in contrast to multidisciplinary research, the collaboration can lead to the emergence of a new technology, discipline or field of science. The core idea behind interdisciplinary collaboration is research by individuals or teams that work together with common data, facilities and materials, and integrate approaches and knowledge from several disciplines to commonly solve a problem that is frequently beyond the scope of one discipline (Committee on Facilitating Interdisciplinary Research et al., 2004).

Transdisciplinary collaboration brings together all disciplines and knowledge relevant to a particular real-world problem. It frequently involves not only several disciplines but multiple non-academic participants as well, combining interdisciplinarity with participatory approaches, therefore ‘transcending’ traditional disciplinary boundaries. This approach is considered to be the most integrative of approaches (Stokols et al., 2003; Stock & Burton, 2011; Wagner et al., 2011).

An additional concept that may be relevant to categorising collaboration into the disciplinary dimension is that of borrowed techniques, which can be defined as the ‘use of one discipline’s methods, skills, or theories in a different discipline’. In the case of research collaboration, these borrowed techniques are external to the disciplinary perimeters of collaborators. When usage is significant, a borrowed technique can become a standard practice in the borrowing discipline (Thompson Klein, 2000; National Research Council, 2004).

2.2.2 Institutional sectors

Another dimension into which research collaboration and collaborative research networks can be categorised is the institutional sector dimension. The institutional sectors that are generally considered include higher education, government, business enterprise, and private non-profit (European Commission, 2013; National Science Board, 2014). Note that sector naming in this report does not coincide exactly with the Frascati manual; sector types were kept almost the same as in the FP6 classification (see methodological annex for more details on sector coding) in order to maintain consistency throughout the framework programmes.

Research collaboration and research networks can be categorised as comprising only intrasectoral collaboration—that is, collaboration between institutions from the same institutional sector—and intersectoral collaboration, which groups research institutions from multiple institutional sectors. In addition, collaboration and networks can comprise public, public–private, and private research partnerships.

In the 1980s and 1990s, several studies suggested that the increasing trend towards public–private interactions in research could be explained by rising cognitive links between science and technology in the innovation process (Narin & Noma, 1985; European Commission, 1997; OECD, 1999), making the distinction between them more difficult (Gibbons et al., 1994). From an institutional point of view and during the same period, governments in industrialised economies started to encourage the development of public–private collaboration in research through various R&D funding schemes in order to increase the economic contribution of public research undertaken in the higher education and government sectors (Feller, 1990; Caracostas & Muldur, 1997; European Commission, 1997; Mowery & Ziedonis, 2001; Hill & Roessner, 1998). Some scholars have described the increasing ties between the government, higher education, and business enterprise sectors in research and innovation as the triple helix model of innovation (Etzkowitz & Leydesdorff, 2000).

2.2.3 Geography

There are various ways of classifying research collaboration and networks into the geographic dimension. For example, they can be categorised as local, regional, national, and international collaboration and networks. They can also be categorised as 'remote' or 'distributed' collaboration and networks, as opposed to those involving actors who are co-located (Sonnenwald, 2007). Finally, 'intra-EU' and 'extra-EU' collaboration have been well studied and 'North–South' collaboration—or collaboration between researchers in developed and developing countries—is a topic of growing importance.

Given the tacit character of scientific and technological knowledge (Foray, 2004) and the coordination costs engendered by collaboration at distance, one would expect research collaboration and networks to mainly be geographically concentrated and localised. Numerous studies have shown there is increasingly frequent research collaboration as well as networks involving entities across regions (Hoekman et al., 2010; Kroll & Stahlecker, 2012) and countries (Guellec & Van Pottelsberghe de la Potterie, 2001; Adams et al., 2005; European Commission, 2013; Leydesdorff et al., 2013; National Science Board, 2014).

While physical proximity remains important in research collaboration and networks, the decreased cost and time of travelling, together with the development of information and communication technologies, may have contributed to increasing research collaboration at distance (Adams et al., 2005; Hoekman et al., 2010).

Governments have increasingly encouraged this development of research collaboration and networks at distance (Adams et al., 2005). One aim was favouring knowledge transfer and integrating research activities to achieve critical mass, as is the case of the ERA initiative and its main pillars over the past two decades, FP6 and FP7 (European Commission, 2008; European Commission, 2012).

2.2.4 Research type

An important dimension in characterising research collaboration and networks is the type of research being conducted and where that research lies in the innovation chain (i.e. how basic or applied that research is) (Smith & Katz, 2000). One way to classify research collaboration and networks into the research type dimension is to group them into the various categories of R&D defined by the OECD Frascati Manual (OECD, 2002)—namely, basic research, applied research, and experimental development. But this typology of R&D activities has been criticised because it relies mainly on the traditional linear model of innovation, whereby advances in science determine the development of technology, while the relationship between science and technology is more interactive (Stokes, 1997). Stokes thus proposes categorising R&D activities into two dimensions. The first dimension concerns the extent to which activities have as their objective the fundamental understanding of scientific problems. The second dimension is about the extent to which there are considerations of use outside the academic sector. Based on these two dimensions, it is possible to distinguish between three types of R&D activities:

- **Pure basic research**. Pure basic research characterises R&D activities in which the quest for fundamental understanding is high and the consideration of use is low.
- **Use-inspired basic research**. Use-inspired basic research characterises R&D activities in which the quest for fundamental understanding is high and the consideration of use is high.
- **Applied research**. Applied research characterises R&D activities in which the quest for fundamental understanding is low and the consideration of use is high.

2.2.5 Type of interaction

A number of scholars have intended to provide a precise definition of *research collaboration* and *network* (Katz & Martin, 1997; Melin, 2000; Smith & Katz, 2000; Jeong, Choi & Kim, 2011; Bozeman et al., 2013), notably to better investigate the determinants, processes, and outcomes of research collaboration and networks. However, as already stressed in this section, there remains a lack of consensus on what research collaboration or networks are. A difficulty in defining these terms is the various types of interaction between collaborators, as these can be formal or informal (Smith & Katz, 2000).

Examples of informal collaboration and networks include informal discussions among researchers in their departments and at conferences, as well as through phone calls and emails (Melin, 2000; Smith & Katz, 2000). At the other extreme, formal collaboration and networks can result in the creation of a legal entity among the collaborators or ad hoc collaborative structures. This type of collaboration and network is often supported by governments through dedicated public R&D and innovation programmes, such as FP6 and FP7.

3 INTERVENTION LOGIC AND THEORY IN THE EUROPEAN UNION

Supporting networking in research is one of the main instruments of the EC intervention through FP7, which is expected to produce outcomes such as increased innovation, strengthened competitiveness, and improved social and environmental well-being (European Commission, 2005b). The present section provides a description of the logic and theory behind this type of intervention by the EC, a logic model produced by the study team, and an explanation of the use of this model in the present study.

3.1 Research collaboration and networks in the European context

The multiannual framework programme is among the EU's main instruments for funding research and innovation in Europe (European Commission, 1995; EPEC, 2011). Since the First Framework Programme in 1984, the role of the framework programme has been modified to better support and coordinate research across Europe and between Europe and third countries considering regional and global changes. One of the most important approaches taken by the European Commission towards the strengthening of European research has been the promotion of pan-European transnational coordination, collaboration, and integration in terms of R&D funding, execution, and governance (Delange, Sloan & Muldur, 2009; European Commission, 1995).

Implicit in this approach is the creation of a Europe-wide science and technology system. This would correct the existing system-level failures in R&D governance caused by the lack of coordination among research funding agencies and decision-making bodies on the one hand, and, on the other, sub-criticality and duplication in the execution of R&D, which could prevent R&D performers from achieving their goals due to the lack of critical mass (European Commission, 2008; Svanfeldt, 2009). In this context, the ERA is seen as a key means to overcoming fragmentation in the execution of R&D, which leads to excessive duplication and limited diffusion of scientific and technological knowledge in Europe among R&D performers within and across institutional sectors (i.e. higher education, government, business enterprise, private non-profit), limited researcher mobility, and sub-criticality.

While all the framework programmes have supported a networking approach in the execution of R&D (European Commission, 2005b), this approach has been extended to new areas of research and intervention along with the increase of the budget allocated to successive framework programmes. The approach gained momentum with the Maastricht Treaty and research and innovation policy increasingly being perceived as key, together with other policies, in boosting economic growth, employment, and competitiveness, and with the Commission's 2000 Communication *Towards a European Research Area*, which expressed concern about the negative impact of the fragmentation and compartmentalisation of national research systems on Europe's competitiveness (Breschi & Malerba, 2009).

The concept of sub-criticality associated with the networking approach does not imply achieving critical mass (if it exists) with a view to benefitting not only from economies of scale through research networks made of similar research entities, but also from economies of scope through research networks made up of groups working in different disciplines. From the latter perspective, critical mass can be achieved through multidisciplinary and interdisciplinary research as well as research borrowing techniques, which can be defined as 'the use of one discipline's methods, skills, or theories in a different discipline' (Committee on Facilitating Interdisciplinary Research et al., 2004). As a result, the networking approach was reinvigorated with FP6 (2002–2006), aimed at facilitating the ERA, particularly through the implementation of new instruments such as the Integrated Projects and Networks of Excellence.

FP7 supports primarily formal collaborative research networks, with identified actors and ties, although these networks can subsequently lead to the emergence of informal links. The supported collaborative research networks include a variety of research institutions from different institutional sectors (e.g. higher education, government, business enterprise, private non-profit) within and across countries, regions, and fields of science and technology. In addition, these collaborative research networks perform different types of research, ranging from pure basic research, through user-oriented basic research, to applied research. This variety of supported collaborative research networks makes the investigation of their determinants, processes, outputs and outcomes challenging given that they are likely to differ.

About two thirds of the overall FP7 budget was reserved for the Cooperation specific programme, which supports all types of research activities carried out by different research bodies in transnational cooperation and aims to gain or consolidate leadership in key scientific and technology areas (European Commission, 2007). Cooperation also places strong emphasis on interdisciplinary research between R&D performers and on research collaborations between R&D performers belonging to different institutional sectors—namely, higher education, government, business enterprise (including SMEs), and private non-profit (European Commission, 2005b; Council of the European Union, 2006).

There were exceptions to the application of the networking approach in FP7. There is no obligation for cross-border partnerships in Ideas, for example. Rather, it mainly concerns the support of individual researchers who carry out frontier research, although such research can be carried out by transnational teams. In this case, the 'European added value' lay in bringing the competition between researchers at the national and regional levels to the European level (European Commission, 2007). Similarly, the People specific programme also focuses on the individual, supporting 'researcher mobility and career development, both for researchers inside the European Union and internationally' (European Commission, 2007).

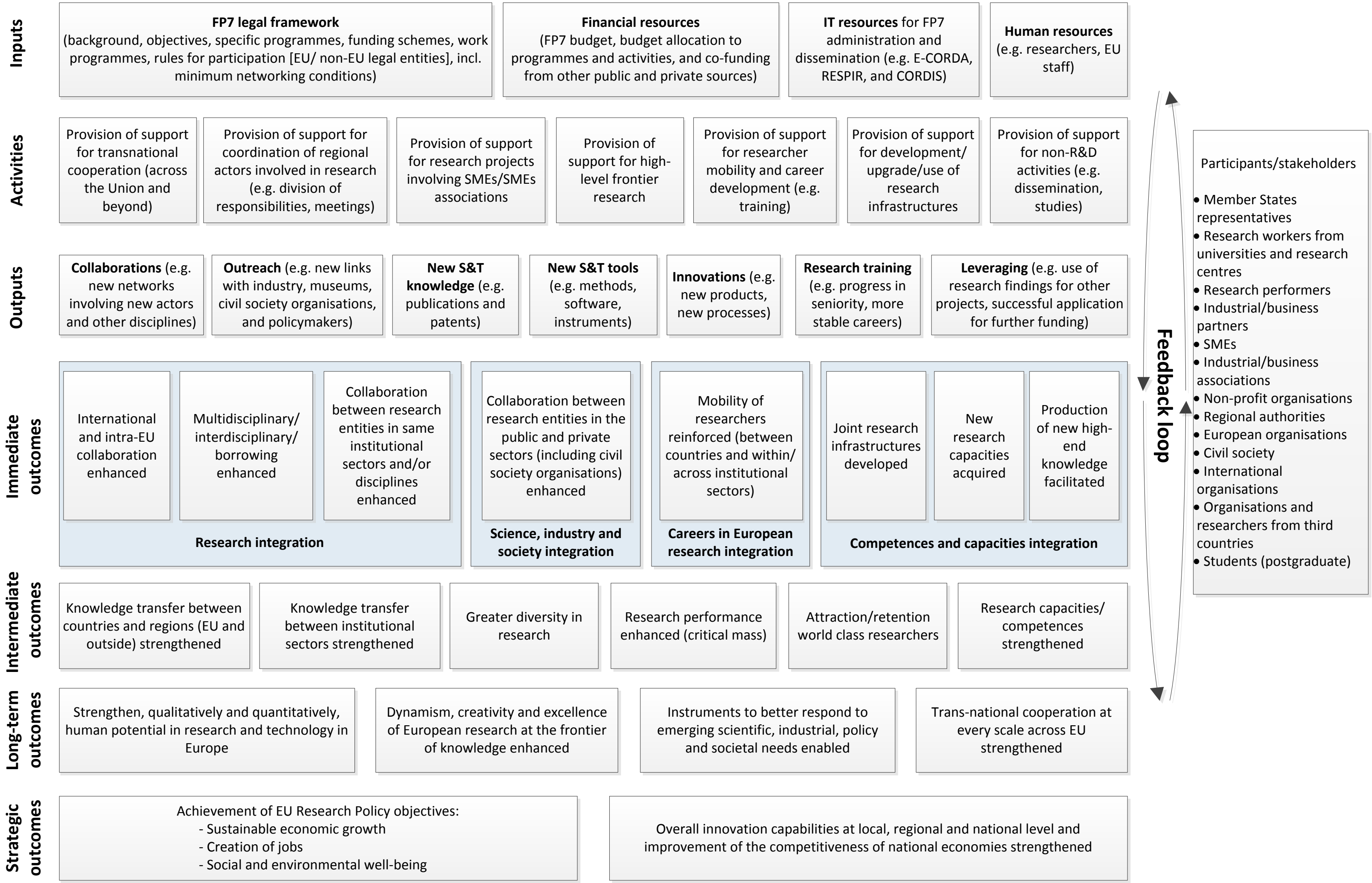
3.2 Logic model of intervention based on cooperation and networking in FP7

This section presents the role of networks in FP7 using a logic model (Figure 2). It presents the logic model's main components (inputs, activities, outputs, and outcomes), and its use in the present study. The sources used in the construction of the logic model are presented in the accompanying Methodological Annex.

Often used in evaluation, logic models are causal visual representations of programmes that show how a programme is intended to work; that is, how resources that are available to deliver the programme are converted into programme activities, which in turn produce intended results. Logic models are therefore typically constructed by distinguishing between programme inputs (i.e. the resources that are required to operate the programme), activities (i.e. the activities that used resources to achieve the intended results), outputs (i.e. the amount of work that is done as the programme is implemented), and outcomes (i.e. the intended results in the short, medium, and long term that are linked to programme activities).

Logic models do not necessarily intend to show one-to-one causality relationships between each element of these categories since relationships can be more complex. For instance, in a logic model, each activity has at least one output, but there can be several outputs for particular activities. Logic models have several benefits justifying their use. They help develop a common language among stakeholders, document and emphasise explicit outcomes, clarify knowledge about what works and why, identify important variables to measure and enable more effective use of evaluation resources, and provide a credible reporting framework.

Figure 2 Logic model of intervention using collaboration and networking in FP7



Source: Science-Metrix using European Commission documents

One of the key underlying assumptions of European intervention in research is that cooperation and networking foster positive outcomes such as increased European competitiveness and better integration of the ERA, which in turn are expected to foster socio-economic betterment.

The inputs or resources required to develop and maintain the programme activities have been grouped in the logic model according to individual resources provided for the four main specific programmes at the heart of the present study (see also Figure 2):

- Documentary resources based on legal framework. These inputs primarily include all the decisions and regulations related to FP7; that is, the legal framework. The decision for the launching of the programme explains its background, the strategic objectives and the rationale associated with the specific programmes and activities, as well as the funding schemes that broadly define how indirect actions are supported and which types of activities are supported. The decision on the rules of participation by legal entities (e.g. research organisations, universities and industry) in actions supported by the programme includes the definition of 'legal entity', the minimum conditions for participation in the specific programmes and activities such as those related to the creation of pan-EU collaborative research networks, the rules for participation of entities from non-EU countries, and the rules for the Community financial contribution (e.g. co-funding principles). The decisions for the launching of the specific programmes (e.g. Cooperation), as well as the work programmes and calls for proposal, define the type(s) of scheme(s) used to fund different actions, the categories of participants that can benefit from it, and the types of activities (e.g. R&D, training, dissemination, and other related activities) that can be funded through each of them.
- Financial resources. These inputs also include the overall budget of the programme and the budget allocation among the different specific programmes and activities. Given that a large share of indirect actions are supported based on a co-funding principle, these financial inputs or resources are complemented by those originating from other sources, including public sources at the international, national and regional/local levels, as well as private sources (e.g. industry, private non-profit sector).
- IT resources. In addition to legal and financial ones, resources include databases and the IT dissemination tools to administer the funds and projects supported by the programme, to report on the outputs from the latter, and to disseminate information on calls for proposals and final results of projects. Examples of these databases and dissemination tools are the E-CORDA, CORDIS, and RESPIR.
- Human resources. Finally, there are human resources, such as the researchers and related staff involved in R&D and related activities, and the staff in EU institutions and agencies in charge of the implementation of the programme.

The above inputs and resources link directly to the activities carried out by research and non-research legal entities through the four specific programmes of FP7 under consideration in the present study: Cooperation, Ideas, People, and Capacities.

- R&D activities. A large share of R&D activities requires networking among different entities, with an assumption that networking generates more benefits than costs (i.e. coordination costs). Activities undertaken by research entities can consist of transnational cooperation across the European Union and beyond. These activities are primarily implemented under the Cooperation specific programme. Other activities performed by research entities are undertaken in the context of researcher mobility between institutions and institutional sectors, often located in different countries. These activities are expected to have an impact on the career development of researchers. They are chiefly supported under the specific programme People. Research entities also carry out frontier research. Activities in support of the development of frontier research are typically financed under the specific programme Ideas. Other research activities such as the development, use, and upgrade of research infrastructure are supported through the specific programme Capacities. Research activities are also performed in the context of collaborative networks encompassing SMEs and other research entities such as research organisations, with the aim of SMEs acquiring R&D capacities. These activities are supported through the specific programme Capacities, though the most R&D-performing SMEs can be supported in the specific programme Cooperation. Finally, some research activities bring together regional actors involved in research. They are supported primarily through the specific programme Capacities.

- Non-R&D activities. While the above activities concern R&D activities, entities—whether research entities or not—can participate in non-R&D activities such as training and dissemination. These activities can be financed in various specific programmes such as Cooperation and Capacities. These activities are typically supported as coordination and support actions and do not necessarily entail networking.

The different activities carried out by legal entities—primarily research ones—in the context of FP7, are expected to produce outputs. These outputs can be diverse, reflecting the various types of supported activities across the four specific programmes, the legal entities involved (e.g. research organisations, universities, industry), types of R&D carried out (e.g. basic research, applied research, experimental development), and fields of science and technology in which R&D is performed. It is almost impossible to establish a one-to-one causality link between each activity and a particular output, as projects can generate several types of outputs. Outputs from the supported activities can consist of the following categories (Cummings & Kiesler, 2007):

- New S&T knowledge. This includes publication of academic articles, books and proceedings; presentation of results at conferences or workshops; development of a new model or approach in the field; patent applications; awards for contributions to the field; etc.
- New scientific and technological tools. These outputs include the development of new abstract methodologies; development of a new kind of tangible instrument; creation of new software; creation of new hardware; creation of new datasets; creation of data repositories; creation of surveys; etc.
- Research training. These outputs consist of career progress in terms of seniority, more stable career positions (e.g. of tenure track), etc.
- Outreach. These outputs translate into new links established with entities that did not take part in the supported projects and that help disseminate research findings to a wider audience. These include partnerships with industry, museums, healthcare institutions, policymakers, government research-performing organisations, civil society organisations, etc.
- Innovation. New products introduced and new processes implemented (as defined in OECD & Eurostat, 2005).
- Leverage. Main research results used as a basis or key inspiration for other projects; by-products used as a basis or key inspiration for other projects; successful application for new funding to further develop research results obtained in the context of the supported projects; successful application for new funding to further develop applications created in the context of the supported projects; etc.

In the context of the promoted networking approach in FP7, an assumption is made that collaborative research is more likely to achieve the above outputs than research undertaken by individual entities. Furthermore, while these different outputs can be equally achieved by research projects involving individual entities, collaborative projects can lead to distinct collaboration outputs (Cummings & Kiesler, 2007), including the establishment of lasting partnerships with new entities at various geographic levels (e.g. local/regional, national, EU, and international), the establishment of lasting partnerships with new entities from different institutional sectors (e.g. higher education, government, industry), and the establishment of lasting partnerships with new entities in different fields of science and technology.

The above outputs are expected to lead to results in the short, medium, and long term. To a large extent, these intended results reflect the objectives of FP7 to be achieved through the promotion of the networking approach.

Immediate outcomes are short-term results emerging directly from the programme outputs. Four types of immediate outcomes can be identified:

- Enhanced integration of research. This relates to the integration of research conducted in the ERA through having enhanced cooperation. This first outcome can be closely associated with the specific programme Cooperation. The integration of research can result from enhanced collaboration between research entities from the ERA and third countries (i.e. increased international collaboration); different fields of science and technology (i.e. increased multidisciplinary and interdisciplinary research and research borrowing); different EU regions and countries (i.e. increased EU collaboration); and same institutional sectors and/or fields of science and technology (increased critical mass).
- Enhanced integration of science, industry, and society. The second type of immediate outcome relates to the integration of science, industry and society through stimulating the collaborative efforts between higher education, the government sector, the business enterprise sector, and other entities such as civil organisations. This outcome can be associated with the four specific programmes.
- Enhanced integration of careers. The third type of immediate outcome relates to the integration of careers in the ERA, achieved by supporting the mobility of researchers throughout Europe and beyond. This outcome can be associated with the specific programme People.
- Enhanced integration of competencies and capacities. The fourth type of immediate outcome refers to the integration of competencies and capacities by facilitating the creation of joint infrastructure and new research capabilities to trigger the production of new knowledge. This outcome can be associated with the specific programmes Capacities and People.

Intermediate outcomes are medium-term results emerging from the immediate outcomes. They include the following:

- Stronger knowledge transfer between regions and countries. This first type of intermediate outcome involves a stronger process of knowledge transfer between countries/regions within and outside the ERA through enhanced collaboration between research entities and facilitated researcher mobility.
- Stronger knowledge transfer between institutional sectors. The second intermediate outcome includes an enhanced knowledge transfer among research entities and researchers from different institutional sectors, notably between the

public research sector (i.e. higher education and government) and the private one (i.e. business enterprise and private non-profit).

- Greater diversity in research. The third intermediate outcome consists of greater diversity in European research through the emergence of new lines of research by the integration of tools, concepts and theories, information, and methods from different disciplines.
- Research performance enhanced. The fourth intermediate outcome is the enhancement of research performance through the achievement of positive critical mass and research efficiency gains. These are made possible by the pooling of financial and human resources in similar fields of science and technology and the reduction of efficiency losses due to the duplication of research undertaken by dispersed research entities across the ERA.
- Attraction and retention of world-class researchers. A fifth intermediate outcome is the attraction and retention of world-class researchers in the ERA.
- Research capacities and competencies strengthened. The final intermediate outcome is the strengthening of research capacities and competencies in the ERA.

In terms of long-term outcomes, it is expected that if the intermediate outcomes are achieved, they will translate into the following:

- More skilled human resources in research and technology in Europe. New people will be involved in research fields, and established research performers will remain in or be attracted to institutions across the EU. Thus, the human potential in research and technology in Europe will be strengthened both quantitatively and qualitatively.
- The enhancement of the dynamism, creativity and excellence of European research at the frontier of knowledge. Investigator-driven basic research based on excellence is conducted.
- The establishment/consolidation of instruments to better respond to emerging scientific, industrial, policy and societal needs. Use of research infrastructures is optimised and new facilities and instruments for research are developed.
- Transnational cooperation at every scale across the EU will be strengthened. Increased collaboration and networking involving people from various sectors (industry, society, research) and levels (EU, national, regional) throughout the EU.

The chaining of outcomes should largely contribute to strengthening the ERA, which is tightly linked to the achievement of the FP7 strategic goals. The first goal revolves around contributing to the achievement of EU Research Policy objectives, which encompass the increase of economic growth, jobs, and social and environmental well-being. The second goal targets the strengthening of the EU's competitiveness through the enhancement of the overall innovation capabilities at the local, regional and national level.

3.3 Use of the logic model in the present study

The logic model and its components were instrumental in addressing all the questions raised in the terms of reference, and especially the first fundamental question of this study: '*How far did the network approach, promoted and implemented by FP7, contribute to the achievement of EU Research Policy objectives?*' The research methods and data collection tools (documentary review, network analysis using E-CORDA, SESAM and the Web of Science bibliometric database, survey, case studies with semi-structured interviews) were used to answer the evaluation questions given the specific strengths associated with each method. The CORDA/network and the survey analyses mainly served to measure 'what', 'to which extent', 'where' and 'who'; the interviews used in the case studies focused more on 'how' and 'why'.

The CORDA/network analysis concentrated on the 'activities', 'outputs' and 'immediate outcomes' components of the logic model and was used to identify the attributes of FP7 projects (e.g. collaborative projects involving several disciplines, public and private entities, entities in the same institutional sector, institutions working in the same discipline, entities from non-EU countries, and entities across and within EU countries and regions) implicitly defined by the specific questions as well as the properties of larger networks supported by FP7 in different activities. These components were also used to examine the evolution of the attributes of projects funded under FP6 and FP7, and of the properties of larger networks supported by these successive programmes.

The logic model was also used to structure the survey questions. The survey analysis made use of the 'inputs', 'activities', 'outputs', and 'immediate outcomes' components to examine the extent to which the network approach supported by FP7 led to the tangible outputs and immediate outcomes depicted in the logic model, using descriptive statistics and multivariate statistics (regression analysis). In the regression analysis, the various assumptions associated in particular with the specific evaluation questions were empirically tested. The dependent variables were the outputs and immediate outcomes, and the independent variables the indicators created from the network analysis based on the 'inputs' and 'activities' components of the logic model. It is important to note that the limitations of the networking approach were reflected in the regression analysis by integrating other independent/control variables, such as project budget amounts (and the EC contribution), the country and region of participants, the start and end year of projects, the type of research undertaken, the type of participants (e.g. firm), and the coordination activities undertaken during the project.

The logic model was also used as a basis for structuring and formulating the semi-structured interview questions used as part of the case studies. The interviews and case studies made use of the logic model to describe and explain how and why the developments related to the foundation, formulation, sustainment, and conclusion stages of selected collaborative networks have occurred.

4 GENERAL STATISTICS ON FP6 AND FP7 COLLABORATION (SQ8)

Project terms of reference: Where applicable and feasible the contractor will analyse the trends and developments and compare with the situation in the previous Framework Programme (FP6). Note that this question is addressed as part of each of the questions above, whenever relevant.

As mentioned in the introduction, FP7 is composed of four specific programmes: Cooperation, Ideas, People, and Capacities. Cooperation comprises a number of thematic areas while Capacities comprises a number of broad areas. Table II presents statistics on the average number of actors on FP7-funded projects for the programmes, specific programmes and the areas of specific support. The term 'actor' can refer to an organisation, country, region (NUTS 3) or an activity sector, depending on the level of analysis required (international, regional, organisational, etc.). This table allows for a comparison of the levels of participation and relative collaborations within a given thematic area, specific programme and framework programme.

These data, like that of several analyses used in the present study are drawn from the E-CORDA database, commonly referred to as CORDA. The CORDA database contains data pertaining to framework programme projects and also contains data on project participants (organisations or individuals) on each project. For each participant the database contains self-declared information such as country of origin, the region and sector. From there it is possible to cross-reference each project to its participants and measure the average number of actors for each given indicator.

Aggregate and even detailed comparisons between FP6 and FP7 are not easy to perform as these programmes had different structures—for instance, the four specific programmes are new to FP7. To facilitate comparisons, Table II presents overall data for FP6 and FP7 in addition to totals without the Marie Curie Actions in FP6 and without People and Ideas in FP7.

As per CORDA data, and reflecting the substantial increase in overall funding compared to FP6 (a 63% increase at 2006 prices [European Commission, 2007]), FP7 supported 2.24 times more projects than FP6, and 1.66 times more projects when excluding Marie Curie Actions from FP6, and People and Ideas from FP7. This is an important increase and certainly placed stress on network density. The larger scale of FP7 and its ambitious objectives to increase the participation of ERA and non-ERA countries, to increase the participation of business enterprises and of organisations from the European periphery means that many newcomers must have had relatively few connections. This in turn means there was a potential to obtain numerous structural holes; that is, poorly connected organisations or countries. This question is examined in Section 9.

Overall, FP7 has a slightly reduced average number of participating countries and organisations per project when compared to FP6. This is the case for the overall figures, and when Marie Curie Actions from FP6 and People and Ideas from FP7 are excluded. The People and Ideas specific programmes average very low scores compared to the FP7 average for most indicators, which is not surprising as these were not designed nor is it their purpose to be cooperative programmes. Hence, the scores observed for Capacities and Cooperation do not mean these programmes performed better in terms of collaboration; this was a core aspect in their design, in contrast to People and Ideas, which aimed to support research excellence.

Within FP7, three research areas stand out for their relatively high level of collaboration—namely, Research Infrastructures, Environment (including Climate Change) and Food, Agriculture and Biotechnology. While these three areas account for only 5.5% of the total number of FP7 projects, they involve, on average, more than 13 collaborating organisations from three sectors of activity. Projects in the latter two research areas also provide particularly good opportunities for ERA and non-ERA collaboration, as on average at least one country from outside the ERA participated in each project.

Table II Average number of actors per project for each thematic area (FP6 and FP7)

	No. of Projects	Avg. No. of Organi-sations	Avg. No. of Countries	Avg. No. of ERA Countries	Avg. No. of Non-ERA Countries	Avg. No. of NUTS3 Regions	Avg. No. of Sectors
FP6	**9,781**	**7.1**	**4.2**	**4.0**	**0.3**	**6.1**	**2.2**
FP6 excluding Marie Curie Actions‡	**5,331**	**11.5**	**6.5**	**6.0**	**0.5**	**9.7**	**3.0**
FP7	**21,963**	**5.2**	**3.3**	**3.2**	**0.2**	**4.6**	**1.9**
FP7 excluding People & Ideas†	**8,867**	**10.5**	**6.2**	**5.8**	**0.4**	**9.1**	**2.9**
COOPERATION	**7,017**	**10.8**	**6.3**	**5.9**	**0.4**	**9.4**	**3.0**
Info. and Comm. Tech.	2,065	9.3	5.7	5.4	0.2	8.1	2.9
Health	977	10.9	6.6	6.0	0.7	9.5	3.1
Nanosci., Nanotech., Mat. and new Prod. Tech.	761	12.3	6.6	6.4	0.2	10.7	3.1
Transport (including Aeronautics)	689	12.3	6.4	6.2	0.3	10.3	3.2
Joint Tech. Initiatives (Annex IV-SP1)	626	7.3	3.4	3.3	0.03	6.0	2.1
Environment (including Climate Change)	443	13.9	8.6	7.5	1.1	12.2	3.3
Food, Agriculture, and Biotechnology	437	14.6	8.9	7.8	1.1	12.8	3.4
Energy	333	11.3	6.4	6.0	0.3	9.6	3.1
Space	240	9.9	6.2	5.7	0.5	8.6	2.9
Security	229	12.0	7.2	7.1	0.1	10.1	3.5
Socio-economic sciences and Humanities	209	10.5	8.2	7.5	0.8	9.9	2.6
General Activities (Annex IV)	8	1.0	1.0	1.0	0	1.0	1.0
CAPACITIES	**1,850**	**9.3**	**5.8**	**5.4**	**0.4**	**8.0**	**2.7**
Research for the benefit of SMEs	905	8.8	5.1	5.1	0.02	7.6	2.7
Research Infrastructures	334	15.1	9.5	8.8	0.7	13.4	3.2
Research Potential	194	1.5	1.4	1.4	0.1	1.5	1.1
Science in Society	162	9.5	7.3	6.7	0.5	8.7	2.8
Activities of International Cooperation	149	8.4	6.4	4.3	2.1	7.0	3.1
Regions of Knowledge	81	11.7	4.4	4.4	0.02	7.1	4.1
Coherent development of research policies	25	5.1	3.8	3.8	0	4.6	2.0
PEOPLE	**9,293**	**1.9**	**1.5**	**1.5**	**0.02**	**1.8**	**1.2**
IDEAS	**3,803**	**1.2**	**1.1**	**1.1**	**0.01**	**1.1**	**1.1**

Note: ‡ Excluding the Marie Curie Actions (equivalent of People under FP7) under FP6 and † excluding People and Ideas under FP7 since they are not specifically designed to formally support cooperation.
The colour gradient indicates whether the score of a given thematic area (under Cooperation) or broad area (under Capacities) is above (green) or below (red) the average across projects inside a given specific programme for each indicator. Only Cooperation and Capacities were analysed in this manner as they are the only specific programmes with more than one underlying area.

Source: Computed by Science-Metrix using CORDA (European Commission) data

In order to compare the level of collaboration in FP6 and FP7 to that generally observed in the ERA, the publications of framework programme funded researchers were cross-referenced to the Web of Science (WoS) to create publications portfolios. Using statements of funding acknowledgement that appear in the WoS, scientific articles can be attributed to specific framework programmes using text-mining techniques. Please note that the technique employed is highly restrictive and aims to maximise precision (the number of papers retrieved were truly supported by framework programmes) rather than recall (capturing all papers that were produced with some support from framework programmes). These numbers are useful for performing statistical tests, but should not be considered as accurately depicting the extent of framework programme support on scientific production as they necessarily underestimate support.

About 50% of all scientific papers that could be attributed to FP7 projects cite at least one FP6-funded paper. However, in the absence of a counterfactual analysis—for example, with a control group—one cannot determine whether this level of level of knowledge chaining is greater in framework programmes than in research projects overall.

As shown in Table III, the level of international collaboration between FP6 and FP7 as measured in scientific paper co-publications is similar. FP7 seems to have favoured more international collaborations between ERA and non-ERA countries, and not surprisingly in this context, FP7 projects had somewhat less collaboration within the ERA than in FP6. Extreme care should be taken when comparing these statistics; as mentioned, FP6 and FP7 do not have a similar composition of underlying programmes and this type of change can rapidly alter statistics. Importantly, collaboration scores between ensembles of different sizes should only be performed by recognising scale effects; that is, the larger the system, the lower its propensity to undertake collaboration with the outside. This is due to the probability of finding collaborators within the system and this probability increases with system size, which means that, conversely, the probability of collaborating with the outside is smaller for larger systems (Archambault et al., 2011).

Table III International collaboration rates of ERA and FP6- and FP7-supported papers

	Intl. Coll. Rate			Intl. Coll. Rate within ERA			Intl. Coll. Rate between ERA and Non-ERA		
	FP6*	FP7*	Delta‡	FP6*	FP7*	Delta‡	FP6*	FP7*	Delta‡
ERA†	35.6%	38.1%	2.6	16.3%	17.3%	1.0	24.0%	26.3%	2.3
FP-supported Papers	56.5%	57.2%	0.7	44.2%	40.9%	-3.4	23.6%	29.7%	6.1

Note: Intl. Coll. Rate = Proportion of papers involving authors from at least two different countries.
Intl. Coll. Rate within ERA = Proportion of papers involving authors from at least two different countries within the ERA.
Intl. Coll. Rate between ERA and non-ERA = Proportion of papers involving authors from at least one country within the ERA and one country outside the ERA.
* Direct attribution of papers to FP6 and FP7 support using funding acknowledgements.
‡ The delta is in percentage points. FP6-supported papers are likely those of the latest FP6 projects; indeed, it was not possible to identify FP6-supported papers in the early years of FP6, since funding acknowledgements in the WoS only started to be indexed more exhaustively starting in 2008. This could render the comparison more conservative if early FP6 projects were less cooperative than the latest FP6 projects.
† Papers produced by authors from the ERA without FP-supported papers.

Source: Computed by Science-Metrix using CORDA (European Commission) and WoS (Thomson Reuters) data

For FP7 participants, the international co-publishing rate clearly increased both within and outside the ERA when comparing their papers published before FP7 to their FP7-supported papers (Table IV). These rates and their respective increase are also noticeably greater than for the ERA as a whole (excluding papers by FP7 participants) over the same period.

Table IV International collaboration rates of ERA and of FP7 participants prior to and while supported

	Intl. Coll. Rate			Intl. Coll. Rate within ERA			Intl. Coll. Rate between ERA and Non-ERA		
	Pre-FP7*	FP7-supported†	Delta‡	Pre-FP7*	FP7-supported†	Delta‡	Pre-FP7*	FP7-supported†	Delta‡
ERA**	33.3%	36.5%	3.1	14.2%	15.7%	1.5	22.9%	25.4%	2.5
FP7	49.0%	58.8%	9.8	31.7%	44.3%	12.6	26.7%	29.6%	2.9
CAPACITIES	56.3%	68.3%	11.9	41.5%	57.8%	16.3	31.1%	36.1%	5.1
COOPERATION	46.8%	58.5%	11.7	30.7%	45.6%	14.9	24.5%	27.5%	3.0
IDEAS	55.8%	60.7%	5.0	36.2%	44.9%	8.7	33.2%	34.8%	1.6
PEOPLE	53.6%	65.1%	11.5	36.0%	51.0%	15.0	29.2%	33.4%	4.2

Note: See above definition of collaboration categories (Table XIX).
*Papers published by FP7 participants in the five years preceding the start of their respective FP7 project. **Without matched FP7 participants. † Direct attribution of papers to FP7 support using funding acknowledgements. ‡ The delta is in percentage points.

Source: Computed by Science-Metrix using CORDA (European Commission) and WoS (Thomson Reuters) data

Note that in the following sections, FP7 is compared to FP6 whenever relevant and feasible.

5 CONTINUITY AND KNOWLEDGE TRANSFER BETWEEN FPS (SQ5)

Project terms of reference: Based on the assumption that scientific innovations are based on the accumulation of knowledge, and looking at network dynamic over time, to what extent are FP project results used as an input for new FP projects, and to what extent has knowledge generated in previous FPs been transformed into new knowledge? Hypothesis: Chaining the scientific outcomes gives good indications that ERA is working in the long term and is well organised and planned.

Among the various potential outputs from FP7 activities, it is expected that research results will be used as a basis or as key inspiration for subsequent projects. Framework programmes aim to achieve long-term objectives by encouraging the chaining of knowledge creation from previously supported projects into new projects. The concept of continuity has been embraced throughout the framework programmes, which were designed with the intention of creating knowledge leveraging (Young, 2013). As stated by the Expert Group in the Interim Evaluation of FP7 (European Commission, 2010a), researchers have to be able to obtain repeat funding to consolidate gains from the support provided by FP7 so far, and to produce enduring impacts. Even Horizon 2020, while undergoing a significant restructure from previous framework programmes, still builds on the experience accumulated from them (European Commission, 2011).

Embedded in the argument that stable funding is necessary to realise the full benefits of past investments, is the idea that continued funding fosters ongoing expertise and momentum, and the retention of internationally mobile research groups in both the academic and business communities. Moreover, research may be directed towards inherently long-term issues such as climate change or power generation (Royal Society of Canada, 2014). On the other hand, there is a risk for complacency or stagnation if less-than-excellent research is being continuously supported. Thus, there is a fine balance in combining continuity with change, in allowing projects to build on previous successes and yet avoiding the risk that researchers continue to pursue non-fruitful research. This aspect will be explored further in Section 5.

Collaboration between individuals involves knowledge flow. Some of the knowledge possessed by individuals in a project is shared in order to commonly address intellectual or technical challenges. This knowledge can be codified (e.g. documents, data sets) or tacit (Polanyi, 1958). One way to facilitate knowledge flow is to encourage the diffusion of research results, but the transmission of tacit knowledge relies more on personal interactions. Some of the most cited works dealing with these concepts suggest that networks help coordinate processes of knowledge transfer and resource sharing (Galbraith, 1977), that social networks facilitate the creation of new knowledge within organisations (Kogut & Zander, 1992), and that in a multi-unit organisation any one unit can access new knowledge through a network of inter-unit links (Hansen, 1999). So, by supporting organisations that were already supported in FP6, FP7 likely increased the extent of knowledge flow, especially the tacit, non-codified knowledge.

New links created between researchers may also increase knowledge flow between them in the future. Singh (2005) showed that although intraregional and intra-institutional knowledge flow is found to be stronger than those across regional or institutional boundaries, the proximity effect on knowledge flow decreases once interpersonal ties have been accounted for. In fact, being in the same region or institution is found to have little additional effect on the probability of knowledge flow among individuals who already have close network ties.

Drawing on this context, this section shows that FP7 built on prior results and is thus making progress towards such outcomes as production of new knowledge, strengthened research capacities and transnational cooperation, as expected given the logic model of FP7 intervention using cooperation and networking (Section 3.2). Specifically, the evidence shows that some of the knowledge created during FP6 is used in FP7, and that there is an intent among project participants to continue knowledge transfer to new or ongoing projects beyond the end of FP7 (Section 5.1). It is shown that the use of knowledge from previous framework programmes in projects is correlated to a large number of desirable outputs/outcomes (such as higher scientific impact, knowledge and S&T tool creation, knowledge transfer and positive impact on careers) (Section 5.2). Finally, it is shown that some aspects of networking in a project increase the extent of knowledge chaining; that is, that the knowledge created in previous framework programmes is being used (Section 5.3).

5.1 Knowledge chaining between framework programmes

Finding 1	There is an amount of knowledge chaining from FP6 to FP7 and knowledge created in FP7 will likely continue to be used in future projects

In order to assess to what extent framework programme project results are used as an input for new framework programme projects, and to what extent knowledge generated in previous framework programmes has been transformed into new knowledge, the publications produced through the support of FP7 were examined to determine the extent to which they refer to publications produced through support from FP6.

The publications of framework programme funded researchers were cross-referenced to the Web of Science (WoS) to create publications portfolios using the technique presented in Section 4. On average, each FP7-supported paper cited 0.48 FP6-supported papers (Table V). FP7-funded papers produced as a result of the People specific programme generally cited more FP6 papers (0.60 FP6 papers per FP7 paper), followed by Ideas, Cooperation and Capacities (ratio of 0.53, 0.35 and 0.31, respectively).

Similarly, 50% of FP7 projects cite papers that were supported by FP6 and 15% of FP7 projects produced at least one paper acknowledging support from both FP6 and FP7.

There is further evidence of knowledge chaining obtained in the survey. About 36% of the survey respondents indicated that they drew on earlier framework programme results (whether their own or others') to a 'high' or 'very high' degree. With regard to specific programmes, survey results indicate that researchers funded under the People, Ideas, and Capacities specific programmes are more likely to draw on their own achievements under FP6. For the Cooperation specific programme, the opposite is true; more respondents drew on the research achievements of other researchers, underlining this specific programme's stronger network effects.

Almost half of the cases in the case study are projects that built on results from former framework programme supported projects. With a few exceptions, projects that do not build on results generated in former framework programmes are typically examples of projects where a new network was created in relation to the respective FP7 project. In contrast, the FP7 projects that built on results generated in connection to FP6 projects usually have more-established networks. That does not mean that the whole network of partners is the same from one project to the next, but that the core of the network has brought some of the project results from a concluded FP6 project to an FP7 project in order to continue their work and collaboration.

A case study on the Climate for Culture FP7 project reveals that participants have explicitly built on results generated in former framework programmes. This project aimed to assess the impact of climate change on European cultural heritage sites and buildings. Appropriate mitigation/adaptation strategies from previous projects were further developed and applied to an assessment of economic impacts. In order to ensure an efficient use of resources, the project also built on the results of a formerly supported project (e.g. the FP6-supported NOAH'S ARK project). Techniques from FP5/6 projects were also reassessed for their applicability in future scenarios in different European and Mediterranean regions. This shows that continuity can take complex forms and can be associated with important departures from previous research projects.

Table V Transfer of results and knowledge from FP6 to FP7

	Projects (FP7)	FP7 projects citing FP6-supported papers	Projects acknowledging both FP6 and FP7 funding	Avg citations to FP6 papers per FP7 papers	% of FP7 projects citing at least one FP6 paper	% of projects acknowledging both FP6 and FP7 funding in at least one FP7 paper
FP7 (overall)	**4,030**	**2,004**	**605**	**0.48**	**50%**	**15%**
FP7 excluding People and Ideas	**1,700**	**711**	**268**	**0.34**	**42%**	**16%**
COOPERATION	**1,390**	**592**	**236**	**0.35**	**43%**	**17%**
Energy	80	39	7	0.26	49%	9%
Environment (including Climate Change)	98	61	23	0.64	62%	23%
Food, Agriculture, and Biotechnology	103	71	23	0.53	69%	22%
Health	159	100	41	0.65	63%	26%
Information and Communication Technologies	427	140	79	0.23	33%	19%
Joint Technology Initiatives (Annex IV-SP1)	77	28	4	0.34	36%	5%
Nanosci., Nanotech., Mat. and new Prod. Tech.	168	75	17	0.31	45%	10%
Security	52	12	11	0.16	23%	21%
Socio-economic sciences and Humanities	30	8	4	0.27	27%	13%
Space	45	17	10	0.28	38%	22%
Transport (including Aeronautics)	151	41	17	0.27	27%	11%
CAPACITIES	**310**	**119**	**32**	**0.31**	**38%**	**10%**
Activities of International Cooperation	10	4	0	0.29	40%	0%
Coherent development of research policies	2	0	0	0	0%	0%
Regions of Knowledge	5	0	0	0	0%	0%
Research for the benefit of SMEs	174	70	13	0.31	40%	7%
Research Infrastructures	37	17	7	0.59	46%	19%
Research Potential	52	23	12	0.31	44%	23%
Science in Society	30	5	0	0.10	17%	0%
PEOPLE	**1,427**	**779**	**215**	**0.60**	**55%**	**15%**
IDEAS	**903**	**514**	**122**	**0.53**	**57%**	**14%**

Source: Computed by Science-Metrix using CORDA (European Commission) and WoS (Thomson Reuters) data

Renewal was also explicit in the AgriPolicy project. DG Agriculture and Rural Development published a call with the exact same text as a previous FP6 call, with the exception that the new call should also include the Western Balkan Countries. The FP6 call had been highly useful for both the participants and the Commission, so DG Agriculture and Rural Development aimed to repeat that success with a similar call. The French consultancy company Euroquality had overall responsibility for gathering partners and submitting the proposal for FP7. Euroquality had also been the project leader in the previous FP6 project and most of the partners from the FP6 project were also included in the FP7 project. The Slovenian partner in the FP6 project had connections to relevant organisations in the Western Balkans and they assisted in enlarging the network with new partners for the FP7 call. The survey conducted in earlier phases of the evaluation also shows that most partners had worked with a large share of the participants before the FP7 project was initiated.

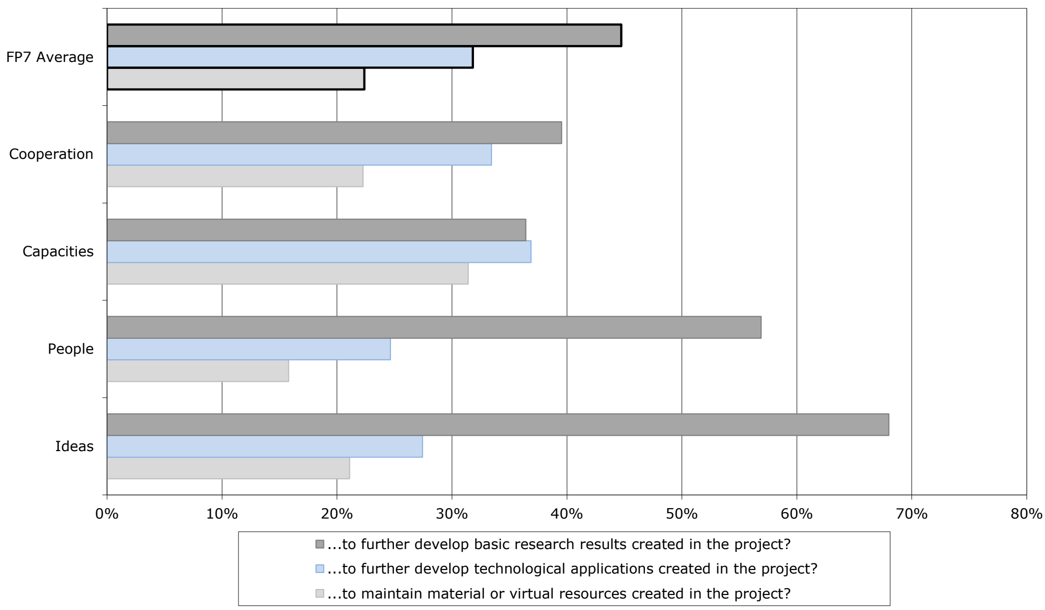
For the partners who had not taken part in the FP6 project the situation was reversed, they had only worked with a small share of the partners previously.

Evidence from the survey also indicates that FP7 project results will likely be used as input for new projects. A large majority (70%) of survey respondents plan to use their project's intended results as the basis or key inspiration for further projects. Some respondents (42%) also plan to use unintended (but not undesirable) project outcomes for future work.

The transformation of knowledge developed in former projects seems to happen when applied in new ways and when 'confronted' with perspectives from other people or by taking a new approach to an old or new topic or problem combining techniques from different academic disciplines and different sectors. It appears that a cross-disciplinary and cross-sectoral project focus is very helpful—if not essential—to the transformation of knowledge. In almost all of the cases, partners from the respective FP7-funded project want to continue to work together in relation to other collaborative projects, both bilaterally and unilaterally. Furthermore, there are also examples of project partners who expressed a wish to continue to work together on new FP-supported projects and have therefore chosen to apply for new funding or are planning to apply. This was confirmed by 5 out of 12 case study examples wherein project partners wished for continued collaboration and have therefore chosen to apply for new funding or are planning to apply. A central reason for applying for new funding is that a new framework programme supported project will enable the partners to continue their collaboration and work on their developed tools, techniques and/or theories. Some of the cases are examples of networks where partners have worked together during several framework programme supported projects, making it possible for them to 'spread knowledge' to others as well as bring in new perspectives when inviting in new partners to their projects.

Similarly, a high share of survey respondents report that their FP7-funded activities have prompted joint applications for further research funding. Follow-up plans for (a) basic research results, (b) technological applications, or (c) material or virtual resources also correspond well to the various objectives (e.g. basic vs. applied research) of the four specific programmes as shown in Figure 3. Respondents in Ideas were 1.5 times more likely than average to further develop basic research, while participants in People were 1.3 times as likely. Conversely, participants in Capacities were 1.4 times more likely to maintain material or resources created in the project and 1.16 times more likely to further develop technological applications, whereas participants in Cooperation were 5% more likely than average to further develop the technological application created in the project.

Figure 3 Planned applications for further funding based on project outcomes



Source: Analysis of survey results, calculations by Fraunhofer ISI

5.2 Effects of research continuity

Finding 2	Grounding FP7 projects in work conducted for FP6 is associated with the publication of more scientific papers that are published in more highly cited journals

Finding 3	Continuity of participation between programmes increases the breadth of knowledge and of tools produced, increases the transfer to businesses and society, but may not trigger innovations

The effect of building on previous knowledge on the output and outcomes of projects was investigated to learn more about the potential benefits of research continuity. To address this question, a regression analysis was performed to explore the effect of building on previous knowledge on expected outputs and outcomes. Three variables were selected to measure the extent that FP7 projects use knowledge created through support from FP6.

SQ5_a comes from the survey, and is a numeric value derived from the following question: *To what degree did your project draw on findings from the Sixth Framework Programme?*

SQ5_b is computed by counting the share of citations to FP6-supported papers per FP7-supported papers. For this test, only papers acknowledging support from FP6 or FP7 were considered as supported papers.

SQ5_c measures the share of FP7-supported papers acknowledging both FP6 and FP7 funding.

The regression model that has been implemented also incorporates—as explanatory variables—numerous networking dimensions (e.g. institutional sectors and geography), as well as numerous controls such as the budget of FP7 projects. These variables have been regressed against a number of dependent variables (see Section 6.3) corresponding to bibliometric indicators quantifying various aspects of the research production of each project, as well as to various outputs/outcomes that come from an auto-evaluation of survey respondents on the performance of their project (refer to the companion methodological annex for details on the regression analysis). The results for the Cooperation and Capacities specific programmes are presented below in Table VI and Table VII.

Though the size effects are relatively small, in FP7 projects, citing publications that have been supported by FP6 is related to an increased number of papers per project as well as an increased level of 'excellence/quality' of those papers as measured with the citation impact of the journals (i.e. Average of Relative Impact Factors, or ARIF) in which they were published. Note that the ARIF, by measuring the scientific impact of publications produced by a given entity (e.g. a country, a region, an organisation) based on the publication venue instead of the actual publications, reflects the scientific 'excellence/quality' of an entity's scientific production. Indeed, the more cited a journal, the more researchers will seek to publish in it. This means that editors can be more selective, thus producing a cycle wherein the most highly cited journals select the best papers, which are then more cited, which in turn increases the impact factor of the journal. Similarly, projects with papers co-acknowledging FP6 and FP7 are linked to an increased number of papers.

Table VI Relationship between continuity and scientific output under the Cooperation and Capacities specific programmes

Explanatory Variables	No. of papers	Avg. of Rel. Impact Factors (ARIF)	Avg. trans-disciplinarity	Avg. no. of ERA countries per paper	Avg. no. of non-ERA countries per paper
SQ5_a	0.015	0.004	0.001	-0.004	0.003
	(0.009)	*(0.014)*	*(0.003)*	*(0.008)*	*(0.008)*
SQ5_b	0.258 ***	0.298 **	0.037	0.049	0.080 **
	(0.038)	*(0.139)*	*(0.024)*	*(0.036)*	*(0.035)*
SQ5_c	0.200 ***	-0.000	-0.001	0.004	-0.046 **
	(0.026)	*(0.037)*	*(0.007)*	*(0.024)*	*(0.023)*
		All other independent and control variables			
R-sq-adj	**0.692**	**0.401**	**0.828**	**0.445**	**0.534**
N	**732**	**250**	**248**	**708**	**708**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All models are statistically significant at $p \leq 0.01$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission), WoS (Thomson Reuters) and survey data

The degree to which the respondents report having drawn on FP6 results in their FP7 project is also related to the breadth of knowledge and the breadth of tools created, to the transfer of research results to the business enterprise sector and/or to society, and also to the effects on careers. There are no observed statistically significant effects of knowledge chaining or continuity between framework programmes on innovations triggered.

Table VII Relationship between continuity and positive project outcomes under the Cooperation and Capacities specific programmes

Explanatory Variables	Breadth of knowledge	Breadth of tools	Transfer of research results	Effects on careers	Innovations triggered
SQ5_a	0.093 ***	0.133 ***	0.041 **	0.063 *	-0.003
	(0.036)	*(0.047)*	*(0.021)*	*(0.034)*	*(0.065)*
SQ5_b	-0.111	0.051	-0.036	-0.299 **	-0.055
	(0.147)	*(0.195)*	*(0.085)*	*(0.141)*	*(0.272)*
SQ5_c	0.165 *	0.137	0.149 **	0.119	0.144
	(0.100)	*(0.132)*	*(0.058)*	*(0.095)*	*(0.183)*
		All other independent and control variables			
R-sq-adj	**0.165**	**0.183**	**0.091**	**0.12**	**[Pseudo] 0.116**
N	**732**	**732**	**681**	**732**	**732**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All models are statistically significant at $p \leq 0.01$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Case studies provide evidence that the transfer of tacit knowledge through partners who have worked together on previous projects may help mitigate obstacles that can arise from an interdisciplinary collaboration. For example, the ATLAS project and the Laserlab Europe II project (ongoing since 2004, with FP6 and FP7 support) are both good examples where prior collaboration was noted as a key success factor. Knowing the capacities and expertise of each party made for easy division of project responsibilities. Joint experience from earlier collaborations also helped identify problems to avoid and allowed for a quick start to many project tasks.

5.3 Effects of networking on continuity

It has been demonstrated that FP7 projects built upon knowledge created in FP6, that a large share of participants in FP7 plan to use the knowledge created in future framework programme projects, and that FP7 projects that use FP6 results are more likely to have positive outputs and outcomes. It is also relevant in this context to assess whether collaboration and networking contribute to this chaining of knowledge.

Survey results showed that researchers supported under the network-oriented Capacities and Cooperation programmes often draw on other teams' findings under FP6. Also, a notable number of respondents indicate that they have drawn substantially on prior results even though, in terms of partners, their consortia are not very similar to those they worked with under FP6. Hence it can be assumed that the knowledge generated in previous framework programmes' consortia flows through involved individuals into a new generation of projects that have a broader range of additional partners.

In order to assess the effect of networking on this chaining of knowledge, different variables of networking have been regressed with three variables related to the chaining of knowledge. The results of the regressions are presented in Table VIII. The number of partners involved in FP7 projects has a significant effect on the number of citations to papers that were produced with FP6 support. The share of new partners and the number of participants from non-ERA countries in an FP7 project are also linked to more citations to FP6-supported papers. It thus seems that the more diverse the participants are in a project, the more chance that knowledge from previous supported projects will be used. Similarly, linking with external partners increases the chance of drawing on findings from FP6 projects.

The variable that is the more clearly linked to knowledge chaining is the proportion of old partners in a project. In an FP7 project, the number of pairs of participants that have already been supported together in FP6 projects is strongly related to the extent to which the project draws on findings from FP6 projects, cites papers supported in FP6 projects and yields papers that directly acknowledge both FP6 and FP7 support.

On the contrary, the approach was unable to show any significant relation between the interdisciplinarity of projects, the number of sectors involved, and the three variables of knowledge chaining.

Table VIII Relationship between networking variables and continuity under the Cooperation and Capacities specific programmes

Explanatory Variables	SQ5_a Project draw on findings from the Sixth Framework Programme	SQ5_b Average number of citations to FP6-supported papers per FP7-supported papers, per project	SQ5_c Share of FP7-supported papers acknowledging both FP6 and FP7 funding
General_SQ (Number of partners)	0.117	0.117 ***	-0.009
SQ1 (Interdisciplinarity)	0.316	0.025	0.003
SQ2_a (Linkage with other sectors)	0.059	0.018	0.014
SQ3_a (Share of new partners)	-0.21	0.076 **	0.024
SQ3_c (Lasting partners)	0.764 **	0.24 ***	0.231 *
SQ4_d (Centrality of project)	0.021	0.002	0.028 ***
SQ6_a (number of non-ERA countries)	0.07	0.08 ***	0.016
SQ7_a (Linkage with external partners)	0.109 ***	0.005	0.021 *
	All other independent and control variables		
R-sq-adj	**0.092**	**0.357**	**0.2**
N	**732**	**930**	**930**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. Variables General_SQ, SQ3_a, SQ3_c, SQ4_d and SQ6_a are log transformed (natural log). All models are statistically significant at $p \leq 0.05$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission) and WoS (Thomson Reuters) data

6 EFFECTS OF NEW ORGANISATIONS AND NEW COLLABORATIONS ON INNOVATION (SQ3)

Project terms of reference: Based on the assumption that high density networks are fostering competitiveness of EU research: to what extent has the FP contributed to new collaboration and integration of new organisations? How many new collaborations emerged due to the FP? Hypothesis: New organisations in the network and new links between existing organisations in the network indicate a way to a common ERA.

This section provides data on the number of new organisations that participated in FP7-supported consortia and what effect this integration has had. According to the FP7 logic model (Section 3.2), new networks involving new actors should lead to greater research integration in the short term and strengthened knowledge transfer in the intermediate term.

Prior studies on the long-term impact of the framework programme model observed that networks within the framework programmes tend to evolve slowly, with new members being tested and admitted only once they have built trust, and with old members sometimes falling by the wayside (EPEC, 2011). Under FP6 it was found that while most project partners were not new, the new partners included more foreign than domestic participants, supporting the idea that new links helped foster cooperation within the ERA. It was also noted that those FP6 projects that involved foreign universities and public research institutes or business enterprises from abroad experienced a positive impact on the overall collaborative behaviour of the organisations (Idea Consult, 2009).

The data collected during the present study demonstrates that the networks supported through FP7 have integrated many new organisations (18,654 out of the 26,014, or 72% of the participating organisations are new; Table X) and new links have been created between organisations that participated in FP6 but were not directly connected at the time. Survey respondents almost unanimously stated that the majority of their new project partners came from ERA Associated Countries, indicating that progress has been made towards the goal of developing a common ERA.

Survey and case study evidence suggest that the inclusion of new organisations strengthens existing networks and has helped stimulate innovation by transferring knowledge from the academic to the business enterprise sector and vice versa. These findings echo those from the INGINEUS project (Impact of Networks, Globalisation, and their INteraction with EU Strategies, 2009–2011). INGINEUS found that pre-existing national innovation networks have been significantly bolstered through the integration of new actors, which has helped to mobilise knowledge content and cut across knowledge disciplines (Borrás & Haakonsson, 2012).

6.1 Role of framework programmes in facilitating new collaborations

Finding 4	The number of participating organisations grew from 20,794 to 26,014 from FP6 to FP7

Finding 5	72% of the organisations participating in FP7 are new relative to FP6

Finding 6	13,434 organisations that participated in FP6, 65% of the total, are not present in FP7

Finding 7	There were more than 450,000 new collaborations in FP7

Finding 8	384,446 collaboration pairs present in FP6, representing 86% of the total, were not renewed in FP7

The number of participating organisations involved in each framework programme (i.e. FP6 and FP7) was counted to assess to what extent FP7 has contributed to the creation of new collaborations and the integration of new organisations. While organisations could participate in more than one project, participating organisations were counted only once to avoid over-representation of more active organisations, which could have skewed the findings. This was especially important considering that many large-scale European organisations were involved in a high number of projects.

The number of pairs of distinct organisations collaborating on the same project, which are referred to as dyads, was also analysed to address the question of new collaborations in the framework programme. As was the case for the count of organisations, dyads were counted only once even if pairs of organisations collaborated on more than one project, basing the analysis on the presence (i.e. counting one dyad) or absence (no dyad) of cooperation between organisations.

Finally, network density indicators were used to examine programmes, thematic areas and broad areas. This indicator takes into account the number of potential collaborations in a network (i.e. theoretical maximum number of dyads if all participants are directly linked together), using this value to normalise the number of actual collaborations in the network (i.e. actual dyads). As such, network density may range from 0 for a completely disconnected network to 1 in a network where all participants are directly connected to one another. To facilitate comparisons, scores were multiplied by 1,000 in Table IX, thus the scores presented theoretically vary from 0 to 1,000.

Note that it is easier to achieve high network densities for low numbers of participants in networks because connecting with participants gets more and more difficult as the number of organisations increases. For instance, a network including only three organisations would be complete (i.e. network density of 1) if each participant organisation collaborated with the other two. By comparison, in a network of 100 participating organisations, a network density of 1 would require all organisations to collaborate with all 99 other organisations, which is much more improbable given the limits to collaboration. This indicator, while not totally scale-independent, remains helpful for cross-network analyses of network density as it is much less scale-dependent than the number of dyads. The density of FP7 has dropped somewhat from FP6, which reflects, as will be shown, that the number of new collaboration pairs has not grown as fast as the number of new participants (i.e. organisations).

A compilation of CORDA data presented at Table IX shows that the number of participating organisations grew from 20,794 to 26,014 from FP6 to FP7. FP7 supported about 5,200 additional organisations compared to FP6, a 25% increase. Similarly, there was a 15% increase in inter-organisational collaborations between the framework programmes (525,721 dyads in FP7 vs. 458,441 in FP6).

To address whether FP7 helped in the creation of new collaborations as opposed to only increasing the number of collaborations, one has to compare organisations and dyads that existed in FP6 and FP7. This analysis, which is detailed at Table X, shows that FP7 was greatly successful in integrating new organisations and also in fostering cooperation between actors that were collaborating in FP6, but were not connected at the time. Indeed, 72% of the organisations (18,654 out of the 26,014) and 86% of the inter-organisational collaboration pairs (451,726 out of the 525,721 dyads) were found to be new in FP7. This estimate certainly is a floor value because organisations are considered as one. However, conceptually, large organisations are not all that homogenous and are themselves composed of individuals with little or no connection between each other. For instance, if Oxford and Cambridge collaborated in both FP6 and FP7, then it would not be considered as a new dyad. However, these organisations are so large that it is likely that at the individual researcher level, the collaborations could in fact be new. Thus, one can conclude that the vast majority of collaboration pairs are new to FP7, and this would be especially true if computed at the individual researcher level. For technical reasons, this researcher-level analysis would be feasible but difficult to carry out, as one would need to disambiguate the names of all researchers, which would be impossible to perform as CORDA does not record all participants' names.

Table IX Number of organisations and dyads per framework round, programme and theme

Programme & Area	Organisations	Dyads	Density (x1000)
FP6 (overall)	20,779	458,278	**2.1**
FP6 excluding Marie Curie Actions	20,283	449,244	**2.2**
FP7 (overall)	25,992	525,474	**1.6**
FP7 excluding People and Ideas	24,885	506,750	**1.6**
COOPERATION	19,857	426,055	2.2
Information and Communication Technologies	5,770	92,885	5.6
Nanosciences, Nanotech., Materials and new Prod. Tech.	4,271	61,038	6.7
Health	3,301	56,599	10.4
Transport (including Aeronautics)	3,229	58,261	11.2
Food, Agriculture, and Biotechnology	2,785	46,716	12.1
Environment (including Climate Change)	2,629	44,190	12.8
Energy	2,045	22,817	10.9
Joint Technology Initiatives (Annex IV-SP1)	1,973	35,127	18.1
Security	1,471	17,502	16.2
Socio-Economic Sciences and Humanities	1,042	12,933	23.8
Space	1,022	15,198	29.1
General Activities (Annex IV)	8	0	0.0
CAPACITIES	8,009	94,552	2.9
Research for the Benefit of SMEs	5,010	32,906	2.6
Research Infrastructures	1,605	39,603	30.8
Science in Society	982	10,207	21.2
Regions of Knowledge	824	6,637	19.6
Activities of International Cooperation	619	6,140	32.1
Research Potential	217	357	15.2
Coherent Development of Research Policies	112	555	89.3
PEOPLE	3,388	28,573	5.0
IDEAS	664	781	3.5

Source: Computed by Science-Metrix using CORDA (European Commission) data

Table X Comparison between the number of organisations and dyads from FP6 to FP7

Status (FP6→FP7)	Organisations	Dyads
New	18,654	451,726
Vanishing	13,434	384,446
Present in both	7,360	73,995
Net change of entity (%)	25.1	14.7
New entity in FP7 (%)	71.7	85.9
Continued entity in FP7 (%)	28.3	14.1
Vanishing entity from FP6 (%)	64.6	83.9

Source: Computed by Science-Metrix using CORDA (European Commission) data

It is important to note that while many new partner pairs appeared in FP7, the turnover was so high that it is very likely that all partner pairs were new in many projects. Thus, previous FP6 participants partnering with new partners in FP7 are likely not that common. Indeed, only 28% of the FP7 organisations took part in FP6 as well. Only 14% of collaborative organisation pairs in FP7 were also present in FP6, indicating that most FP6 dyads (86% or 384,446) were lost during the transition from FP6 to FP7, as was also the case for most FP6 organisations, with 65% of these vanishing from FP6 to FP7 (13,434).

With regards to the geographic origin of these new projects, almost 90% of the survey respondents stated that more than 50% of their new project partners come from ERA Associated Countries. On the other hand, a much smaller share of survey participants reported a similar proportion of partners from the local environment (less than 15%), other regions of the respondent's home country (less than 30%) or non-European countries (less than 15%). Thus, FP7 appears to have achieved its objective of strengthening EU-wide networking and collaboration among researchers while also being opened to non-EU countries.

The most commonly mentioned reason to undertake projects under FP7 rather than under a different programme was to establish linkages with excellent research partners in other countries. This statement was supported by more than 60% of the survey participants. FP7 thus appears to be achieving its objective to support research excellence.

The Cooperation specific programme fostered the most inter-organisational collaboration with 426,255 dyads and 19,873 participating organisations, followed by Capacities, People, and Ideas, in that order. These results are not surprising given the stated goals of each of these specific programmes. In the case of thematic areas falling under the Cooperation specific programme, a progressive increase in the number of dyads can be observed as the number of organisations increases, with only a few thematic areas, such as Joint Technology Initiatives (Annex IV-SP1), breaking this pattern. In this particular case, this thematic area resulted in more than 35,000 dyads based on 2,000 organisations, which is much higher than for the other thematic areas with similar numbers of organisations. This is also reflected in the network density indicator, which is higher for Joint Technology Initiatives than for most other thematic areas.

A similar analysis conducted for Capacities yields a different finding, where correlation between numbers of organisations and dyads is not as strong, indicating more diversified collaboration patterns across broad areas compared to what was observed across thematic areas in Cooperation. Again, this is not surprising considering that broad areas cover vastly different types of projects as opposed to thematic areas, which are more tightly connected to traditional fields of scientific research. For instance, the broad area Research for the Benefit of SMEs, which comprised 5,000 organisations and resulted in close to 33,000 inter-organisation collaborations, generated fewer collaborations than the broad area Research Infrastructure (40,000 inter-organisation collaborations) even though this broad area comprised only one third the number of organisations (1,600 organisations). This large discrepancy can be confirmed when comparing network density for both broad areas, where the density measure is 10 times greater for Research Infrastructure compared to Research for the Benefit of SMEs. It is telling that the Coherent Development of Research Policies has the densest inter-organisational network of all broad and thematic areas, suggesting that this area of Capacities has succeeded in its mission to bring policy actors closer. Likewise, the Activities of International Cooperation is the second-densest network (Table IX above).

6.2 Role played by new partners

Finding 9 New partners help strengthen networks and promote innovation

A regression analysis was performed to examine more specifically whether the number of partnerships in FP7 projects had a positive and statistically significant effect on innovation. The results of a regression analysis show that the number of partners has a positive influence on the transfer of knowledge to society and to business enterprises (Table XI). Another important question is whether having new partners has a positive effect on a project's outcomes. Regression analysis reveals that the share of new partners involved in a participant's project has a notable positive effect on innovations triggered and on the breadth of knowledge created.

Table XI Effects of number of partners and of new partners on the outcomes of the Cooperation and Capacities specific programmes

Explanatory Variables	**Effects on careers**	**Breadth of knowledge**	**Breadth of tools**	**Transfer of research results**	**Innovations triggered**
No. of Partners	-0.132	0.067	0.163 *	0.003	-0.019
	-(0.152)	*-(0.201)*	*-(0.089)*	*-(0.145)*	*-(0.277)*
Proportion of	0.065	0.361 *	0.006	0.059	0.611 **
new partners	*-(0.147)*	*-(0.195)*	*-(0.084)*	*-(0.141)*	*-(0.281)*
			All other independent and control variables		
R-sq-adj	**0.165**	**0.183**	**0.091**	**0.12**	**[Pseudo] 0.116**
N	**732**	**732**	**681**	**732**	**732**

Note: *: p ≤ 0.10; **: p ≤ 0.05.
Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission), WoS (Thomson Reuters) and survey data

A cross-case study analysis of the case evidence shows that existing networks are strengthened by the inclusion and addition of new organisations or partners. It was found that participants in mature networks have the desire to strengthen and continue to build their network and thus often have established processes in place to integrate new members. Such processes include ensuring new member representation on all project committees (as in the Laserlab Europe II project) and conducting regular monitoring activities for new members (as in the AgriPolicy project). Reciprocally, by working with more established organisations and EU12 and EU15 Member States, newer and candidate states have been able to gain experience at the international level, further their research capabilities, and strengthen their own networks. More specifically, organisations in newer and Candidate Member States benefit because international collaboration raises their profile and allows an opportunity to work on a more international level.

The case studies suggest that networks stimulate innovation by transferring knowledge from the academic to the business enterprise sector and vice versa. Two thirds of the case studies included private sector businesses as part of the project networks, covering the range from pure basic research, to use-inspired basic research, to applied research. The common theme across these cases is that while it took significant effort to work together when partners were from different institutional sectors with unlike motivations, knowledge is shared and transferred across sectors, ultimately fostering creativity and innovation.

6.3 Is there an ideal number of partners in collaboration projects?

Finding 10	There does not appear to be a turning point related to the number of participants involved in a project where the benefits of adding more participants decrease

At the workshop conducted with FP7 participants, as well as in case studies, mention was made that there might be 'a sweet spot' as to the number of participants in a framework programme project. According to FP7 participants, when the number of partners gets too large, there seem to be diminishing returns because collaboration becomes too complex and time is lost in management.

To examine this issue, the performance of FP7 projects was measured through the construction of a composite indicator synthesising the positive outputs/outcomes measured with bibliometric indicators and the survey. More specifically, the composite indicator considered outcomes such as scientific production and scientific impact as well as survey data in relation to team size (size measured by number of participants, of sectors, of ERA countries, etc.). This subsequently allowed for studying differences in the performance of projects according to a number of network dimensions (e.g. in addition to the number of participants, the multidisciplinarity of projects, the number of sectors involved, the number of countries) to see whether or not an optimal size exists with respect to these dimensions. The outputs/outcomes integrated in the composite measure are as follows:

Bibliometric statistics produced using CORDA and WoS data

- Logarithm (to normalise the data in as much as possible) of the number of peer-reviewed publications resulting from a project (Science-Metrix: Data produced using CORDA and WoS data)
- Natural logarithm (to normalise the data in as much as possible) of the average number of ERA countries involved in the peer-reviewed publications of a project to assess the extent to which project partnerships really translate into co-publications (Science-Metrix: Data produced using CORDA and WoS data)
- Natural logarithm (to normalise the data in as much as possible) of the average number of non-ERA countries involved in the peer-reviewed publications of a project to assess the extent to which project partnerships really translate into co-publications (Science-Metrix: Data produced using CORDA and WoS data)
- Scientific 'quality' (i.e. Average of Relative Impact Factors) of a project's peer-reviewed publications (Science-Metrix: Data produced using CORDA and WoS data)
- Average interdisciplinarity of a project's peer-reviewed publications to assess the extent to which the multidisciplinarity of a project team translates into transdisciplinary work (Science-Metrix: Data produced using CORDA and WoS data)

Statistics produced using survey data

- Number of types of S&T knowledge produced as part of a project

- The number of researchers that have moved on to more senior positions
- The extent to which an FP7 project has helped the participants to enhance knowledge transfer from science to society and to the market
- Number of types of S&T tools created as part of a project
- Has an FP7 project prompted the participants to introduce any innovation (i.e. yes/no)?

Prior to computing the composite measure, a descriptive analysis of this set of positive outcomes was performed through an Exploratory Factor Analysis (EFA) as well as a correlation analysis. The main conclusion drawn from both analyses is that there are not strong redundancies in the dataset of positive outputs/outcomes, with the EFA's two significant factors only explaining 30% of the variance in the dataset and the strongest correlation coefficient between any two variables in the dataset being equal to 0.42 ($R^2 = 0.18$). It therefore appeared that a simple unweighted average of the rescaled scores across variables would provide a decent composite measure reflecting equally well each of the positive outcomes measured. However, missing data were very common for two variables (i.e. the scientific 'quality' and average transdisciplinarity of a project's peer-reviewed publications). Consequently, these two variables were discarded to only retain cases without missing data across all selected outcomes not requiring data imputation. This provided a sample of 900 projects.

The score of a project for a given variable was then rescaled between 0 and 1 by dividing it by the maximum score across projects. This procedure was performed for all outcomes. Subsequently, an unweighted average of a project's rescaled score multiplied by 100 was computed to obtain a composite measure ranging from 0 to 100. To validate the composite measure, a correlation matrix (based on Spearman coefficients) was then built to examine the correlation pattern of the composite indicator with each of its source variables. This led to some manual adjustments in the weighting of individual variables to distribute more evenly, in as much as possible, the percentage of the variance in each of the source variables, which is explained by the composite measure.

On average, the final composite measure explains 21% of the variance in each of the positive outputs/outcomes considered, the percentage of explained variance ranging from a low of 17% (i.e. the extent to which an FP7 project has helped the participants to enhance knowledge transfer from science to society and to the market) to a high of 31% (i.e. the number of types of S&T tools created as part of a project). Consequently, a project performing well across all outputs/outcomes captured by the composite indicator will likely outperform a project performing really well on one or a few dimensions only. In other words, the composite gives, to some degree, more weight to projects with a well-balanced set of outcomes.

As a result, in cases of an unexpected finding, one should not conclude too rapidly that the FP7 projects bearing a specific characteristic are detrimental to the production of positive outputs/outcomes. Indeed, the goals targeted across FP7 specific programmes—as well as within a given specific programme at the thematic area, broad area or call level—can vary considerably, such that this approach might not offer sufficient granularity to determine the optimal size (for various dimensions) of teams under specific circumstances. In such cases, further research would be required to specifically measure the expected outputs/outcomes of the thematic area, broad area or call of interest against the specific networking characteristics that were promoted under the corresponding thematic area, broad area or call. This would be difficult to achieve here given that the sample sizes available would rapidly get very small as one moved towards more disaggregated groups of projects.

Based on this analysis, there does not appear to be a turning point related to the number of participants involved in a project where the benefits of adding more participants decrease. For instance, in most of the specific programmes examined, the composite performance of projects increases continuously as the number of participants on a project increases over the size bins examined. This is the case for the Capacities and People specific programmes for which significant differences are observed across groups. However, it is difficult to conclude that the number of participants relates positively with the extent of positive outcomes generated for the Cooperation specific programmes. In this case, the increase in performance is slight and not significant across groups (Table XII).

Table XII Performance of FP7 projects relative to the number of participants

	Cooperation				Capacities				People		
Descriptive Stats	**(1-9)**	**(10-13)**	**(14-19)**	**(20-67)**	**(1-9)**	**(10-14)**	**(15-20)**	**(21-54)**	**(1)**	**(2-7)**	**(8-16)**
N of Cases	118	133	127	122	31	29	28	23	125	43	41
Minimum	12.0	14.0	13.6	14.8	14.7	16.2	18.7	25.2	11.0	12.4	16.5
Maximum	64.5	53.5	50.6	57.2	72.0	41.6	55.5	64.7	75.7	52.9	65.3
Median	30.7	31.4	31.4	32.2	26.4	31.0	34.1	36.5	25.8	27.3	31.3
Arithmetic Mean	31.0	31.2	31.8	32.9	29.8	30.9	34.7	40.0	27.5	28.8	32.0
Mean Rank Sum*	234	244	253	271	41	51	61	77	95	107	133
Standard Deviation	7.8	7.1	7.3	7.4	11.4	6.0	9.5	10.8	9.5	8.1	7.9
Variance	61.5	50.5	54.0	54.1	130.5	36.4	89.8	117.2	89.3	66.3	62.1

Note: * Significant differences exist between groups for Capacities (p = 0.00) and People (p = 0.00); tested using a Kruskal-Wallis test. The test could not be performed for Ideas. The range of size (i.e. number of participants) by group is indicated in the column headers in parentheses.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Importantly, the increase in outcomes means that increasing the number of participants is effective in terms of obtaining the outcomes sought in FP7. However, the fact that this is an effective means of obtaining results does not mean that it is an efficient means of obtaining these results. It is indeed possible that decreasing returns to scale are present that would decrease the efficiency of opting for larger teams.

7 MULTIDISCIPLINARITY AND INTERDISCIPLINARITY: KNOWLEDGE WEAVING AND THE EMERGENCE OF RESEARCH FIELDS (SQ1)

Project terms of reference: Based on the assumption that innovation demands recombination of existing knowledge and new and scientific perspectives: to what extent does the FP link separate fields of knowledge, bridge different field of science, and facilitate new scientific disciplines? Hypothesis: High diversity of linked knowledge increases the probability of the emergence of innovation.

Many studies have pointed to the particular structural effects of the framework programmes that have led to increased cross-fertilisation among experts from different disciplines (Cunningham & Ramlogan, 2012; EPEC, 2011). As discussed in Section 2.2.1, governments are increasingly funding programmes and instruments to promote interdisciplinary research networks, with the ultimate aim of spurring greater innovation. In the case of the framework programmes, the findings of this study suggest that FP7 projects are quite multidisciplinary in terms of the diversity of disciplines that are involved in the Cooperation and Capacities specific programmes, but not all that multidisciplinary in People and quite narrowly disciplinary, on average, in Ideas. This is not surprising given the respective goals and structures of these specific programmes. The study shows that not only have disparate fields of scientific knowledge been brought together as part of these projects, especially in Cooperation and Capacities, but even within some of the People and Ideas specific programmes' projects linkages have been created among scientists who otherwise would have been unlikely to work together.

The present study also found that the multidisciplinary work fostered under FP7 exerts a small, yet significant effect on interdisciplinarity. Other studies have had similar findings, noting that the focus on greater collaboration among fields has resulted in a greater number of network interactions of a more interdisciplinary nature (Scherngell & Lata, 2011), and that participating institutions (in FP6) experienced a 'gradual change of perspective and work culture' and an increased focus on multidisciplinary and intersectoral research (Rønnest, 2009). The European Commission (2013) impact assessment on Horizon 2020 noted that while the thematic priorities of the framework programmes have remained focused on the basic coverage of scientific disciplines, they have increasingly spotlighted the interdisciplinary nature of the challenges involved.

Despite the widespread push for research that involves or spans multiple fields—and associated assumptions of the benefits of such research—this study finds that the collaborative approach promoted under FP7 reinforced linkages between scientists working in similar fields more frequently than between scientists from different disciplines. Note, however, that both categories are not mutually exclusive as a project can reinforce linkages between researchers from the same disciplines while at the same time increasing linkages with researchers from other disciplines. This indicates that there are limits to the presence of interdisciplinarity within many types of networks and among certain disciplines, depending on their structure and purpose.

While this study, as well as others, points to an increase in the multidisciplinarity and interdisciplinarity of projects and networks under the framework programmes, only sparse evidence exists to support the idea that this leads to the emergence of innovation in the form of new lines of research, methods/tools and technologies. A number of case studies performed as a review of the long-term impacts of the framework programmes (EPEC, 2011) did imply that they play a critical role in setting a foundation for the creation of new knowledge and supporting the creation of new disciplines, fields and communities within fields. This study shows that, as per survey responses, the majority of projects produced new lines of research. This has to be interpreted with care as these data are self-reported and it is possible that most researchers feel their work is on new lines.

No evidence was found that multidisciplinary research formally supported by FP7 is a prerequisite to start new lines of research. For instance, in People and Ideas, in which multidisciplinarity is not formally promoted as is the case for Capacities and Cooperation, participants reported more frequently pursuing new lines of research (Section 7.3). Yet, the discoveries resulting from People and Ideas are as interdisciplinary as they are for Cooperation and Capacities. This could result from informal multidisciplinary collaboration—through partnerships beyond the immediate FP7 project team—in the execution of projects by participants in the People and Ideas specific programmes. If this is the case, the methods implemented here could not have detected the importance of multidisciplinary research on the emergence of new lines of research. Finally, a regression analysis did not show a significant relationship between increased multidisciplinarity and the production of outcomes sought in FP7 such as triggering innovation in the form of new products or processes (Section 7.4).

Importantly, as per the aphorism, absence of evidence is not evidence of absence. It is possible that the methods employed did not provide unambiguous evidence supporting the role of the multi-/interdisciplinary approach under FP7 in fostering the emergence of innovation.

It is evident that increasing linkages between researchers from different fields (or even different sectors/countries, as will be seen later in this report) may also impose challenges for project management. A study by Hardy and Lawrence (2006) suggests that while such projects bring together partners from different backgrounds, approaches and goals, the distribution of power may be highly unequal. The needs of the stakeholders represented by the project participants potentially conflict with the demands of the wider collaboration. That study drew attention to the existence of *struggle*. To overcome this, Hardy and Lawrence suggest establishing and juggling the competing influences rather than allowing one or the other to dominate the collaboration. Such findings were indeed reflected in the case studies and workshop conducted for this study and, as such, the question of project management in the context of networks is raised in this section and repeated where relevant throughout the report.

7.1 Linking researchers and projects from separate fields of science

Finding 11	FP7 linked researchers and projects from fields of science that do not otherwise frequently exchange knowledge

In investigating the disciplinary mixing that occurred in European research networks as a result of FP7 participation, the first question that has been addressed is whether or not FP7 projects brought together researchers from different disciplines to work on common scientific endeavours. This question was examined with three methods, which all lend support to Finding 11.

7.1.1 Involvement of researchers from different disciplines

The first method is based on an SNA approach measuring the level of mixing that occurred from the participation in joint programmes by researchers with different disciplinary backgrounds. To achieve this, a discipline was first attributed to researchers who participated in at least one FP7 project. This was achieved by retrieving the peer-reviewed publications of those researchers in a bibliographic database (i.e. the Web of Science [WoS]). The WoS publication database also contains the institutional addresses of researchers thus making it possible to create links between countries through the co-authorship of papers and therefore to examine scientific collaboration. It was then possible to attribute a discipline to each researcher based on the main subfield of research within which he or she is most active. Subsequently, the level of disciplinary mixing in a given FP7 project was measured by quantifying the diversity of disciplines (i.e. those of the participating researchers) involved, taking account of the distance between scientific subfields. This means that the greater the distance that separates the disciplines involved, the larger the extent of disciplinary mixing.

For example, if an astrophysicist and a mathematician are involved in a project, the level of disciplinary mixing will be less than for a project involving an astrophysicist and an architect. Indeed, the flow of knowledge between the former two disciplines—established on the basis of a citation network analysis of the scientific literature indexed in the WoS—is much larger than between the latter two. Thus, in the latter project, the extent of disciplinary mixing is higher because the disciplines involved do not exchange knowledge as frequently as in the former project. Note that the likelihood of observing researchers from different disciplines increases with the number of participants on a project. Nevertheless, there is no correlation between the number of participants and the level of disciplinary mixing for projects with at least two participants since the indicator is normalised to account for differences in the former variable. The level of disciplinary mixing falls down to zero when only one participant is involved, which, unsurprisingly, is most often the case for the Ideas specific programme.

Here, the indicator measuring the level of disciplinary mixing is referred to as 'multidisciplinarity' since it only measures the diversity of disciplines involved and not the extent to which knowledge, materials, databases, and approaches from several disciplines are integrated to solve a common problem that is beyond the scope of any one discipline (see definitions of the various categories of disciplinary mixing in research networks introduced in Section 2.2.1). In other words, even if researchers from many disciplines are involved on a project, they might still perform research separately by exploring different facets of the core project's problems to be addressed, and they might as well publish their respective findings on their own (i.e. without co-authoring with their project partners). The multidisciplinarity indicator ranges from 0, meaning no disciplinary mixing at all, to 1, meaning very strong disciplinary mixing.

The multidisciplinarity of projects was then averaged overall, by specific programme as well as at the thematic area level, to characterise the extent of disciplinary mixing throughout the various components of FP7 (Table XIII). Besides the average of the multidisciplinarity scores of projects, the Gini coefficient of the multidisciplinarity scores was also computed to indicate whether the underlying distribution of the scores in a given component of FP7 is uniform (i.e. projects having relatively similar scores) or non-uniform (i.e. a few projects having large multidisciplinarity scores with the remaining majority of projects having relatively small scores) across projects. The Gini coefficient of any distribution ranges from 0, indicating that all scores are equal in which case the score of each project is equal to the average multidisciplinarity across projects, to 1, indicating that one project is multidisciplinary with the remaining ones involving only one discipline.

The analysis shows that FP7 projects are, on the whole, moderately multidisciplinary considering the average score of about 0.20 for the whole period considered (i.e. 2007–2014). However, the relatively high Gini coefficient of about 0.68 indicates that there are large differences in the multidisciplinarity scores of projects. This in fact reflects heterogeneity in the level of disciplinary mixing across specific programmes and thematic areas with some of them showing a small level of multidisciplinarity and others showing a much larger level of disciplinary mixing.

The Cooperation specific programme stands out as the most multidisciplinary with an average score of 0.44, above the Capacities (0.38), People (0.05) and Ideas (0.01) specific programmes. The observed scores for People and Ideas are very low but they have rather high Gini coefficients (respectively, 0.86 and 0.97). This indicates that most projects in these two specific programmes are disciplinary, with only a handful of multidisciplinary projects; they respectively include 86% and 97% of projects with a multidisciplinarity score of 0. Under Cooperation and Capacities, the Gini coefficients are much smaller (respectively, 0.27 and 0.34) indicating that most projects in these specific programmes are multidisciplinary to a various extent; they respectively include 97% and 86% of multidisciplinary projects.

These differences and the actual ranking of those specific programmes based on the multidisciplinarity of their respective projects are not surprising given the different emphasis placed on the formal creation of networks across them (see the definition of the specific programmes in Section 1.1). For instance, reflecting their focus on the individual researcher rather than collaboration, projects under the People (93% of projects) and Ideas (81%) specific programmes more often involve a single participant compared to Cooperation (13%) and Capacities (1%). This basically means that bridges are—usually—not formally created across disciplines in the former two specific programmes compared to the latter two. Yet combining a large number of researchers in a collaborative project does not mean it is necessarily multidisciplinary, as the big science projects in high-energy physics demonstrate. The scores noted for Cooperation and Capacities reveal that these specific programmes, by promoting collaborative projects, truly succeeded in linking researchers from various disciplines to achieve multidisciplinarity. Note that there is an even wider range of scores when looking at individual thematic areas within the specific programmes with the average multidisciplinarity ranging from a low of 0.01 in Ideas, to a high of 0.52 for the Security thematic area.

Table XIII Trends in the multidisciplinarity of FP7 projects by specific programmes and thematic areas, 2007–2014

	2007-2010			2011-2014			Delta (2011-14 vs. 2007-10)		Total		
	N	Avg.	Gini	N	Avg.	Gini	Avg.	Gini	N	Avg.	Gini
FP7*	**6,277**	**0.21**	**0.65**	**8,264**	**0.19**	**0.67**	**-0.021**	**0.025**	**14,770**	**0.20**	**0.68**
FP7 excluding People and Ideas	**2,815**	**0.42**	**0.31**	**2,910**	**0.44**	**0.28**	**0.017**	**-0.025**	**5,725**	**0.43**	**0.29**
COOPERATION	**2,310**	**0.43**	**0.29**	**2,437**	**0.45**	**0.27**	**0.015**	**-0.009**	**4,747**	**0.44**	**0.28**
Energy	131	0.41	0.33	105	0.40	0.32	-0.012	-0.011	236	0.41	0.30
Environment (including Climate Change)	206	0.49	0.23	193	0.51	0.21	0.016	-0.014	399	0.50	0.20
Food, Agriculture, and Biotechnology	187	0.48	0.23	229	0.49	0.23	0.012	-0.002	416	0.48	0.22
General Activities (Annex IV)	1	N/A	N/A	1	N/A	N/A	N/A	N/A	2	N/A	N/A
Health	454	0.42	0.27	466	0.45	0.25	0.035	-0.013	920	0.43	0.24
Information and Communication Technologies	500	0.37	0.35	397	0.40	0.32	0.023	-0.025	897	0.38	0.29
Joint Technology Initiatives (Annex IV-SP1)	65	0.31	0.48	194	0.32	0.48	0.010	-0.006	259	0.32	0.48
Nanosci, Nanotech, Materials and new Prod Tech	290	0.49	0.24	356	0.48	0.24	-0.013	0.004	646	0.49	0.24
Security	66	0.51	0.18	100	0.52	0.21	0.005	0.024	166	0.52	0.22
Socio-economic sciences and Humanities	112	0.39	0.36	61	0.48	0.32	0.095	-0.044	173	0.42	0.23
Space	56	0.48	0.22	124	0.41	0.27	-0.075	0.057	180	0.43	0.30
Transport (including Aeronautics)	242	0.45	0.27	211	0.49	0.25	0.041	-0.015	453	0.47	0.24
CAPACITIES	**505**	**0.37**	**0.39**	**473**	**0.39**	**0.34**	**0.020**	**-0.025**	**978**	**0.38**	**0.37**
Activities of International Cooperation	19	0.51	0.19	39	0.41	0.25	-0.099	0.059	58	0.45	0.27
Coherent development of research policies	5	N/A	N/A	2	N/A	N/A	N/A	N/A	7	N/A	N/A
Regions of Knowledge	18	N/A	N/A	13	N/A	N/A	N/A	N/A	31	0.51	0.23
Research for the benefit of SMEs	175	0.39	0.31	231	0.40	0.29	0.014	-0.021	406	0.40	0.27
Research Infrastructures	146	0.45	0.30	95	0.49	0.28	0.040	-0.023	241	0.47	0.24
Research Potential	82	0.07	0.88	47	0.00	0.92	-0.072	0.045	129	0.05	0.79
Science in Society	60	0.41	0.32	46	0.47	0.29	0.061	-0.024	106	0.44	0.26
PEOPLE*	**2,589**	**0.05**	**0.90**	**3,563**	**0.08**	**0.88**	**0.027**	**-0.022**	**6,381**	**0.07**	**0.86**
IDEAS	**873**	**0.01**	**0.97**	**1,791**	**0.01**	**0.97**	**0.000**	**0.000**	**2,664**	**0.01**	**0.97**

Note: *The total population size for FP7 as a whole is not equal to the sum across 2007–2010 and 2011–2014 since a number of projects under people had an unknown start year in CORDA. The years are based on the starting year of projects as found in CORDA.

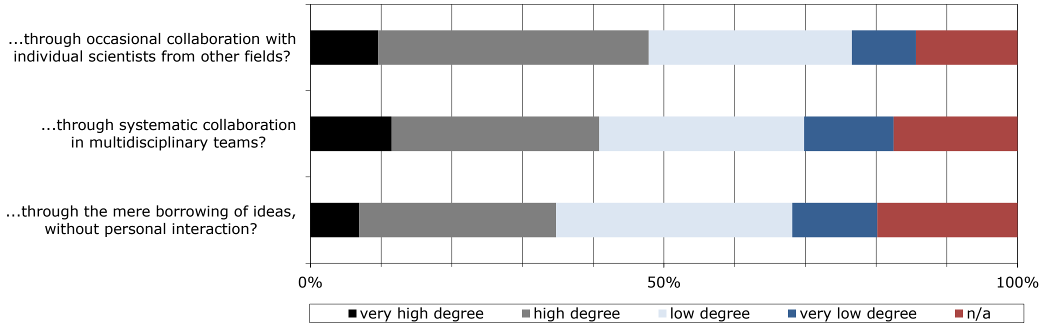
Source: Computed by Science-Metrix using CORDA (European Commission) data

7.1.2 Contribution of FP7 to linkages with researchers outside core research activities

The second approach implemented to address the above question consisted of performing a survey during which FP7 participants were asked to answer the following question: 'To what degree has the FP7 allowed you to strengthen linkages with researchers working in fields of science and technology that are not at the core of your organisation's usual research activities…'. The potential answers to this question and the survey results are presented in Figure 4.

A considerable share of survey respondents stated that their FP7 project had helped them to strengthen links to researchers working in fields outside their habitual research activities in three principal ways. Firstly (grouping responses of 'to a high degree' and to a 'very high degree'), about 48% of the survey participants stated that their linkages with other fields of science and technology were strengthened through occasional collaboration with scientists from other fields, 41% experienced a strengthening of these linkages through systematic collaborations in multidisciplinary teams while more than 35% reported that linkages took place through borrowing ideas but without personal interaction (Figure 4).

Figure 4 Extent to which FP7 strengthened linkages with researchers in S&T fields outside of survey respondents' core research activities...



Source: Analysis of survey results, calculations by Fraunhofer ISI

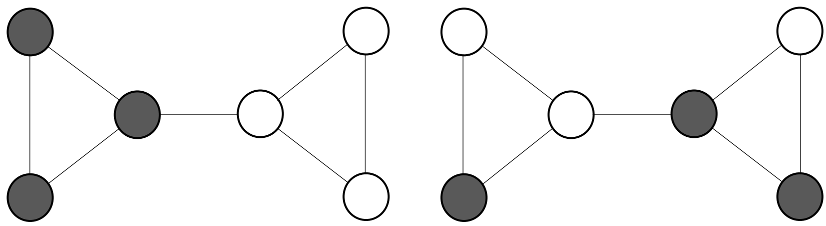
7.1.3 Researchers providing links between thematic/broad areas

A last, less formal approach through which FP7 might have facilitated the exchange of knowledge from different disciplines is from researchers participating in multiple projects (at least two) falling under different thematic/broad areas. Indeed, if a researcher participates in more than one project from different thematic/broad areas, this researcher might channel between both teams tacit knowledge/expertise as well as knowledge produced as part of either project. Thus, the second question that was addressed with regards to the disciplinary mixing that occurred in European research networks as a result of FP7 participation is whether or not researchers participating in more than one project could have contributed to the flow of information between different thematic/broad areas. As FP7 does not directly promote multiple participation at the researcher level, such an effect, if it occurs, would somehow be a collateral effect of FP7 participation.

To answer this question, all FP7 projects—and their corresponding thematic/broad area—were linked by examining the overlap between their respective participants (i.e. scientific contact or administrative contact if information on the former is unavailable) in a network. A network is a graph that consists of a set of actors (or nodes) and a set of ties (or links), whereby the relationships between actors are represented by the ties linking them (see Figure 5 for an example). In the particular case where there are two different types of actors—for example FP7 projects and participants, as is the case here—the graph displaying the connections between actors is referred to as a two-mode network. In such a network, only the ties between actor types, not within them, are analysed; that is, direct ties within one type of actor—for example, a direct tie between researcher A and B in the network—are disregarded. Thus, if researcher A and B both participated in project #1, they will each have a tie connecting them with project #1 but there will be no tie between them (e.g. RA—P1—RB). Bridges across two projects therefore occur when one individual, say researcher A, participates in at least two projects, say project #1 and #2 (e.g. P1—RA—P2).

Given its sheer size, the two-mode network connecting FP7 projects and participants cannot be displayed graphically to appreciate the extent to which projects from the same thematic/broad area tend to cluster together—that is, the extent to which they are preferentially forming homophilic groups on projects from the same thematic/broad area—as opposed to being dispersed randomly with respect to this dimension—that is, the extent to which they are forming heterophilic links through projects from different thematic priorities (Figure 5). A homophily indicator was developed to reflect the extent to which projects are linked given a shared characteristic, which in this case is their respective thematic/broad area. Homophily ranges from -1 (highly heterophilic) to 1 (highly homophilic), with 0 representing a neutral network whereby the observed occurrences of homophilic (i.e. two projects from the same thematic/broad area) and heterophilic (i.e. two projects from different thematic/broad area) pairs are equal to their expected occurrences based on a random network sharing the same characteristics as the network analysed (i.e. with the same number of actors and ties as well as the same frequency distribution of actors across thematic priorities).

Figure 5 Network graphs showing, to the left, a highly homophilic network and, to the right, a somewhat heterophilic network



Note: The networks are displayed in one mode for simplicity. Actors (i.e. nodes) are represented by bubbles, and ties by lines between actors. There are two sets of nodes each sharing a common characteristic (i.e. their colour or, alternatively, a given thematic area).

The results demonstrate that although researchers participating in more than one project do link projects from different thematic/broad areas, the 8% share of heterophilic pairs remains well below expectation, such that the FP7 network is highly homophilic (homophily = 0.94) (Table XIV). Nevertheless, the share of heterophilic project pairs—that is, pairs consisting of projects from two thematic areas connected by a shared participant—almost doubled from 5.6% for 2007–2010 to 9.8% for 2011–2014. This indicates that as FP7 went on, there was an increase in the extent of disciplinary mixing through the increased presence of bridges between thematic/broad areas.

Table XIV Trends in the homophily of the FP7 network in regards to the aggregation of projects according to their corresponding thematic area, 2007–2014

Year	Share of heterophilic pairs	Share of homophilic pairs	Homophily
2007-2010	5.6%	94.4%	0.96
2011-2014	9.8%	90.2%	0.93
2007-2014	**7.9%**	**92.1%**	**0.94**

Note: Refer to the above text for an explanation of ‘homophily’. The years are based on the starting year of projects as found in CORDA.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Considered together, these findings suggest that FP7 served to link researchers and projects from different fields of science who, in some cases, do not frequently exchange knowledge.

7.2 Multidisciplinary team work and interdisciplinarity

Finding 12 FP7 fostered interdisciplinary research even in specific programmes where cooperation and networking are not sought

To investigate the extent to which the bridges that have been successfully established by FP7—by connecting researchers from different horizons on common projects—really led to the integration of knowledge from disconnected fields of science, a third question was addressed: Does the level of multidisciplinarity on a given FP7 project (i.e. the diversity of disciplines from which the researchers on the project team are coming) relate positively to the level of knowledge integration observed in the resulting research publications?

To address this question, the multidisciplinarity of projects was computed with the method described in Section 7.1.1. Because it accounts for the distances separating the disciplines observed among a team's researchers—as measured through an analysis of citation flows between disciplines in the scientific literature—a positive relationship with the level of disciplinary integration in the publications resulting from the team's work would be indicative that not only did FP7 foster the integration of knowledge from different disciplines, but that it also did so for somewhat disconnected fields of science that do not regularly exchange knowledge.

As stated above in Section 7.1.1, bringing together researchers from different disciplines on a common project (i.e. multidisciplinary research) does not warrant that the knowledge coming from those disciplines will be integrated to solve a common problem that is beyond the scope of any one discipline (i.e. interdisciplinary research, refer to Section 2.2.1 for a deeper discussion of the conceptual difference between multidisciplinary and interdisciplinary research). Indeed, the researchers involved could have paired their efforts to secure funding while each addressed a different facet of the problem without true interaction and integration of knowledge. To measure the integration of knowledge, one can characterise the disciplinary mixing that occurred within the research outputs resulting from the team's work—for example, by measuring this dimension in the scientific publications resulting from a given FP7 project.

In doing so, it is important to consider each publication separately. Indeed, if the diversity of disciplines is measured taking all publications produced by the project's researchers as a single output, one could not differentiate multidisciplinary from interdisciplinary research. For example, consider a situation involving two researchers on a project—again, one astrophysicist and one architect. They then each produce one publication with the project's funding—one publication using an approach purely based on astrophysics to solve problem #1 and one publication using an approach purely based on architectural concepts to solve the same problem. If the diversity of disciplines is measured by taking the project's pool of publications as a single unit, diversity will be apparent but will reflect multidisciplinarity rather than interdisciplinarity. If the diversity of disciplines is instead measured within each publication (i.e. what is the diversity of knowledge referenced in the publication), then no diversity will be apparent since the scope of each publication remains within the realm of each researcher's discipline (i.e. the publications are purely disciplinary) reflecting the absence of true integration of the diversity of knowledge available in the project's team.

To perform this test, FP7-supported publications first had to be identified. The publication portfolios of researchers who participated in at least one FP7 project were constructed using the technique presented in Section 4 to identify their core research area and to subsequently measure the level of disciplinary mixing among a project's team members. Using these portfolios, FP7-supported publications were identified as those acknowledging FP7 financial support, and they were linked to their corresponding project through the project's identifier, acronym or other unique characteristics that appeared in the funding acknowledgement. For researchers who participated in a single project, the link could be made directly even if no project identifier was provided in the acknowledgement. It was then possible to measure the level of disciplinary mixing and integration within each FP7-supported publication by quantifying the diversity of scientific subfields from which knowledge was borrowed (i.e. the diversity of subfields appearing in the publication's reference list) in performing the work. In a similar manner to the computation described above for the multidisciplinarity of FP7 team, this computation accounts for the inherent proximity between scientific subfields appearing in the reference list of papers (refer to the attached methodological annex for details on the regression analysis).

Subsequently, to analyse whether or not the multidisciplinarity of research teams promoted by FP7 exerts a positive and statistically significant effect on the interdisciplinarity of the papers resulting from the work of those teams (i.e. one of the immediate outcomes of FP7 as outlined in the programme's logic model, Figure 2), a regression analysis was performed. The regression model that has been implemented incorporates—as explanatory variables—numerous networking dimensions beyond the disciplinary facet (e.g. institutional sectors and geography), as well as numerous controls such as the interdisciplinarity of the research publications produced by a given team's members prior to their participation in FP7 (refer to the companion methodological annex for details on the regression analysis).

The explanatory variable with the largest significant effect on the interdisciplinarity of FP7-supported papers in the regression model is the multidisciplinarity of project teams (Table XV). In addition, the multidisciplinarity of project teams maintains a slight but significant effect (i.e. small regression coefficient = small size effect) on this dependent variable beyond what can be explained by the level of interdisciplinarity observed in the papers produced by project teams prior to their participation in FP7. Since the selected indicators of multidisciplinary and interdisciplinary research account for the extent of knowledge exchange between disciplines (the higher the score on either indicator, the smaller the usual flow of knowledge between disciplines), the analysis shows that multidisciplinarity in FP7 projects exerts a positive effect on the integration of otherwise *a priori* disconnected knowledge (i.e. on interdisciplinarity). This finding only applies to the Cooperation and Capacities specific programmes since not enough data points were available to run this analysis for the People and Ideas specific programmes.

Table XV Relationship between the multidisciplinarity of project teams and scientific output under the Cooperation and Capacities specific programmes

Explanatory Variables	No. of papers	Avg. of Rel. Impact Factors (ARIF)	Avg. trans-disciplinarity	Avg. no. of ERA countries per paper	Avg. no. of non-ERA countries per paper
Multidisciplinarity	-0.148 ***	0.028	0.071 ***	-0.040	0.072
	(0.056)	*(0.087)*	*(0.017)*	*(0.053)*	*(0.052)*
			All other independent and control variables		
R-sq-adj	**0.692**	**0.401**	**0.828**	**0.445**	**0.534**
N	**732**	**250**	**248**	**708**	**708**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All models are statistically significant at p ≤ 0.01. *: p ≤ 0.10; **: p ≤ 0.05; ***: p ≤ 0.01.

Source: Computed by Science-Metrix using CORDA (European Commission) data

It is interesting to note that the level of interdisciplinarity observed among FP7-supported papers for the People and Ideas specific programmes, when all projects within a specific programme are grouped, is similar to that observed for the Cooperation and Capacities specific programmes (Table XVI), whereas the level of multidisciplinarity observed within FP7 project teams for the former two specific programmes was much smaller than for the latter two (Table XIII). This indicates that although the formal promotion of multidisciplinary work can have a slight positive effect on the integration of *a priori* disconnected knowledge, it is not a prerequisite to achieving interdisciplinarity. This might be due to the presence of informal multidisciplinary collaboration (i.e. partnerships beyond the immediate project team) in the execution of FP7 projects for participants in the People and Ideas specific programmes.

Table XVI Trends in the interdisciplinarity of FP7-supported papers by specific programme as well as by thematic area and broad area, 2007–2014

	2007-2010			2011-2014			Delta (2011-14 vs. 2007-10)		Total		
	N	Avg.	Gini	N	Avg.	Gini	Avg.	Gini	N	Avg.	Gini
FP7	**85,065**	**0.52**	**0.19**	**64,679**	**0.51**	**0.20**	**-0.003**	**0.010**	**150,165**	**0.51**	**0.20**
COOPERATION	**46,251**	**0.55**	**0.16**	**28,715**	**0.54**	**0.17**	**-0.004**	**0.013**	**74,966**	**0.54**	**0.16**
Energy	1,419	0.54	0.16	680	0.52	0.17	-0.023	0.010	2,099	0.53	0.17
Environment (including Climate Change)	5,410	0.53	0.19	2,737	0.52	0.22	-0.018	0.023	8,147	0.53	0.20
Food, Agriculture, and Biotechnology	4,446	0.58	0.13	3,188	0.60	0.12	0.021	-0.007	7,634	0.59	0.12
General Activities (Annex IV)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Health	20,160	0.55	0.14	10,559	0.55	0.14	0.005	0.006	30,719	0.55	0.14
Information and Communication Technologies	5,043	0.51	0.20	2,909	0.51	0.20	0.009	0.001	7,952	0.51	0.20
Joint Technology Initiatives (Annex IV-SP1)	811	0.59	0.11	1,940	0.53	0.17	-0.052	0.055	2,751	0.55	0.15
Nanosci, Nanotech, Materials and new Prod Tech	6,764	0.58	0.14	4,368	0.59	0.14	0.003	-0.004	11,132	0.58	0.14
Security	375	0.48	0.26	325	0.40	0.33	-0.076	0.070	700	0.44	0.30
Socio-economic sciences and Humanities	134	0.56	0.20	119	0.55	0.19	-0.008	-0.013	253	0.56	0.20
Space	895	0.46	0.24	1,355	0.37	0.34	-0.089	0.100	2,250	0.41	0.30
Transport (including Aeronautics)	794	0.47	0.24	535	0.51	0.20	0.048	-0.044	1,329	0.49	0.22
CAPACITIES	**6,904**	**0.41**	**0.33**	**4,822**	**0.42**	**0.32**	**0.011**	**-0.010**	**11,726**	**0.42**	**0.32**
Activities of International Cooperation	123	0.56	0.15	141	0.60	0.11	0.035	-0.040	264	0.58	0.13
Coherent development of research policies	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Regions of Knowledge	93	0.55	0.13	34	0.33	0.31	-0.219	0.177	127	0.49	0.20
Research for the benefit of SMEs	858	0.54	0.20	714	0.56	0.16	0.017	-0.035	1,572	0.55	0.18
Research Infrastructures	5,044	0.37	0.36	3,584	0.39	0.35	0.015	-0.012	8,628	0.38	0.36
Research Potential	596	0.46	0.28	114	0.59	0.10	0.129	-0.173	710	0.48	0.25
Science in Society	190	0.58	0.15	233	0.38	0.41	-0.195	0.256	423	0.47	0.30
PEOPLE	**20,450**	**0.49**	**0.22**	**21,104**	**0.51**	**0.21**	**0.017**	**-0.012**	**41,975**	**0.50**	**0.21**
IDEAS	**11,460**	**0.50**	**0.20**	**10,038**	**0.48**	**0.23**	**-0.019**	**0.030**	**21,498**	**0.49**	**0.21**

Note: The N scores refer to the number of FP7-supported papers instead of the number of FP7 projects.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Also of interest is the fact that the cross-case analysis of the findings from the 12 case studies revealed that networks generally inspire researchers to broaden their perspective. As researchers work together with academics from different disciplines and/or partners from other institutional sectors, they become more aware of what others in their field are doing as well as how other partners are thinking and working, which stimulates creativity and innovation. This is consistent with the hypothesis that by connecting researchers from different disciplinary horizons, interdisciplinary research is fostered.

Case study examples of this include:

- EMIF. This project brought together people with different takes on Alzheimer's disease and metabolic complications of obesity. EMIF connected epidemiologists and bio-disease historians, who are very different in their approach and way of working. At the time of the case study, the project was only one and a half years into the five-year project period, but partners had already started working together in new constellations outside of EMIF.
- GP-TCM. According to the interviewees, the linkages between researchers have strengthened to a very high degree in all levels of collaboration, from borrowing ideas without personal interaction to occasional collaboration between individual scientists, as well as systematic collaboration in multidisciplinary teams.
- ATLAS. By bringing together partners from different scientific fields, new lines of research emerged. This project brought together physicists, software developers, laser experts, medical doctors, molecular biologists, and so forth. In an interview with the coordinator, it was stated that some of their discoveries have changed standard views on biomedicine.

7.3 Multidisciplinarity, interdisciplinarity and the emergence of new lines of research and innovation

Finding 13	The majority of the research projects in FP7 involved new lines of research

Finding 14	Multidisciplinary research formally supported by FP7 does not appear to be a prerequisite to start new lines of research

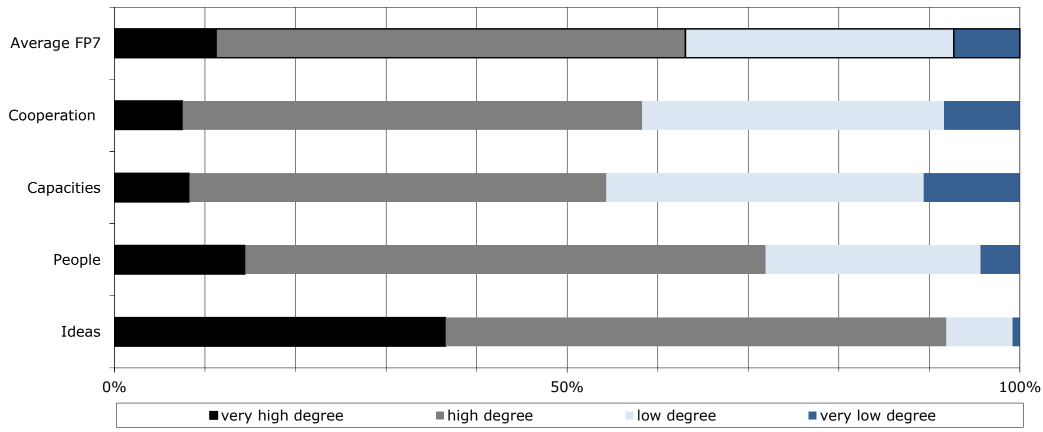
Finding 15	No statistically significant link was found between multidisciplinarity and innovative capacity

An underlying hypothesis of the FP7 intervention logic is that linking/integrating a high diversity of knowledge through multidisciplinary and interdisciplinary research paves the way to the emergence of innovation such as new research topics, methods/tools or technologies.

To assess whether new lines of research may or may not have happened under FP7, the following question was asked to FP7 participants in the survey: 'To what degree has your FP7 project initiated a new line of research?' Grouping responses of to a 'very high degree' and to a 'high degree' (Figure 6), more than half of the survey respondents (63%) reported that their FP7 projects opened up a new field of research. This is especially true for the Ideas (92%) and People (72%) specific programmes compared to Cooperation (58%) and Capacities (54%).

The very high share observed for Ideas is not surprising since it focuses on supporting excellence to achieve frontier research. However, this, at first sight, does not support the underlying hypothesis that multidisciplinary research supported under FP7 is a prerequisite to foster the emergence of new lines of research. Indeed, Section 7.1.1 has shown that both Ideas and People were not multidisciplinary compared to Capacities and Cooperation. Although the former two programmes do not specifically support multidisciplinary research proactively, the discoveries resulting from them are nevertheless as interdisciplinary as they are for the latter two programmes (see above Table XVI). As stated above, this might result from informal multidisciplinary collaboration—through partnerships beyond the immediate FP7 project team—in the execution of projects for participants in the People and Ideas specific programmes. However, it could also be that participants in the People and Ideas specific programmes manage to match the level of interdisciplinarity observed for the Cooperation and Capacities specific programmes through their individual work integrating knowledge/approaches from various disciplines rather than through informal teamwork crossing disciplinary boundaries. Since the implemented methods did not allow showing a clear causal link between multidisciplinary and interdisciplinary research conducted under FP7 and the emergence of new lines of research, further research into the question is warranted.

Figure 6 Degree to which FP7 projects initiated a new line of research



Source: Analysis of survey results, calculations by Fraunhofer ISI

A regression analysis was used to examine whether there is a link between multidisciplinary teamwork and the emergence of new methods or technologies. The explanatory variables included in the regression model (Table XVII) were run with innovation as the dependent variable. This was measured through the survey, when researchers were asked to indicate whether the FP7 project had prompted their organisation to introduce product or process innovations. Based on this analysis, multidisciplinary research has not been shown to exert a significant effect on triggering innovation in the form of new products or processes. Yet the fact this study has not shown a positive link does not mean it does not exist, and further research is warranted to verify the findings using other types of data.

Table XVII Relationship between the multidisciplinarity of project teams and positive project outcomes under the Cooperation and Capacities specific programmes

Explanatory Variables	Breadth Knowledge	Breadth Tools	Transfer of Research Results	Effects on Careers		Innovations triggered
Multidisciplinarity	-0.047	0.326	-0.038	-0.005		-0.387
	(0.220)	*(0.291)*	*(0.130)*	*(0.210)*		*(0.404)*
All other independent and control variables						
R-sq-adj	**0.165**	**0.183**	**0.091**	**0.12**	**[Pseudo]**	**0.116**
N	**732**	**732**	**681**	**732**		**732**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All models are statistically significant at $p \leq 0.01$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Further insight into the question was obtained from a case study performed on the ATLAS project (under Cooperation), a project that visibly linked and integrated separate fields of science (i.e. with high multidisciplinarity and interdisciplinarity scores as described above). The ultimate goal of the project required bringing together individuals from different scientific disciplines and those working in academia and in industry. In this project, private–public networking occurred as it involved SMEs and universities. It also showed a clear case of a multidisciplinary network comprising physicists, oncologists, molecular biologists, medical doctors, chemists, IT experts and mathematicians.

The case study revealed that the ensuing exchange of ideas from heterogeneous perspectives stimulated creativity and innovation, and an entirely new laser-based technology was developed for analysing protein bindings in DNA for use in both research and clinical contexts. This project might be considered as a trigger point for future transformation. It was able to build a highly multidisciplinary team whose collaboration was fruitful and managed to balance the basic and applied aspects of each participant's specific field, whether that was in science or in industry.

Similarly, new methods or technologies were developed in at least two other case studies, one of which, Self Optimising Measuring Machine Tools (SOMMACT), is under the Cooperation specific programme and shows a good level of multidisciplinarity. The other case study, Smart Structured Rotating Reactors (SSRS), came under the Ideas specific programme and therefore did not exhibit multidisciplinarity as a direct outcome of participation in FP7. This evidence shows that though multidisciplinarity may help trigger innovation, it is not necessarily a required condition.

Thus, there are cases where multidisciplinarity is present when a new combination of knowledge is present and leads to fairly radically new technologies. It is not possible, however, to isolate this statistically from the FP7 data and say that multidisciplinarity and interdisciplinarity are the *cause* or even a clearly important contributing factor behind the emergence of these innovative technologies. Yet one has to be careful, as the absence of the demonstration in the present context does not constitute proof that multidisciplinarity is not instrumental in spurring innovative theories and technologies.

7.4 Is there an ideal level of multidisciplinarity in collaboration projects?

Finding 16	Project management difficulties may be incurred by increased multidisciplinarity and interdisciplinarity

Finding 17	Generally speaking, there does not seem to be an ideal level of multidisciplinarity to obtain the outcomes sought in FP7

The case studies and the workshop revealed that despite the advantages of multidisciplinary projects, challenges can also arise. Some project participants had a hard time valuing the diversity in their projects. It took a lot of extra time and effort for researchers from different disciplines to understand each other's way of thinking and to obtain the mutual benefits and synergies from taking a multidisciplinary and interdisciplinary approach.

This was illustrated in the case study of Climate for Culture, which was a large, multidisciplinary project. In this case, potential synergies from collaboration between partners across work packages did not always occur, as some partners found it overwhelming to get to know all of the other partners in the project besides those assigned to the same work package as them. The project had three phases and the first planning and networking phase took place over the first and second year of the five-year project. A significant amount of time was needed and devoted to engaging partners and involving researchers. Furthering this, due to partners' different academic or institutional backgrounds, aligning expectations and understanding was a significant challenge.

Similarly, one challenge highlighted by a participant in the RESPECT project was that of tackling and overcoming the different work cultures and norms between different fields and types of organisations. They described how they found it difficult at times to interact with organisations that did not have the same procedures or ways of working. A cooperation phase was initiated at the start of this three-year project so the project partners could to get to know one another and align interests and goals.

On a slightly different note, the ATLAS project team valued the multidisciplinary aspect of their project but also recognised multidisciplinarity as a challenge. From the survey findings and as elaborated on in the case study, 'discrepancies in scientific expertise' was found to be one of the three biggest obstacles in the collaboration. Acknowledging the vast differences in scientific expertise amongst the consortium, the project coordinator made an effort to organise the project in a way that allowed for an unrestrained flow of knowledge sharing despite some barriers. The coordinator arranged various social activities over the course of the project to create an atmosphere where partners from different scientific fields could ask each other questions about their different areas of expertise in more casual and simple terms: as the coordinator said in their interview, 'Explain it like you would to a child'.

Importantly though, it was found that previous collaboration between project partners may mitigate obstacles that arise from a multidisciplinary and/or interdisciplinary project. A past history of working together can bridge diversity, build trust and strengthen personal relationships, facilitating the flow of information within the networks. Case study examples of this include:

- Laserlab Europe. Since its founding in 2004 under FP6, this large network of European research organisations has continued to grow and expand in FP7. As the network has been established for more than 10 years now, many of the challenges and difficulties that new networks encounter—such as language barriers, cultural differences, and different academic traditions, for example—have already been overcome in earlier phases. Therefore, during FP7, the consortium was able to bring in new members and easily integrate them into the network.

- AgriPolicy. A similar project was conducted in FP6 and was furthered again in FP7. The same project leader managed both projects and most of the partners from the FP6 project were also included in that of FP7. No significant challenges in regards to integrating new partners were mentioned when conducting the case study. However, many of the partners in the project were from the fields of Agriculture or Agricultural Economics.
- ATLAS. Some of the partners involved in the ATLAS project had worked together in previous projects. This had significance for the project, as the application and project formation process was eased because the coordinator and some of the participants already knew one another and knew who had the proper expertise and capacity to deliver. The joint experience of partners from earlier collaborations allowed the partners to begin tasks more quickly.

The above difficulties that may arise from multidisciplinary team work raise the question of how to achieve the proper balance in network team composition. For instance, is there an optimal number of different disciplines that would help maximise the positive outputs/outcomes as specified in the logic model of FP7 (Figure 2)?

To answer this question, the performance of FP7 projects was measured with the composite indicator presented in Section 6.3. The main finding is that the multidisciplinarity of project teams does not appear to exert a positive or negative effect on positive outcomes measured through the composite indicator except under the People specific programme, where significant differences are observed between groups. In this case, a positive effect is visible and there does not appear to be a turning point where the benefits of increasing the multidisciplinarity of teams decrease or level off. This is not contradictory with the above finding showing a slight positive effect of multidisciplinarity on the interdisciplinarity of FP7-supported publications, since the sets of outputs/outcomes measured here are broader. Thus, apart from the case of People, there is no observed ideal level of multidisciplinarity in terms of obtaining positive outcomes. In People, it seems that the more multidisciplinary the project team is, the better it is at generating the outcomes examined in the regression model (as measured collectively with the composite indicator).

Table XVIII Performance, as measured with a composite measure of positive outputs/outcomes, of FP7 projects across networks of varying sizes as regards their multidisciplinarity, by specific programme

	Cooperation				Capacities				People		
Descriptive Stats	**(0.00-0.38)**	**(0.39-0.53)**	**(0.54-0.63)**	**(0.64-0.86)**	**(0.00-0.28)**	**(0.29-0.46)**	**(0.47-0.59)**	**(0.60-0.80)**	**(0)**	**(0.18-0.44)**	**(0.45-0.72)**
N of Cases	123	117	120	123	27	26	24	28	134	30	29
Minimum	13.6	14.8	14.0	12.0	14.7	18.7	16.2	21.9	11.0	12.4	16.5
Maximum	46.8	54.2	64.5	57.2	64.7	62.0	72.0	43.9	75.7	45.7	52.9
Median	31.6	31.0	31.8	30.2	32.4	31.2	31.4	33.4	26.0	29.5	31.2
Arithmetic Mean	31.8	31.2	32.9	31.0	33.1	34.9	33.3	33.8	27.5	30.4	31.2
Mean Rank Sum*	247	233	260	228	49.9	53.8	50.8	57.1	88	115	120
Standard Deviation	6.9	7.3	8.2	7.2	11.1	11.9	12.0	6.6	9.6	7.7	7.4
Variance	46.9	53.9	66.6	51.7	122.7	141.1	144.9	44.0	93.0	59.5	54.6

Note: * Significant differences exist between groups for People (global p = 0.00). Tested using a Kruskal-Wallis test. The test could not be performed for Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

8 BRIDGING THE FLOW OF INNOVATION THROUGH INTERSECTORAL COLLABORATION (SQ2)

Project terms of reference: Based on the assumption that success of innovation depends on the link between basic research, applied research, and business/industry: to what extent does the FP link different types of organisations (universities, industry, SME, etc.) and bridge the flow of innovation ideas between them? Hypothesis: Links between different types of organisations foster success of innovation.

Similarly to EU framework programmes, governments the world over are increasingly adopting policies to augment the exchange of knowledge and the rate of collaboration between actors from different sectors. These collaborative relationships can bring together the private, government, non-government and academic sectors to address complex issues that are critical to the development of national economies through innovation.

A key positive finding of this study is that FP7 has successfully promoted intersectoral collaboration between academia, research organisations and the public sector and that intersectoral integration progressed from FP6 to FP7.

Cross-sector collaborations are meant to promote innovation by enabling organisations to pool wide-ranging expertise and resources (Trist, 1983) and allow participants to search for solutions that 'go beyond their own limited vision of what is possible' and open up access and agendas to wider participation by a broader range of stakeholders (Gray, 1989). Intersectoral collaboration also becomes a platform from which to launch new formats to promote innovation, such as incubators, science parks and venture capital firms (Etzkowitz, 2003).

Interestingly, while there is general support in the literature for the value of cross-sector collaboration, there is little information suggesting that an optimal number or composition of cross-sector partners exists. One study found that invention projects (i.e. those focusing on basic research rather than applied outcomes) were organised in wide, open networks with little structure and with a large number of partners. On the other hand, innovation projects were found to be carried out in well-structured networks with limited external contacts (Arranz & Arroyabe, 2006).

Results from the present study suggest that crossing too many institutional boundaries may have a detrimental effect on some outputs/outcomes, with limited evidence showing an increase in positive outputs/outcomes, taken generally, as the number of sectors on a project increases. As such, networked projects are a balancing act, and optimal ratios for number/type of partners/sectors may vary to a great extent depending on the project's ultimate goals, highlighting the importance of avoiding a one-size-fits-all approach to building a network team.

The above finding on the effect of the number of sectors on the production of positive outputs/outcomes (including innovation) in a given project raises another question. Perhaps the type of intersectoral collaboration matters more for producing positive outputs/outcomes in a project than the absolute number of sectors involved? For instance, a key objective of the framework programmes is to improve the competitiveness of national economies throughout Europe and, as such, a strong focus has been placed on the integration of SMEs under FP7. It therefore seems plausible that the integration of the private sector in particular might have had a positive and significant effect on the production of desirable outputs/outcomes as specified in the logic model of FP7 (see Figure 2).

As discussed in Section 2.2.2, there is a growing trend to support intersectoral collaboration, and more particularly public–private interactions. This may be defined as research as 'an R&D-based relationship involving at least one private firm and at least one public-sector organisation that are mutually committed to reaching a common R&D goal by pooling resources and/or coordinating activities' (PCAST, 2008). Public–private research partnerships and collaborative networks are said to be extremely well positioned to develop critical research mass and to apply multidisciplinary approaches to address specific scientific, technological and societal issues (Cunningham & Ramlogan, 2012). Significant benefits for the private partners include increased access to new research and discoveries, while for the public sector benefits include access to industry expertise and secured funds (Lee, 2000).

There are countless articles in the scientific literature making the case for industry–university collaboration as a particularly effective way to foster innovation (e.g. Ponds, Van Oort & Frenken, 2009). Universities are major sources of new knowledge and ideas and a primary engine for discovery research that can lead to innovation. Quantitative studies have demonstrated that commercial innovation centres benefit from the presence of universities and that communities surrounding technical universities experience higher than average rates of growth (Doutriaux & Sorondo, 2005). The university–industry link is associated with innovativeness in general, and some authors even claim that firms that collaborate with universities tend to introduce the most original innovations (Broström & Lööf, 2008).

In the present study, results clearly demonstrate a positive and significant effect of the integration of the private sector (including SMEs) in collaborative projects funded by FP7 on (1) the transfer of knowledge to the business sector, and (2) the production of innovation in the form of new products and processes. In addition, the results indicate that the integration of the private sector (including SMEs) improved in FP7 networks relative to FP6 networks.

8.1 Intersectoral collaboration

Finding 18	FP6 and FP7 have successfully promoted intersectoral collaborations and the level of intersectoral collaboration is largely unchanged in FP7

Finding 19	Though FP7 strengthened links with researchers in other sectors, it strengthened links even more between researchers within the same sector

8.1.1 Linking organisations in different sectors of activity

Organisations from a diverse set of activity sectors participated in FP6 and FP7. These sectors include:

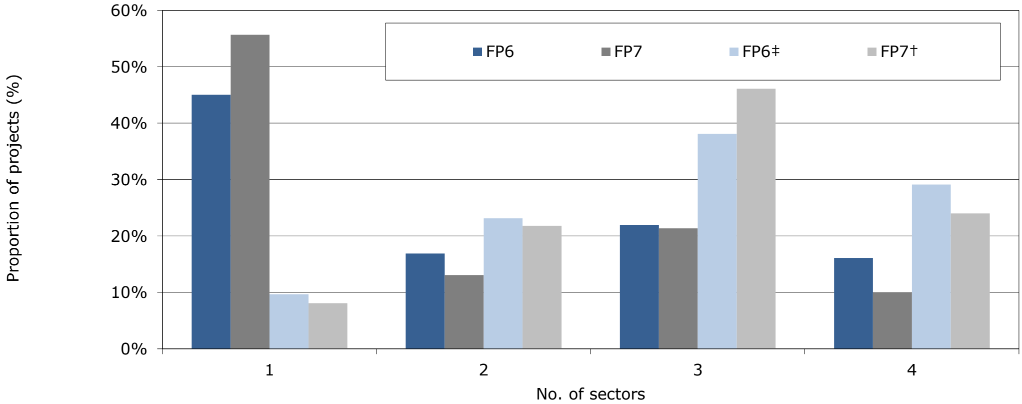
- Higher education (HES);
- Research organisations (excluding education) (REC);
- Public body (excluding research and education) (PUB);
- Private for profit (excluding education and including the following sub-group: small or medium-sized enterprises [SMEs]) (PRC); and
- Others (OTH).

The latest framework programmes (such as FP6 and FP7) aim to link these types of organisations with the idea that innovation is facilitated by the interactions taking place between the actors along the whole route from knowledge creation to the production of marketable inventions—that is, university–industry–government interactions (Etzkowitz, 2003). This way, the basic knowledge produced as part of public research would more easily find its way to the private sector, thereby fuelling innovation. Importantly, however, there is an understanding in Europe that the linear innovation model has shown its limits and this explains why, increasingly, framework programmes place business enterprise at the core of cooperative research activities (Section 8.2).

As a first step towards characterising the extent to which the framework programmes successfully integrated the above sectors of activity in both FP6 and FP7, data on the sectoral affiliation of project participants in both programmes were extracted from CORDA to count the number of distinct sectors per project. Manual quality control was performed to validate the sector attributed to each organisation in the database and a number of erroneous entries were corrected. Additionally, because the sector classification changed from FP6 to FP7, some alterations were performed to match the categories found for FP7 with the FP6 format in CORDA. FP6 featured higher education, industrials, research organisations, others and undefined. In FP7, the others category was split into public body (i.e. not research and not higher education) and others, while the undefined category was dropped as seemingly all organisations could be classified. To align categories between both framework programmes, public body organisations in FP7 were merged with those classified as others to produce the Public Body & Others category. The undefined category in FP6 was ignored as it represents organisations whose sector is ambiguous or unknown.

Figure 7 presents the frequency distribution of projects according to their number of participating sectors in both FP6 and FP7. Note that because some of their underlying specific programmes were not formally designed to support cooperation, the data presented in Figure 7 were produced with and without these specific programmes—namely, People (i.e. Marie Curie Actions) under both FP6 and FP7 and Ideas (i.e. European Research Council) under FP7.

Figure 7 Frequency distribution of projects by number of sectors



Note: †FP7 data without People and Ideas data as they are the least collaborative of the thematic priorities (which means that a majority of projects from this thematic area have only 1 actor).
‡FP6 data without *Marie Curie Actions* data as they are the least collaborative of the thematic priorities (which means that a majority of projects from this thematic area have only one participant).

Source: Computed by Science-Metrix using CORDA (European Commission) data

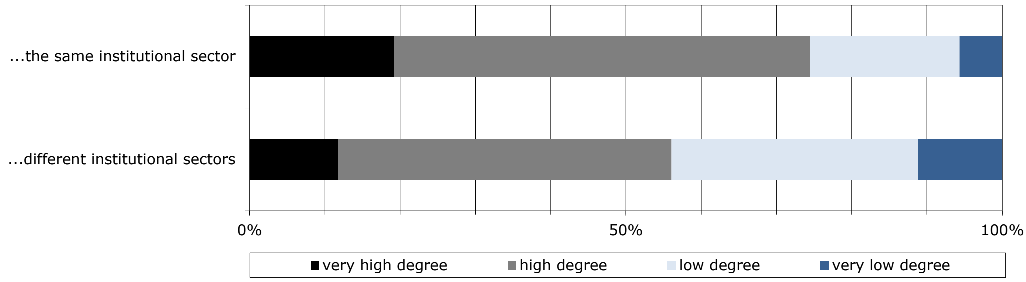
When the People and Ideas specific programmes are kept in, the results show that projects without intersectoral collaboration account for nearly half of all FP6 projects and slightly more than half of all FP7 projects. The slightly greater share for FP7 is not surprising as there wasn't the equivalent of Ideas in FP6. As such, FP7 included more components than FP6 that were not designed to directly support collaborative projects.

When People and Ideas are excluded, the results show that 70% of the core collaborative projects under FP7 involve three or more sectors, thereby indicating that it has successfully promoted intersectoral collaborations. This is very similar to what was achieved under FP6, where 67% of the projects involved three or more sectors. In fact, the mean (2.86 and 2.80, respectively) and median (3) number of sectors per project for FP6 and FP7 are the same when excluding the People and Ideas specific programmes.

While the data previously highlighted examine the number of sectors present in a project, it is also important to examine how strong the links are. After all, though FP7 may have succeeded in bringing researchers from several sectors into the same project, these researchers may have preferred relations with researchers from their own sector, within the project. This was examined by asking the following question to survey respondents: 'To what degree has the FP7 project allowed you to strengthen collaborations with researchers from...?' The choice of answers and their frequencies are presented in Figure 8. The survey results corroborate the above finding obtained from the analysis of CORDA data, wherein at least half of the respondents indicated that their FP7 projects enabled them to strengthen their linkages with researchers from other sectors. Importantly though, an even larger proportion of researchers mentioned that FP7 strengthened linkages with researchers from their own sector.

As in the case of multidisciplinarity examined in the previous section, these data reveal how strong affinities are between researchers who have similar training, end-goals, and values, in other words homophily often trumps heterophily. Thus, even though FP7 strengthened multisectorality and multidisciplinarity, it strengthened intrasectoral and intradisciplinary links even more, which is likely an unintended consequence.

Figure 8 FP7 projects' contribution to strengthen linkages with researchers from other institutional sectors as stated by respondents



Source: Analysis of survey results, calculations by Fraunhofer ISI

8.1.2 Bridging the flow of innovation ideas between sectors

By linking participants from different sectors of activities, framework programmes aim to bridge the flow of innovation ideas between sectors with the expectation that it will foster innovation. To characterise the extent to which the intersectoral integration resulting from framework programmes might have fostered the flow of innovation ideas between sectors, SNA was used.

The extent to which organisations agglomerate according to a shared characteristic (i.e. their corresponding sector of activity) in the co-participation network of FP6 and FP7 reflects, to some degree, the ease with which information can flow between sectors. Indeed, in a network where organisations group almost exclusively with actors from the same sector with a low density of ties between sectors (i.e. a homophilic network), information produced in any one sector can reach an actor outside that sector with difficulty. Whereas in a network where organisations do not seem to cluster preferentially with actors from the same sector (i.e. a heterophilic network), information produced in any one sector can more easily reach an actor outside the given sector.

In a similar manner to the approach presented in Section 7.1.3 to study the flow of knowledge between thematic/broad areas, a homophily indicator was computed to reflect the extent to which organisations collaborate according to a shared characteristic, which in this case is their respective sector of activity. In this case, the analysis is based on a one-mode network (see Section 7.1.3 for a definition of one- and two-mode networks) in which the actors are the participating organisations and the ties between them are established based on their participation in common projects (i.e. their co-participation). Homophily ranges from -1 (highly heterophilic) to 1 (highly homophilic), with 0 representing a neutral network whereby the observed occurrences of homophilic (i.e. two organisations from the same sector) and heterophilic (i.e. two organisations from different sectors) pairs are equal to their expected occurrences based on a random network sharing the same characteristics as the network analysed (i.e. with the same number of actors and ties as well as the same frequency distribution of actors across sectors).

Research networks naturally tend towards homophily with respect to various dimensions (e.g. disciplines, geography, institutional sectors). As such, without a proper benchmark, it is difficult to interpret whether the observed homophily score for the FP7 network of participation reflects a positive influence of the programme on the flow of innovation ideas between sectors. Indeed, even if the FP7 network tended towards homophily, the programme could nevertheless have improved the flow of information between sectors relative to other research networks (e.g. the co-participation network of organisations under FP6, the co-publication networks of European organisations). Here, to appreciate the role of FP7 in bridging the flow of innovation ideas between sectors, the selected benchmark is the co-participation network of organisations under FP6 (Table XIX). The homophily indicator has also been computed for each of the specific programmes as well as each of the thematic/broad areas under FP7.

Table XIX Homophily indicator per programme for intersectoral networking

Programme	Homophily Indicator
FP6 (overall)	**0.14**
FP7 (overall)	**-0.11**
COOPERATION	**-0.11**
Socio-economic sciences and Humanities	0.29
Environment (including Climate Change)	0.23
Health	0.17
Space	0.17
Security	0.10
Food, Agriculture, and Biotechnology	0.09
Information and Communication Technologies	-0.06
Energy	-0.06
Transport (including Aeronautics)	-0.09
Joint Technology Initiatives (Annex IV-SP1)	-0.10
Nanosciences, Nanotechnologies, Materials and new Production Technologies	-0.23
CAPACITIES	**0.06**
Science in Society	0.27
Research Infrastructures	0.26
Coherent development of research policies	0.25
Activities of International Cooperation	0.23
Research Potential	0.15
Regions of Knowledge	0.06
Research for the benefit of SMEs	-0.25
PEOPLE	**0.27**
IDEAS	**0.23**

Note: Refer to the above text for an explanation of 'homophily'.
Source: Computed by Science-Metrix using CORDA (European Commission) data

The results show that while FP6 (homophily = 0.14) slightly tends towards homophily, FP7 (-0.11) slightly tends towards heterophily. Firstly, this indicates that the integration of sectors promoted under FP7 appears to have increased the ease with which innovation ideas can *potentially* flow between institutional sectors relative to FP6.

Table XX compares the observed occurrences of each pair of sectors (both homophilic and heterophilic pairs) within the FP7 network of participation in their expected occurrences (that is 0). As for the homophily indicator (see above), the expected occurrences of each pair is estimated based on a random network of the same size (i.e. same number of actors/organisations and ties/co-participations) with the same frequency distribution of organisations across sectors. A ratio above one indicates that a given pair is observed more frequently than expected (highlighted in green in Table XX), whereas a score below one indicates the opposite (highlighted in red in Table XX).

The results show that networking affinity is stronger within the higher education sector (HES) with the HES–HES pair having the strongest ratio overall and by specific programmes (except for Ideas) across all pairs (both homophilic and heterophilic pairs). Other common pairs relative to expectations include public body PUB–PUB, research organisations REC–REC, HES–REC, HES–PUB, and PUB–REC. In fact, the higher education sector, research organisations and public bodies appear to dominate all co-participation ties in the FP7 network with their homophilic pairs, as well as the heterophilic ties between themselves, having the strongest ratios among all pairs. This is not surprising since they participate much more frequently on a recurring basis in a variety of FP7 projects—under many of the specific programmes and their associated calls—than business enterprises (and SMEs). This can be partly explained by the fact that these organisations are much larger than the median business enterprise and cover a much wider range of scientific disciplines (e.g. Centre national de la recherche scientifique [CNRS] and the Max Planck Institutes).

Table XX Ratio of observed-to-expected occurrences of homophilic and heterophilic pairs between sectors under FP7

Pairs		OVERALL	Specific programmes: CAPACITIES	COOPERATION	IDEAS	PEOPLE
Homophilic Pairs						
Higher Education	Higher Education	19.15	8.31	14.38	1.42	3.86
Public Body	Public Body	2.65	5.27	1.98	N/A	1.36
Research Organisations	Research Organisations	4.71	5.21	3.55	0.72	0.98
Others	Others	0.75	1.17	0.69	N/A	2.85
Private	Private	0.37	0.42	0.41	2.21	0.25
Heterophilic Pairs						
Higher Education	Research Organisations	7.67	5.29	5.92	0.82	1.67
Higher Education	Public Body	2.20	2.05	1.82	0.51	0.84
Public Body	Research Organisations	1.76	2.62	1.36	0.53	0.49
Higher Education	Private	1.49	0.61	1.49	0.43	0.83
Higher Education	Others	1.49	1.34	1.39	0.42	0.93
Others	Research Organisations	0.94	1.17	0.87	N/A	0.41
Private	Research Organisations	0.84	0.61	0.83	0.58	0.40
Others	Public Body	0.77	1.34	0.65	N/A	1.39
Private	Public Body	0.26	0.26	0.28	N/A	0.09
Others	Private	0.24	0.34	0.28	N/A	0.15

Note: Refer to the above text for an explanation on the ratio of observed-to-expected occurrences of sectoral pairs in the FP7 network.

Source: Computed by Science-Metrix using CORDA (European Commission) data

This, as will be seen in Section 9.1, has a sizeable effect on the structure of the network of FP7 participation with the large academic (e.g. University College London, Université Paris VI) and research organisations being centrally located, and with the majority of business enterprises (and SMEs) being located at the periphery of the network. In fact, private companies do not have the same tradition of collaborating with each other; they rather collaborate on a one-to-one basis with the higher education sector. Indeed, the strongest and only ratio above 1—indicating that a pair is observed more frequently than expected—for any of the pairs including the private sector is the HES–PRC pair (1.49). All other pairs involving the private sector are observed less frequently than expected.

8.2 The role of SMEs in intersectoral collaboration

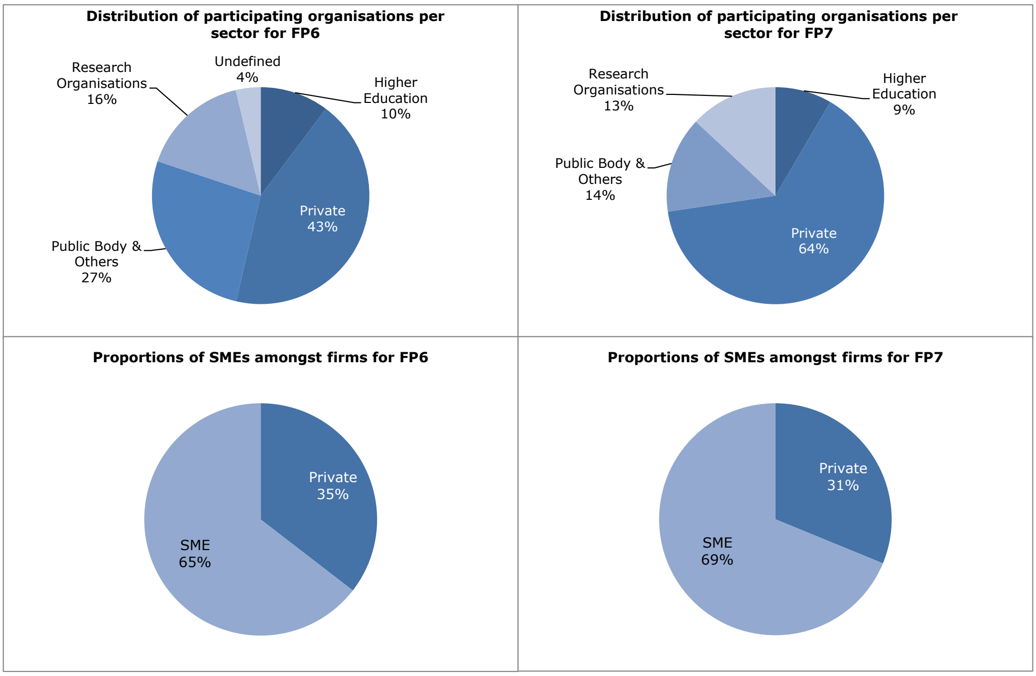
8.2.1 The place of SMEs in FP7 compared to FP6

Given the important role that business enterprises (including SMEs) appear to play in fostering innovation within the collaborative projects supported through the framework programme, it is of interest to characterise whether or not their integration progressed in FP7 relative to FP6. This was first achieved through an analysis of framework programme participation based on CORDA data.

As shown in Figure 9, private firms represent the largest group of distinct organisations among all participating organisations under FP7 (65%). They are followed by public bodies and other organisations (14%), research organisations

(13%) and the higher education sector (8%). Comparing the distribution of the distinct number of participating organisations across sectors from FP6 to FP7 reveals a substantial increase in the diversity of participating firms with their share among all participating organisations having increased from 44% to 65%. Also noticeable is an increase in the share of SMEs among participating firms going from 57% in FP6 to 69% in FP7 (Figure 9).

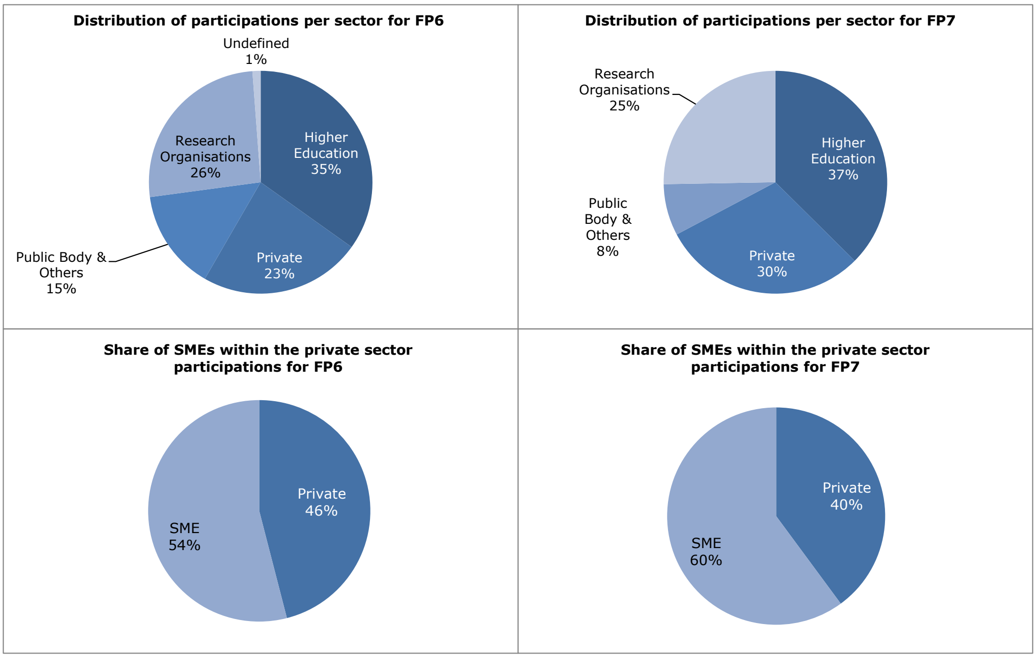
Figure 9 Distribution of the number of distinct organisations per sector: comparison between FP6 and FP7



Source: Computed by Science-Metrix using CORDA (European Commission) data

When looking at the actual participation level of each sector in FP7—that is, the actual number of times organisations from a given sector participated in FP7 projects (Figure 10), as opposed to the number of unique organisations from a given sector having participated in FP7 projects (Figure 9)—the picture is different. For example, the higher education sector dominates the network having a 37% share of all FP7 participations, slightly ahead of the private sector (30%) and of research organisations (25%). Finally, public bodies and other organisations (8%) appear to participate on an occasional basis in FP7. Here again, an increase in the share of the private sector, from 23% to 30%, is visible from FP6 to FP7, as well as in the share of SMEs within the firms' participations (54% to 60%). The strong prevalence of academic and research organisations in FP7 participations—despite their small shares among all participating organisations—is due to the fact that, compared to firms (and SMEs), they represent large organisations performing research in a broad range of scientific disciplines. Consequently, they participate much more frequently on a recurring basis in a variety of FP7 projects than firms (and SMEs). This, as will be seen in Section 9.1, has a sizeable effect on the structure of the network of FP7 participation with the large academic (e.g. University College London, Université Paris VI) and research organisations (e.g. Centre national de la recherche scientifique [CNRS] and the Max Planck Institutes) being centrally located, and with the majority of firms (and SMEs) being located at the periphery of the network.

Figure 10 Distribution of the number of projects in which organisations participated per sector: comparison between FP6 and FP7



Source: Computed by Science-Metrix using CORDA (European Commission) data

Additional data on framework programme participation broken down by programme, specific programme, thematic area, as well as broad area are shown in Table XXI. From FP6 to FP7, the share of participations by SMEs increased from nearly 13% to about 18%. In Capacities, SMEs make up nearly a third of all participating organisations. This is, in part, due to the inclusion of the broad area Research for the benefit of SMEs, in which SMEs account for 58% of participations. Under Cooperation, it is noteworthy that SMEs account for the largest share of all participations in industry-driven sectors such as Nanosciences, Joint Technology Initiatives and Security.

Survey results add nuance to the findings regarding the participation of the private sector. The majority of survey respondents indicated that large businesses enterprises or SMEs only make up a 0–5% share of their project partners. This is not surprising since private firms (including SMEs) do not tend to collaborate with each other, as was shown above in Section 8.1.2. They rather tend to collaborate on a one-to-one basis, and frequently with the higher education sector. Despite this, the integration of SMEs and large business firms into European research networks does seem to be improving. The survey responses also show that among the new FP7 project partners more are SMEs or large businesses than is the case for partners that participants previously collaborated with under FP6 or outside the context of FP6 or FP7. These improvements suggest that the emphasis on cross-sector collaborations under FP7 has already had some effect.

Table XXI Share of participations by sector for FP6 and FP7 as well as for the specific programmes, thematic areas and broad areas of FP7

	Total Participations	HES	REC	PUB & OTH	SMEs	PRC (other than SMEs)	UND
FP6 (overall)	70,096	34.9%	26.0%	14.5%	12.7%	10.8%	1.2%
FP6 excluding Marie Curie Actions	61,867	30.9%	25.8%	16.3%	14.1%	11.9%	1.2%
FP7 (overall)	115,954	37.5%	25.3%	7.5%	17.9%	11.9%	N/A
FP7 excluding People and Ideas	93,845	31.0%	25.6%	8.6%	21.0%	13.8%	N/A
COOPERATION	76,519	32.8%	25.3%	4.0%	18.8%	15.8%	3.3%
Energy	3,784	23.4%	24.0%	4.5%	17.9%	26.3%	4.0%
Environment (including Climate Change)	6,192	35.2%	36.8%	6.7%	13.7%	4.0%	3.5%
Food, Agriculture, and Biotechnology	6,417	35.6%	31.7%	4.2%	19.2%	5.7%	3.7%
General Activities (Annex IV)	8	25.0%	62.5%	N/A	N/A	N/A	12.5%
Health	10,661	48.2%	25.6%	4.4%	15.7%	3.2%	2.9%
Information and Communication Technologies	19,466	35.1%	21.5%	3.3%	18.1%	18.8%	3.1%
Joint Technology Initiatives (Annex IV-SP1)	4,627	23.4%	19.6%	1.4%	22.1%	31.6%	1.9%
Nanosciences, nanotech., mat. & new prod. tech.	9,457	26.2%	24.5%	1.1%	28.1%	17.0%	3.1%
Security	2,792	19.9%	23.6%	10.5%	21.6%	20.4%	4.0%
Socio-economic sciences and Humanities	2,218	59.3%	26.6%	4.9%	3.6%	1.2%	4.4%
Space	2,389	23.2%	38.0%	6.2%	18.3%	12.2%	2.1%
Transport (including Aeronautics)	8,508	20.8%	21.7%	4.0%	19.5%	29.3%	4.8%
CAPACITIES	17,326	23.2%	27.0%	7.2%	30.3%	5.2%	7.2%
Activities of International Cooperation	1,266	18.7%	37.4%	24.4%	6.9%	2.9%	9.6%
Coherent development of research policies	128	9.4%	20.3%	45.3%	10.2%	1.6%	13.3%
Regions of Knowledge	954	17.5%	14.4%	21.1%	17.0%	11.9%	18.1%
Research for the benefit of SMEs	8,024	11.3%	16.3%	1.8%	58.0%	6.7%	5.9%
Research Infrastructures	5,115	36.4%	44.6%	7.5%	4.5%	2.8%	4.2%
Research Potential	294	45.9%	43.9%	6.5%	1.4%	0.7%	1.7%
Science in Society	1,545	45.2%	21.2%	8.4%	6.1%	4.1%	15.1%
PEOPLE	17,659	63.1%	23.0%	1.7%	6.1%	4.5%	1.6%
IDEAS	4,450	71.8%	26.9%	0.3%	0.4%	0.6%	0.1%

Note: HES = Higher education sector; REC = Research organisations; PUB = Public body; PRC = Private; OTH = Others; UND = Undefined.

Source: Computed by Science-Metrix using CORDA (European Commission) data

8.2.2 SMEs and innovation

Finding 20 The integration of business enterprises, including SMEs, in intersectoral partnerships fosters innovation

The effect of the number of sectors on the production of positive outputs/outcomes (including innovation) in a given project raises an important question: Perhaps the type of intersectoral collaboration matters more than the absolute number of sectors involved on a project towards producing positive outputs/outcomes? As previously noted, one key objective of framework programmes is improving the competitiveness of national economies throughout Europe and, as such, there was a strong focus on the integration of SMEs in FP7. It therefore seems plausible that the integration of business enterprises in particular might have had a positive and significant effect on the production of desirable outputs/outcomes as specified in the logic model of FP7 (see Figure 2).

To address this question, the composite indicator of positive outputs/outcomes emanating from FP7 was again used to investigate differences in the performance of projects in the presence and absence of SMEs (and private firms generally).

Whereas the presence of SMEs in a project appears to significantly improve the resulting outcomes for People, it does not appear to influence the resulting outcomes under Cooperation and impairs outcomes significantly under Capacities (Table XXII; the same finding holds true for business enterprises generally, data not shown).

This latter result is rather surprising, especially since the Capacities specific programme includes the Research for the Benefit of SMEs broad area, which aims 'to strengthen the innovation capacity of SMEs in Europe and their contribution to the development of new technology based products and markets'. However, projects scoring well based on the composite measure are more likely those having produced a balanced set of outputs/outcomes, which might not be the goal of projects involving SMEs as these projects are more likely to focus on bridging the gap between research and innovation to produce new marketable inventions. If instead of comparing the composite indicator between projects with and without SMEs, one looks at the performance of both groups of projects across individual sets of outputs/outcomes related to innovation in the business sector, the findings are strikingly different.

Table XXII Performance, as measured with a composite measure of positive outputs/outcomes, of FP7 projects involving or not SMEs, by specific programme

	Cooperation		Capacities		People	
Descriptive Stats	**Absence**	**Presence**	**Absence**	**Presence**	**Absence**	**Presence**
N of Cases	128	372	45	66	172	37
Minimum	14.0	12.0	18.5	14.7	11.0	19.6
Maximum	57.2	64.5	62.0	72.0	75.7	41.8
Median	31.3	31.4	35.6	29.3	26.2	29.6
Arithmetic Mean	31.9	31.6	37.1	31.0	28.3	30.4
Mean Rank Sum*	249	251	70	46	101	126
Standard Deviation	8.3	7.1	9.6	10.0	9.6	5.4
Variance	69.3	50.3	91.6	100.8	92.2	29.5

Note: * There are statistically significant differences between groups for Capacities (p = 0.00) and People (p = 0.00); tested using a Kruskal-Wallis test. The test could not be performed for Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Knowledge transfer from research to market (Table XXIII) and the propensity of projects to introduce innovation in the form of new products or processes (Table XXIV) are both significantly increased in the presence of SMEs in all specific programmes (again, the same findings hold true for private firms generally, data not shown). This reinforces the idea that the specificities of specific programmes as well as of their underlying thematic areas, broad areas or calls must be taken into account to adequately identify optimal values towards achieving the proper balance in network team composition.

Table XXIII Extent to which FP7 projects involving or not SMEs enhanced knowledge transfer from research to the market, by specific programme

	Cooperation		Capacities		People	
Descriptive Stats	**Absence**	**Presence**	**Absence**	**Presence**	**Absence**	**Presence**
N of Cases	126	486	40	125	157	35
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	4.0	4.0	4.0	4.0	4.0	4.0
Median	2.0	2.0	2.0	3.0	2.0	2.0
Arithmetic Mean	2.1	2.4	2.2	2.5	2.0	2.3
Mean Rank Sum*	258	319	69	87	92	117
Standard Deviation	0.9	0.8	0.9	0.9	0.8	0.9
Variance	0.8	0.7	0.7	0.7	0.7	0.8

Note: Statistically significant differences are observed for all specific programmes (p = 0.00 for Cooperation; p = 0.02 for Capacities; and p = 0.01 for People); tested using a Kruskal-Wallis test. The test could not be performed for Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Table XXIV Differences in the propensity of FP7 projects involving or not SMEs to introduce innovation (i.e. new products or processes), by specific programme

	Cooperation			Capacities			People		
	No innovation	Innovation(s) triggered	N	No innovation	Innovation(s) triggered	N	No innovation	Innovation(s) triggered	N
No SMEs	1.32	0.90	582	1.26	0.85	147	1.06	0.67	301
SMEs	0.64	1.11	520	0.77	1.12	171	0.84	1.89	113
N	252	850	1,102	113	205	318	352	62	414

Note: Significant departures from expectations are observed for all groups (green = above expectations; red = below expectations); tested using a Chi-Square Test for two independent samples. The test could not be performed for Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

These findings are important in terms of setting expectations. While the expectations of EU and EC policymakers place innovation and competitiveness very high in the scale of positive achievements, and this is also a positive achievement for business enterprises, an even more positive outcome for a university programme participant might be to present the results of research at a conference, and to publish papers in peer-reviewed journals. As such, the balance of power and the mix of partners may tilt projects towards greater scientific achievements (such as publishing papers) or towards more marketable outcomes and innovations. The data presented in the present section suggests that not all projects are aligned; if they were, the composite indicator and the analysis of transfer to market and innovation would be more broadly aligned.

8.3 Is there an ideal number of sectors in collaboration projects?

Finding 21 There is no clear evidence suggesting that there is an ideal number of sectors in a project to achieve the outcomes sought in FP7

Finding 22 There is a lack of evidence to claim that increased intersectorality lends the positive outcomes sought in FP7

Finding 23 Extensive intersectoral linkages may have an adverse effect on innovation

Finding 24 Largely multisectoral projects can bring specific management challenges

To investigate the extent to which the bridges that have been successfully established by FP7—by connecting organisations from different activity sectors on common projects—really fosters innovation, the following question was addressed: Does the number of sectors involved on a given FP7 project relate positively to innovation and other positive outputs/outcomes?

The performance of FP7 projects was measured through the construction of a composite indicator synthesising the positive outputs/outcomes measured with bibliometric indicators and the survey. This subsequently allowed for studying differences in the performance of projects according to the number of sectors to see whether or not an optimal size exists with respect to these dimensions. The construction of the composite indicator is presented in Section 6.3.

There does not appear to be a turning point related to the number of sectors involved in a project where the benefits of adding more sectors either increase or decrease. In other words, there is a lack of evidence to claim that increased intersectorality lends the positive outcomes sought in FP7. For People, the composite performance of projects appears to increase when moving from a project with a single sector to projects involving at least two sectors. For Cooperation and Capacities, there are no significant differences across groups (Table XXV), yet in Cooperation greater scores are achieved for greater multisectoral diversity (see Mean Rank Sum).

Table XXV Performance, as measured with a composite measure of positive outcomes, of FP7 projects across networks of varying number of sectors involved

	Cooperation			Capacities			People		
Descriptive Stats	**(1-2)**	**(3)**	**(4-5)**	**(1-2)**	**(3)**	**(4-5)**	**(1)**	**(2)**	**(3-5)**
N of Cases	58	297	145	26	50	35	140	28	41
Minimum	13.6	12.0	14.0	18.5	14.7	18.7	11.0	19.8	12.4
Maximum	47.0	64.5	47.4	62.0	72.0	64.7	75.7	65.3	41.8
Median	31.1	31.0	32.3	34.5	31.1	35.5	26.0	28.6	30.1
Arithmetic Mean	31.0	31.6	32.1	34.7	31.5	35.3	27.7	31.7	29.9
Mean Rank Sum*	240	246	264	59	50	63	97	122	122
Standard Deviation	7.7	7.6	6.9	11.2	9.7	10.1	9.3	10.2	6.5
Variance	60.0	57.7	48.1	125.1	94.1	102.4	86.5	104.3	41.9

Note: * Statistically significant differences across groups are observed for People (p = 0.02); tested using a Kruskal-Wallis test. The test could not be performed for Ideas. The range of size (i.e. number of sectors) by group is indicated in the column headers in parentheses.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Additional regression analyses were performed (i.e. one regression per output/outcome) to verify whether or not the intersectoral partnerships promoted by FP7 exert a positive and statistically significant effect on innovation and other positive outputs/outcomes as specified in the logic model of FP7 (Figure 2). Refer to Section 6.3 for a list of the outputs/outcomes that were considered in the regression analyses (i.e. they are those considered in the composite indicator of positive outputs/outcomes). The regression model that has been implemented incorporates—as explanatory variables—numerous networking dimensions beyond the sectoral facet (e.g. number of participants) as well as numerous controls such as the project budget (refer to the accompanying methodological annex for details on the regression analysis).

The regression, as seen in Table XXVI, showed that crossing too many sectoral boundaries between cooperation partners decreases to a slight degree

- the number of types of S&T knowledge produced as part of a project (or the breadth of knowledge output);
- the number of types of S&T tools created as part of a project (or the breadth of S&T tools created);
- the transfer of research results to the business sector and society; and
- the triggering of innovations.

These results hold true not only for the Capacities and Cooperation specific programmes but also for Ideas and People.

Table XXVI Relationship between the extent of intersectoral linkages and positive project outcomes under the Cooperation and Capacities specific programmes

Explanatory Variables	**Breadth Knowledge**	**Breadth Tools**	**Transfer of Research Results**	**Effects on Careers**		**Innovations triggered**
Extent of intersectorial linkages	-0.100 *	-0.168 **	-0.083 **	-0.048		-0.341 ***
	(0.059)	*(0.078)*	*(0.034)*	*(0.057)*		*(0.109)*
		All other independent and control variables				
R-sq-adj	**0.165**	**0.183**	**0.091**	**0.12**	**[Pseudo]**	**0.116**
N	**732**	**732**	**681**	**732**		**732**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All models are statistically significant at $p \leq 0.01$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Case study evidence reveals that largely multisectoral projects can bring specific management challenges. The Self Optimising Measuring Machine Tools (SOMMACT) project incorporated participants from five sectors (large private business, SME, university, public body and research organisations). These different institutions all had differing expectations as to the benefits they could gain from the consortium. For example, SMEs saw the possibility of selling new products, academics saw an opportunity for advanced research, while the larger business enterprises sought to promote the project activities to their members. Such diverging interests had the potential to become an obstacle to the overall success of the project but were not. According to interviewees, this was due to the prioritisation of balanced expectations, with an emphasis on synergies rather than competing interests. Interviewees from the SOMMACT case also stated that the large number of partners presented a minor challenge at project end. While the project succeeded in bridging different sectors and competencies, it was suggested by project participants that it would have been easier to disseminate a clear and uniform message if fewer partners had been involved in the dissemination and outreach activities.

Thus, though the quantitative evidence suggests that more multisectoral projects yield greater positive outcomes and innovation, it remains that partners should not be added for the sake of getting large. The case study evidence points to the role played by having a unique purpose, a shared vision and common interest in a project’s success, but that aligning those was possible with purposeful project management.

9 STRUCTURAL HOLES AND THE BENEFICIARIES OF CURRENT NETWORK STRUCTURE (SQ4)

Project terms of reference: Based on the assumption that research collaboration is the core idea of ERA bringing competitive advantage: where are the structural holes (missing links) in the structure of the FP network, and who benefits from them? Hypothesis: By identifying and bridging structural holes ERA will be more integrated and EU research more competitive.

Structural holes are areas of a network where the actors have few links between them or no link at all (i.e. an area with few ties). In the network structure literature, structural holes are subject to opposing views. On the one hand, authors have made the case that actors in open social structures with many structural holes can take advantage of 'bridges' to connect with new members in different clusters, allowing access to new information that will benefit performance (Burt, 1992). For example, Burt (2004) finds that higher compensations, positive performance evaluations or promotions are disproportionately in the hands of managers whose networks are rich in structural holes. A contrasting perspective is one of closed networks: actors in tighter embedded networks obtain more coordination, trust each other and develop better communication skills, which lead to superior results overall (Coleman, 1988).

Two hypotheses were tested by Ajuha (2000): the more structural holes spanned by a firm, the [a) more] or [b) less] the firm's subsequent innovation output. His data support Coleman's position that having many structural holes is associated with reduced innovation output. However, Ajhua also concludes that whether structural holes are good, bad or irrelevant is liable to be a function of the context. When developing a collaborative milieu and overcoming opportunism are essential to success, closed networks are likely to be more beneficial. When speedy access to diverse information is essential, structural holes are likely to be advantageous (Ahuja, 2000).

In defining the terms of reference of this project, the EC followed the assumption that by bridging structural holes the ERA will be more integrated and EU research more competitive. Pushing the concept of a more integrated and innovative ERA further, the positive effects of network density are well documented in the literature. For example, network density has been shown to ease knowledge transfer, above and beyond the positive effects of strong interpersonal connections (Reagans & McEvily, 2003). It has been suggested that greater network density, combined with a larger set of ties, can increase one's ability to generate novel knowledge because density facilitates trust among network participants, increasing their willingness to share valuable knowledge (Gonzalez-Brambila & Veloso, 2013). A dense network of direct and indirect ties also helps build a reputation mechanism and coalitions to constrain opportunism (Gilsing & Nooteboom, 2008).

The collected evidence indicates that, in general, the co-participation networks of framework programmes (FP6 and FP7) are characterised by a core-periphery structure whereby a minority of actors are centrally located (i.e. universities and research organisations) benefiting from the structural holes between the less central/peripheral actors (i.e. firms, including SMEs, and public bodies).

There is support in the literature for this observation. For instance, it is the universities and research organisations (not the private sector) who are often acknowledged as constituting the 'backbone' or 'building blocks' of framework programme research collaboration networks and as prominent figures in the ERA (Cassi, Corrocher, Malerba & Vonortas, 2008a). In an analysis of the 'Life sciences, genomics and biotechnology for health' network of FP6, the authors found that the network was made up of a dense core of government research organisations and universities, which acted as hubs that helped to bring new partners (primarily firms and non-profit organisations) into the network (Ortega & Aguillo, 2010). Similarly, the existence of a stable core of interlinked actors consisting mainly of universities and research organisations has been repeatedly observed, as there has been 'significant overlap in participants for consecutive FPs' and 'recurring collaboration amongst the same organisations within FPs' (Roediger-Schluga & Barber, 2007).

Complementing these findings there is some indication in this study that entities that are centrally located within the networks could accrue benefits, but likewise could provide benefits to members of the networks who do not have the substantial means and accumulated knowledge of the large structural bridges.

For example, Gilsing et al. (2008) found that highly central organisations enjoy the strongest improvements of their explorative innovation performance and this effect declines steadily when centrality decreases. Peripheral positions show the least performance, although such positions can be attractive when cooperating with partners at a very large technological distance. In other words, success rates for exploration are not spread equally across network positions (Gilsing & Nooteboom, 2008). Similarly, with regard to position in the network, Gonzalez-Brambila et al. (2013) find that paper outputs seem to be most helped by non-dense networks and by being a central player. However, high impact can be achieved through more and frequent collaborations and environments rich in structural holes.

In the literature, there is a set of views that confers great value to the identification of the 'most important' actors; that is, those in a strategic location with many close relationships. The idea is that these actors have advantages because they can access and transmit new information sooner than actors on the periphery (Freeman, 1982; Wasserman & Faust, 1994).

Based on the EC assumption that fewer structural holes equates to better integration, the co-participation networks of framework programmes are fairly unequally balanced across actors with ample room for improvements in the integration of the peripheral players (i.e. firms, including SMEs, and public bodies). In fact, project participants responded that they would like to see more cooperation with these sectors more frequently than with universities and research organisations. Yet the collected evidence also indicates that, in general, the framework programme did not fill structural holes from FP6 to FP7 at the national level. On the other hand, some countries from Eastern Europe increased their level of attractiveness in FP7 relative to FP6. Additionally, while the number of participating organisations increased in FP7 relative to FP6, the network density was somewhat maintained, indicating an appreciable increase in the number of ties. At the regional and national levels, density increased while keeping constant the number of actors to maximise comparability across framework programmes; otherwise, one would have expected, as is the case with organisations, to observe a decrease in density even in the presence of a densification of the core of the networks. Such an approach was not feasible at the organisational level.

9.1 Network structure

Finding 25	The FP6 and FP7 networks are characterised by a core-periphery structure at the organisational, regional and national levels

Finding 26	Universities and research organisations derive an advantage from being centrally located in the co-participation network of framework programmes (FP6 and FP7)

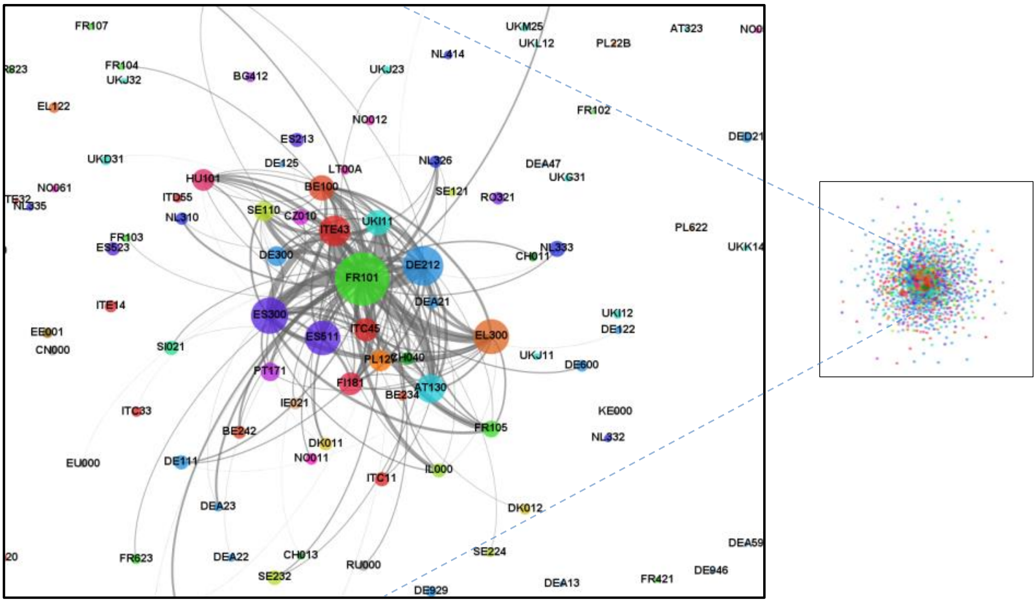
Finding 27	At the regional and national levels, density increased from FP6 to FP7 while keeping constant the number of actors; otherwise, one would have expected, as is the case with organisations, to observe a decrease in density even in the presence of a densification of the core of the networks

Finding 28	As a consequence of an increased number of participating organisations in FP7 relative to FP6, the network density dropped by 25% despite an increased amount of co-participations

For all levels of analysis—organisational, regional, and national—and for all programmes (i.e. FP6, FP7, Cooperation, Capacities, People and Ideas), networks are characterised by a core-periphery structure. This structure can be detected through a visual inspection of a collaboration network, whereby a few influential actors (i.e. hubs) located at the centre of the graphic representation establish strong ties between themselves and weaker connections with the periphery where the density of ties—and consequently the flow of knowledge—is reduced between the peripheral players. This means that actors are unequally represented in the network, some of them participating in a large number of projects (i.e. the central players or hubs) while others are participating rather infrequently. Figure 11 and Figure 12 illustrate this at the NUTS 3 regional level for FP6 and FP7, respectively; note that similar structures are observed for the other levels of analysis (i.e. local and national) as well as for the specific programmes of FP7.

This type of structure can also be detected using various network statistics. In this regard, the betweenness centrality of actors (i.e. organisations, NUTS 3 regions or countries) is highly informative as it reflects the number of shortest paths from all actors to all others that pass through a given actor normalised by the total number of shortest paths in a network. In other words, the higher the number of shortest paths on which an actor appears, the higher its centrality in the network as it falls between all others to the greatest extent.

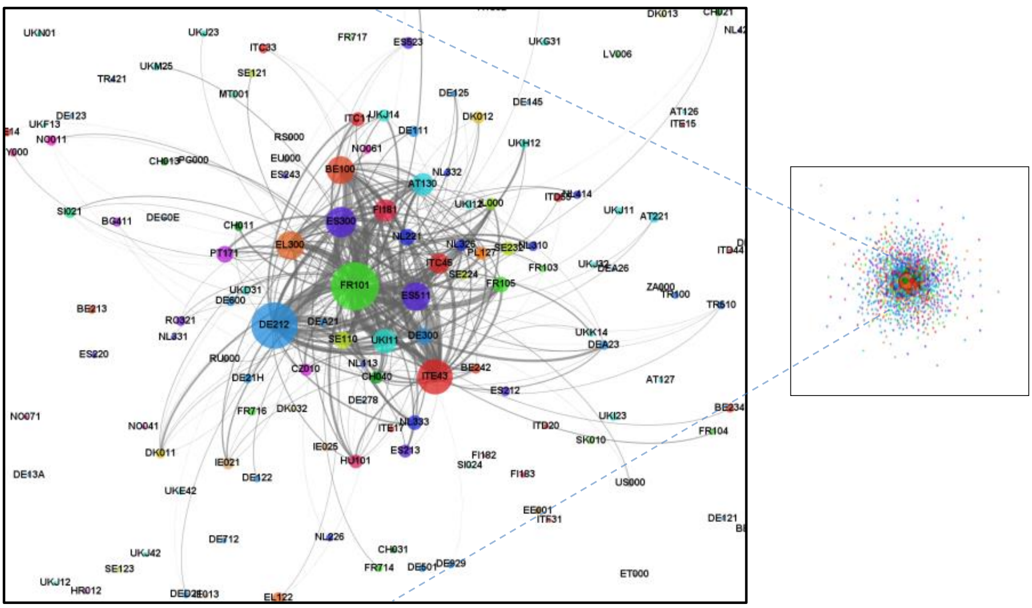
Figure 11 Overall FP6 network at the NUTS 3 level



Note: Ties representing at least one hundred collaborations are shown. The NUTS 3 network is shown as a representative example of the structure of all three levels of analysis (i.e. local, regional and national).

Source: Computed by Science-Metrix using CORDA (European Commission) data

Figure 12 Overall FP7 network at the NUTS 3 level



Note: Ties representing at least one hundred collaborations are shown. The NUTS 3 network is shown as a representative example of the structure of all three levels of analysis (i.e. local, regional and national).

Source: Computed by Science-Metrix using CORDA (European Commission) data

In a core-periphery structure, central actors—those with high centrality scores—are therefore crucial to the network structure, as knowledge exchange in between peripheral actors—those with low centrality scores—must often flow through them.

Thus, by looking at the distribution of betweenness centrality scores, one can appreciate the extent to which a network is characterised by a core-periphery structure. Table XXVII shows this distribution for FP6, FP7 and each of FP7's specific programmes, as well as for each level of analysis (i.e. local, regional and national).

The Gini coefficient of the betweenness centrality scores is shown for each network in Table XXVII to indicate whether the underlying distribution of the scores across actors is uniform (i.e. projects having relatively similar scores) or non-uniform (i.e. a few projects having large scores with the remaining majority of projects having relatively small scores) as would be expected for a core-periphery structure. The Gini coefficient of any distribution ranges from 0 indicating that all scores are equal, in which case the score of each actor is equal to the average centrality across actors, to 1 indicating that one actor is highly central with all ties between any two actors in the network including this highly central player (extreme case of core-periphery structure). As can be seen in Table XXVII the Gini coefficient of all networks examined ranges from 0.82 to 0.98 indicating that all networks are characterised by a highly uneven distribution of centrality scores typical of core-periphery structures. For instance, the level of inequality between actors is similar between FP6 and FP7 networks for all levels of analysis (see the Gini coefficients in Table XXVII).

It is worth nothing that the density of the co-participation network, which measures how well the actors of a network are interconnected, declined slightly from FP6 to FP7 at the organisational level (Table XXVII). This is not unexpected since the number of actors (i.e. organisations) increased by an appreciable margin in FP7 making it difficult for any set of actors to maintain density. Indeed, since the number of possible ties increases much faster than the number of actors in a network, it is usually difficult to maintain density—that is, the number of actual ties over the total possible number of ties—when the number of actors increases. Despite this slight decrease in density, it is worth noting that the actual number of partnerships increased by an appreciable margin in FP7 relative to FP6.

Table XXVII Distribution of normalised betweenness centrality scores of countries, regions (NUTS 3) and organisations in the co-participation networks of various programmes along various network statistics

		FP6	FP7	Cooperation	Capacities	People	Ideas
		Country level					
Nodes*		183	183	183	183	183	183
Edges		4,159	4,827	4,149	2,991	782	131
No Connected Components		28	7	18	45	119	142
Density*		0.2497	0.2899	0.2491	0.1796	0.0470	0.0079
Modularity		0.052	0.048	0.042	0.068	0.025	0.092
Clustering Coef	Avg.	0.684	0.776	0.725	0.637	0.325	0.135
	Gini	0.247	0.145	0.203	0.323	0.649	0.854
Betweeness Centrality	Avg.	0.00264	0.00360	0.00320	0.00219	0.00048	0.00031
	Gini	0.831	0.816	0.825	0.888	0.903	0.969
		NUTS 3 level					
Nodes*		1,472	1,472	1,472	1,472	1,472	1,472
Edges		101,141	110,779	95,411	35,991	15,146	581
No Connected Components		175	78	178	394	761	1,255
Density*		0.0934	0.1023	0.0881	0.0332	0.0140	0.0005
Modularity		0.078	0.072	0.080	0.142	0.146	0.476
Clustering Coef	Avg.	0.648	0.697	0.656	0.510	0.320	0.049
	Gini	0.242	0.179	0.242	0.400	0.624	0.937
Betweeness Centrality	Avg.	0.00049	0.00057	0.00048	0.00040	0.00020	0.00003
	Gini	0.891	0.891	0.903	0.924	0.930	0.975
		Organisation level					
Nodes*		20,794	26,014	19,873	8,013	3,391	664
Edges		458,427	525,702	426,240	94,562	28,576	781
No Connected Components		184	213	57	68	381	254
Density*		0.0021	0.0016	0.0022	0.0029	0.0050	0.0035
Modularity		0.435	0.400	0.410	0.564	0.404	0.701
Clustering Coef	Avg.	0.832	0.806	0.808	0.859	0.677	0.192
	Gini	0.152	0.170	0.167	0.130	0.302	0.785
Betweeness Centrality	Avg.	0.00009	0.00007	0.00009	0.00026	0.00045	0.00170
	Gini	0.972	0.974	0.972	0.962	0.937	0.897

Note: When comparing individual FP7 specific programmes, a higher density is observed for People and Ideas compared to Capacities and Cooperation at the organisational level. This can be explained by the fact that organisations participating on a recurring basis (i.e. large universities and research organisations situated in the core of the network) are more frequent in the former two specific programmes (as seen earlier in Table XXI). A higher proportion of recurring participants generally improve the overall connectivity of a network by increasing its density.

* The number of actors at the national and regional levels was artificially kept constant to maintain the comparability of the network density across framework programmes and specific programmes. Thus, note that the actual number of actors at these levels of analysis might diverge from the numbers displayed in the table. This was not feasible at the organisational level since organisations are more prone to structural changes (e.g. merger, acquisition, re-branding, and bankruptcy).

Source: Computed by Science-Metrix using CORDA (European Commission) data

Compared to organisations, regions (NUTS 3) and countries are less prone to structural changes (e.g. merger, acquisition, re-branding, and bankruptcy) and their existence is less ephemeral. As such, when analysing density at these aggregation levels, it makes sense, to some extent, to consider that the networks include all actors who could have participated in either FP6 or FP7 even if they did not. In that case, they can therefore be regarded as isolates in the networks. That is, they do not contribute to any linkages in the networks. This approach allows an appreciation of the increased level of partnerships in FP7 since the networks being compared are of the same size and are thus more amenable to an analysis of change in network density over time—that is, the theoretical maximum number of ties is the same in each network since the number of actors (regions or countries) is held constant across FP6 and FP7. The number of actors was set to the pooled set of actors in FP6 and FP7. Thus, note that the actual number of countries/regions that indeed participated in either FP6 or FP7 might diverge from the numbers displayed in Table XXVII. Additionally, it must be pointed out that the framework programmes aim at realising the ERA. Consequently, the core of the co-participation network of any edition of the framework programme is expected to comprise ERA Associated Countries (mostly European countries) at the national level and most of the participations are from those countries. Thus, the expansion in the number of actors between framework programmes at the national level mostly comes from the addition of non-ERA countries with low levels of participation (note that this is not the case at the organisational level). In other words, new actors are added, but they contribute very few ties to the network structure relative to the increase in the theoretical maximum number of ties that result from their inclusion. It results that a reduction in density would be almost inevitable in spite of an increased number of ties in the core of the network if the size of the networks being compared is not held constant. Using this approach, the density increased at the regional (NUTS 3) and national levels indicating that the number of ties increased from FP6 to FP7.

9.2 Structural holes/bridges

Finding 29	Structural holes mostly exist between peripheral actors (i.e. the private sector, including SMES, and public bodies) where direct links between actors are missing

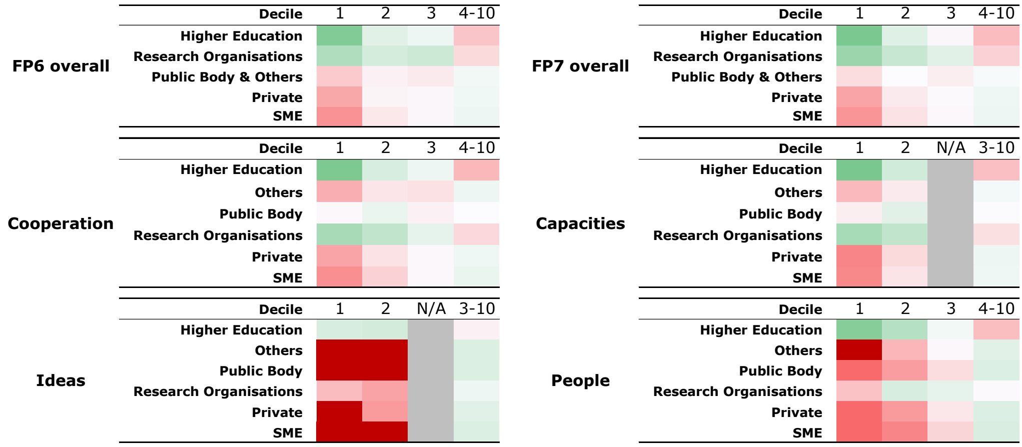
Networks with a core-periphery structure, such as those described above, are characterised by the presence of multiple structural holes between peripheral actors (low betweenness centrality) where the lack or sporadic presence of ties hampers the direct circulation of knowledge. According to the scientific literature (see above introduction of Section 9) centrally located players (high betweenness centrality) derive an advantage from the presence of structural holes in networks with a marked core-periphery structure because the exchange of knowledge between peripheral actors often has to travel through them. In other words, actors occupying this key position can bridge over structural holes and potentially control the information flow to their advantage, as they have a privileged access to knowledge. However, actors are usually found in this position for a reason. For instance, they are often involved in a considerable number of projects by virtue of their size (note that Section 11.1.2 later investigates the integration of actors using a method that partly removes the effect of the sheer size of actors).

The benefit of being a central player was exemplified by two case studies (Climate for Culture and Good Practice in Traditional Chinese Medicine [GP-TCM]). In the former case, researchers at the network core held a comprehensive understanding of the entire project, instead of only dealing with individual project components as was the case for peripheral partners. In the latter, partners at the core of the project's network exerted more influence on how the project was managed than those at the periphery.

At the local level—that is, at the level of organisations—the betweenness centrality of actors can be used to identify the types of organisations (i.e. universities, research organisations, public bodies, private firms [including SMEs]) between which structural holes exists (i.e. between the peripheral actors) as well as to identify the types of organisations that derive a benefit from those structural holes (i.e. the central actors bridging the structural holes).

This was first done by establishing bins—for each network—corresponding to deciles of the distribution of the centrality scores of all organisations regardless of their sector; the first decile corresponds to the 10% highest scores and the 10th decile corresponds to the 10% lowest scores. Due to equalities in the scores across some bins, some of them were grouped together. For example, deciles 4 to 10 were merged together. Assuming a uniform distribution of centrality scores across sectors (i.e. universities, research organisations, public bodies, private firms [including SMEs]), 10% of the organisations in each sector would be expected to fall in each decile (or 60% if deciles 4 to 10 are merged). For a given sector, a positive departure (highlighted in green in Figure 13) from expectation in the deciles corresponding to low betweenness scores, combined with a negative departure (highlighted in red in Figure 13) in the deciles corresponding to the high betweenness scores, would therefore be indicative that organisations in this sector are often surrounded by structural holes. The opposite pattern would be that organisations in the corresponding sector are often those deriving an advantage from structural holes.

Figure 13 Heat map of expected to observed ratio of the number of organisations in betweenness centrality bins (deciles) as an indicator of dominance in co-participation networks



Note: The lower the decile numbering, the higher the betweenness scores. Scores in the table (i.e. ratio of observed to expected proportion of organisations from a given sector in a given decile) are coloured according to the extent of departure from expectation (red = negative departure and green = positive departure; grey = merged with next deciles). Deciles containing low betweenness centrality values (4–10 or 3–10 in the cases of Capacities and Ideas) were merged together.

Source: Computed by Science-Metrix using CORDA (European Commission) data

The analysis shows that the key sectors in terms of position within the co-participation network of the framework programmes remained largely unchanged from FP6 to FP7 (Figure 13). In both framework programmes, participants from the higher education and research organisations sectors were mostly found in the bins corresponding to the largest values of the distribution of betweenness centrality scores (i.e. deciles 1 and 2) and appeared less frequently than expected in the bins corresponding to the smallest scores (i.e. deciles 4–10). They are therefore the sectors that derive an advantage from the presence of structural holes in the networks. Broadly speaking, the opposite pattern is observed for the private sector (Business Enterprise), including SMEs, and to a lesser extent for the Public Body & Others sector. This indicates that organisations in these sectors are surrounded by structural holes and are therefore in a less privileged position compared to the higher education sector or research organisations when requiring access to information from various parts of the network. Similar findings are observed for Cooperation and Capacities. For Ideas and People, it is mostly the higher education sector that benefits from the presence of structural holes with the remaining sectors being mostly affected by the presence of structural holes to various degrees.

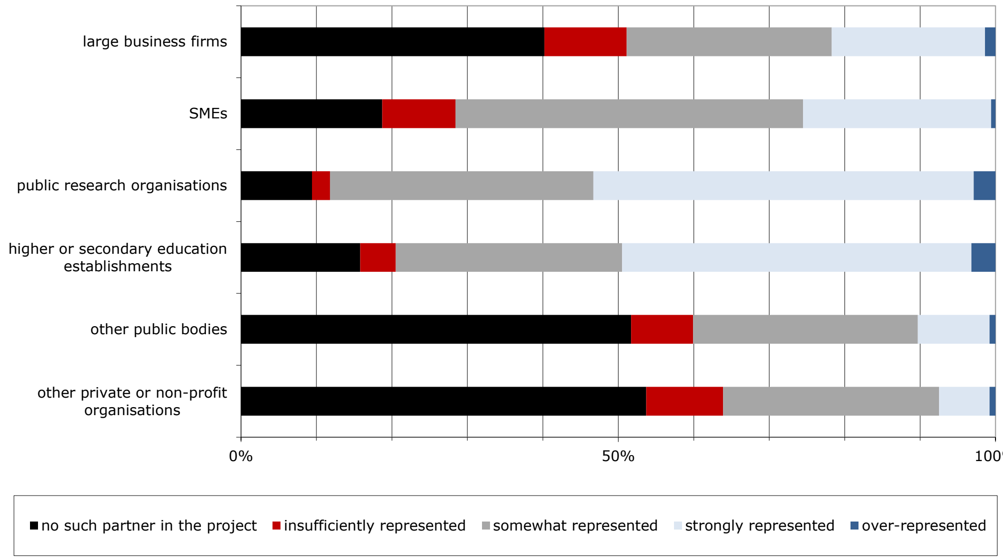
It is noteworthy that although organisations from the private sector dominate the network in terms of their share of the total number of unique/distinct participants (i.e. 65%, of which 69% are SMEs, see Figure 9), they were largely underrepresented within the 10% most central organisations in the network (i.e. decile 1). This is true in all specific programmes and most thematic areas. This is explained by the fact that private firms, although very common among participants, took part in comparatively fewer projects, whereas higher education and research organisations took part in multiple projects (see Figure 10). This participation in multiple projects necessarily translates into more co-participation and better overall integration within the network (higher betweenness centrality).

This is in line with findings in the literature, which indicate that business enterprises traditionally prefer to have exclusivity in a market and either protect with a patent or keep their recipe as secret as possible. In other words, firms do not want to cooperate much, at least compared to universities and other public organisations. However, this may be changing. Cooperation in R&D, or more generally in innovation activities, is often pursued by firms to benefit from complementarities, to reduce risk or to save costs, to internalise knowledge spillovers, and to increase their standing (Mairesse, 2010; Archambault & Larivière, 2011).

The success of the innovation activities of firms partially depends on integration of new knowledge in the innovation process. Part of this knowledge reaches firms from external sources. Importantly, firms that rate available external information sources as more important inputs to their innovation process often engage in R&D collaborations (Cassiman & Veugelers, 2006). Yet these collaborations can involve various types of partners: competitors, suppliers, clients or customers, commercial labs, higher education institutions, government or public research institutions. The choice of the partner often affects the outcomes of innovation activities. For instance, R&D collaborations with customers or suppliers tend to focus on incremental innovations, whereas cooperation with universities is instrumental in producing more radical innovations (Mairesse, 2010; Tether, 2002).

Thus, there may be an impetus for increasing cooperation with and amongst the private sector. Interesting findings from the survey also support this notion. Respondents were asked to rank underrepresented sectors and the perception was that large business firms were most underrepresented in the consortiums (11%), followed by other private or non-profit organisations, (10%), SMEs (9%) and other public bodies (8%) (Figure 14).

Figure 14 Degree of representation of partners (by organisational type) in FP7 consortiums as perceived by survey participants



Source: Analysis of survey results, calculations by Fraunhofer ISI

Similarly, if they were to start their project anew, the highest share of respondents indicated that they would prefer to integrate a larger number of SMEs (27%), followed by those favouring the stronger participation of large business enterprises (17%), 'other public bodies' or 'other private or non-profit organisations' (15% each). While this gives an indication of where structural holes may exist, one also has to take into account that on average around half of the respondents stated they would include the same number of sector partners if they were to start their research project again, thus suggesting that structural holes are not perceived as a critical problem.

One of the hypotheses of the terms of reference of the present study is that by identifying and bridging structural holes, the ERA will be more integrated and EU research more competitive as the benefits of being centrally located would be spread more evenly across actors (see project terms of reference, start of Section 9). In Section 11.1.2—which studies changes in the integration of countries across framework programmes—multiple analyses have been performed to assess whether structural holes in the co-participation network of FP6 have been filled in the co-participation network of FP7. The main finding is that the framework programme did not generally fill structural holes, though a number of the smaller European countries are more integrated in FP7 than they were in FP6 (e.g. the former Yugoslav Republic of Macedonia, Serbia, Croatia, and Bosnia and Herzegovina).

Whether EU research as a whole would become more competitive if structural holes between the more peripheral areas of the ERA networks were filled is a question that warrants further exploration. While, indeed, the scientific output would likely be more evenly distributed across the network, an orientation away from the most productive knowledge brokers could, in parallel, result in a reduction in scientific productivity. Potentially, a certain level of inequality and structural holes may be inevitable and perhaps is even beneficial for complex research systems.

10 CONTRIBUTION OF FP7 TO INTEGRATION OF ERA REGIONS (SQ7)

Project terms of reference: Based on the assumption that FPs should play a proactive role in developing excellence across all countries and regions in the ERA: to what extent do FPs contribute to integrate regions and foster a wider participation of relevant actors and stakeholders? (SQ7)

The 2013 European Commission's Regional Competitiveness Index (RCI) states that territorial competitiveness in the EU has a strong regional dimension, which national level analysis does not properly capture. The gap and variation in regional competitiveness should stimulate a debate on the extent to which these gaps are harmful for their national competitiveness and the extent to which the internal variation can be remediated (Annoni & Dijkstra, 2013).

Given this context, several positive conclusions from this study regarding regional collaboration were found, as follows. Using co-participation on FP7 projects to prepare network analyses, it was shown that several regions were added to the network relative to FP6. Also, more co-participations are observed in FP7 relative to FP6. Also, the evidence shows that although the overall probabilistic affinity of NUTS 3 regions remained mostly stable from FP6 to FP7, NUTS 3 regions from smaller countries with lower levels of participation experienced the strongest levels of integration in the network in FP7 relative to FP6.

These findings were also supported by survey respondents who stated that FP7 helped strengthen collaboration with other regions from the ERA and EU28 countries, and third countries. Case study evidence further highlights the policy and economic benefits to the ERA from regionally integrated projects.

As such, it is clear that the framework programme has fostered a wider participation of relevant actors and stakeholders at the regional level, thus creating a strong base for cooperation at the national level.

10.1 Level of participation and connectedness by NUTS 3 regions

Finding 30	Framework programmes (FP6 and FP7) clearly contribute to inter-regional research relations within the ERA with about nine regions per project

Finding 31	FP7 facilitated the integration of 93 additional regions in the ERA

Finding 32	NUTS 3 level regions collaborated more intensively (i.e. participated more frequently) in FP7 than they did in FP6 (more and stronger ties and stronger centrality on average)

Finding 33	Framework programme networks have the capacity to incorporate new regions without losing cohesiveness (FP7 vs. FP6)

As a first step towards characterising the extent of regional cooperation that took place in the framework programme, data on the regional affiliation of project participants in both FP6 and FP7 were extracted from the CORDA database and subsequently cleaned to count the number of NUTS 3 level regions—from ERA regions (i.e. EU28, EU15, latest EU members, candidate/EFTA, ERA and non-ERA countries)—that co-participated in projects from both programmes. Note that in comparing the level of cross-regional co-participation in the framework programme, some of the specific programmes under FP6 and FP7 were omitted since they were not formally designed to support cooperation, namely People (i.e. Marie Curie Actions) under both FP6 and FP7 and Ideas (i.e. European Research Council) under FP7.

Table XXVIII presents the number of FP6 and FP7 participating NUTS 3 level regions. NUTS 3 level regions from all 42 ERA countries (i.e. EU28, candidate and EFTA countries) participated in both framework programmes and an increase of 93 NUTS 3 regions was observed from FP6 to FP7. Furthermore, the number of projects in which these NUTS 3 regions participated increased in FP7 relative to FP6, whereas the average number of NUTS 3 level regions per project for ERA countries, as well as the sub-groups presented here, remained roughly stable, showing a slight decrease in FP7 relative to FP6. The extent of cross-regional co-participation within the ERA in both FP6 and FP7 shows that framework programmes successfully allowed regions to pool their effort/expertise on projects addressing common scientific challenges. For example, there were, on average, about nine NUTS 3 level regions per project under both FP6 and FP7. Not only did participation in the framework programme increase from FP6 to FP7, but participation intensity also greatly increased—standing at 42 projects per NUTS 3 level region in FP6 and reaching 72 projects per NUTS 3 region on average during FP7.

Table XXVIII Number of participating NUTS 3 level regions in FP6 and FP7

	No. NUTS 3-level regions		No. Projects		Distinct NUTS 3-level regions/project		No. Projects/NUTS 3-level regions	
	FP6‡	FP7†	FP6‡	FP7†	FP6‡	FP7†	FP6‡	FP7†
Total	1,291	1,384	5,331	8,867	9.67	9.04	42.30	72.30

Note: †FP7 data without People and Ideas as they are not designed to formally support cooperation (which means that a majority of projects from these specific programmes only have one participant).
‡FP6 data without Marie Curie Actions for the same reason as above for People and Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Table XXIX presents SNA indicators for both FP6 and FP7. Network density, which is used to assess the completion level of a network (i.e. the percentage of possible links between actors if they were all connected to one another is actually observed in the network), increased from 0.09 in FP6 to 0.10 in FP7 while keeping the number of actors constant between framework programmes (see rationale for keeping the number of regions constant between FP6 and FP7 in Section 9.1). This represents a modest increase of 1%, indicating that the network included more ties in FP7.

Table XXIX SNA network indicators for NUTS 3 regions in FP6 and FP7

Indicator		FP6	FP7
Density*		0.09	0.10
Betweeness Centrality (X 100,000)	Avg.	48.85	56.71
	Gini	0.89	0.89
Unweighted Degree	Avg.	0.09	0.10
	Gini	0.61	0.59
Weighted Degree	Avg.	0.36	0.46
	Gini	0.81	0.81

Note: When comparing individual FP7 specific programmes, a higher density is observed for People and Ideas compared to Capacities and Cooperation at the organisational level. This can be explained by the fact that organisations participating on a recurring basis (i.e. large universities and research organisations situated in the core of the network) are more frequent in the former two specific programmes (as seen earlier in Table XXI). A higher proportion of recurring participants generally improve the overall connectivity of a network by increasing its density.
* The number of actors at the regional level was artificially kept constant to maintain the comparability of the network density across framework programmes (see Section 9.1 for rationale).

Source: Computed by Science-Metrix using CORDA (European Commission) data

Similarly, the unweighted degree indicator, which is indicative of the average number of collaborators for each NUTS 3 region, also increased one degree point, again pointing toward a certain increase in the level of collaboration between established partners in the network.

A larger increase is observed for the average weighted degree of the networks (indicative of the number of partners and their collaboration intensity, i.e. the number of co-participating projects), which went from 0.36 during FP6 to 0.46 in FP7, an increase of close to 30% of the original value. However, as the high Gini index shows (0.81), the distribution of co-participations is not evenly distributed among regions, and this has not changed between FP6 and FP7. This result indicates that the average number of collaborations per NUTS 3 region also greatly increased during FP7, thus indicating that NUTS3 level regions collaborated more intensively with each other, though inequalities between regions remained.

Additionally, an increase in the average betweenness centrality of NUTS 3 regions in the network clearly indicates that FP7 reinforced ties between NUTS 3 regions. However, this increase might not have been distributed uniformly across regions. Because the Gini coefficient did not change, one could assume that inequalities between NUTS 3 regions remain unchanged such that integration might not have progressed.

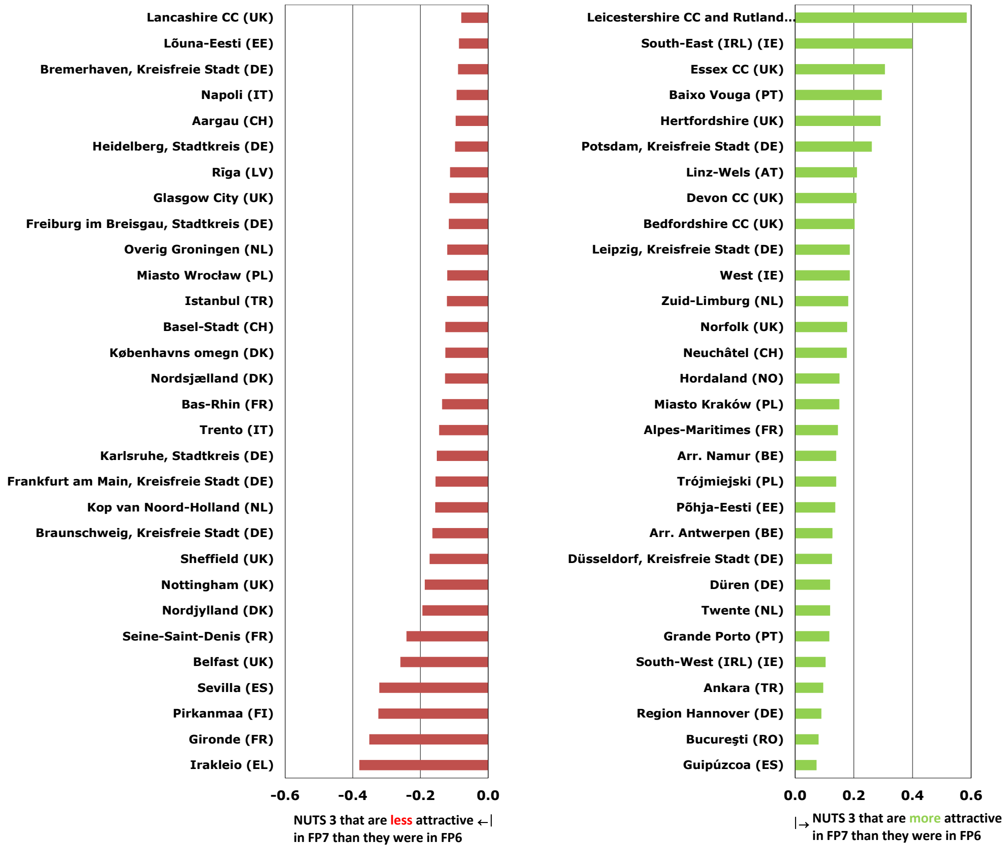
Note that most centrality measures in collaboration networks are sensitive to scale; that is, in the present case, to differences in the number of projects in which NUTS 3 level regions participated. In other words, the more a NUTS 3 level region participates, the more it will be central in the network. Although it is useful to analyse integration by accounting for such differences, it is also of interest to study integration by removing size effects. This can be achieved by computing the affinity of a NUTS 3 level region to partner with others based on a random assortment of NUTS 3 level regions, which accounts for the respective participation level of each NUTS 3 region in a network. The probabilistic affinity index (PAI) that is obtained in this manner compares the number of co-participations between any two NUTS 3 regions to their expected number of co-participations based on their respective shares of all participations in the network. A score above one therefore indicates that two NUTS 3 regions preferentially partner with one another, whereas a score below one means the opposite.

By looking at how the affinities of a given NUTS (i.e. its affinities for each of the other NUTS 3 regions in the network) changed from FP6 to FP7, it is therefore possible to appreciate whether it became a more prominent actor in the network taking account of its size (i.e. its number of participations). Such an analysis is presented in Section 11.1.2 at the country level. It showed that a number of the smaller countries—that is, some former Yugoslav countries as well as some EU Member States located in Central and Eastern Europe—are more integrated in the co-participation network under FP7 than under FP6, their average pairwise affinities within the network having shown the greatest increase among all countries involved.

Integration of regions within the ERA network is a crucial aspect of FP7, and examining collaboration between regions brings complementary insight into the statistics at country level presented in the next section (Section 11). With an average value of 0.002 across all NUTS 3 regions considered in this analysis, these results tend to corroborate that the integration level of NUTS 3 regions was mostly stable from FP6 to FP7. However, some regions had a remarkable increase in their integration in the network, while some experienced a decrease. Figure 15 presents the 30 NUTS 3 regions presenting the highest increases and decreases in integration from FP6 to FP7.

Of the NUTS with the highest increases, many are located in countries presenting high centrality levels in the ERA network as presented at Table XXX, with the UK and Germany presenting 15 and 8 NUTS regions each among these respectively. However, all things being equal, the increase for the UK is more important, as it represents an increased integration for 11% of all NUTS 3 regions in the country when normalised by its total number of NUTS 3 regions, while the same percentage stands at only 2% for Germany. As such, while other European countries highly active in FP7 also present many NUTS 3 regions with increased integration, it is interesting to note the presence of smaller countries (e.g. Poland, Croatia, Romania, Slovakia, Greece, Slovenia, Turkey, Estonia, Lithuania and Iceland). For these countries, while the numbers of NUTS with increased integration are somewhat lower, these nevertheless account for notable shares of their total numbers of NUTS 3 regions. Furthermore, given the levels of participation of these smaller countries, most of these only had a few NUTS 3 regions that could be considered in this analysis. It is safe to assume that most of these would have even more regions with increased integration if the probabilistic affinity indicator could have been computed for entities with lower levels of co-participation.

Figure 15 NUTS 3 regions with the strongest increases and decreases in attractiveness in FP7



Note: Only NUTS 3 regions presenting at least one partnership with another NUTS 3 region for which their expected number of co-participations stood at 30 co-projects or more, and this in both FP6 and FP7 (but not necessarily with the same NUTS 3 region in each FP) could be used in this analysis.

Source: Computed by Science-Metrix using CORDA (European Commission) data

These results are in line with the findings presented at Figure 17 regarding the increased integration of countries. Excluding countries comprising a single NUTS 3 region and which were consequently excluded in the integration analysis of NUTS 3 regions (e.g. the former Yugoslav Republic of Macedonia, Serbia, Bosnia and Herzegovina, Mexico, Cyprus, Malta, Israel, Morocco), most of the countries with a great increase in integration for FP7 have NUTS 3 regions presenting increased levels of integration (e.g. Estonia, Turkey, Slovakia, Slovenia, Iceland).

Table XXX Distribution of NUTS 3 regions with increased integration in FP7 by country

Country	No. of NUTS 3 with increasing attractiveness from FP6 to FP7	Total no. of NUTS 3 in country	% with increase	Country	No. of NUTS 3 with increasing attractiveness from FP6 to FP7	Total no. of NUTS 3 in country	% with increase
United Kingdom	15	133	11%	Croatia	1	21	5%
Germany	8	429	2%	Romania	1	42	2%
Belgium	7	44	16%	Switzerland	1	26	4%
Italy	6	107	6%	Slovakia	1	8	13%
Netherlands	6	40	15%	Czech Republic	1	14	7%
France	5	101	5%	Greece	1	51	2%
Ireland	4	8	50%	Slovenia	1	12	8%
Norway	3	19	16%	Denmark	1	11	9%
Poland	3	66	5%	Turkey	1	81	1%
Portugal	2	30	7%	Lithuania	1	10	10%
Spain	2	59	3%	Estonia	1	5	20%
Sweden	2	21	10%	Iceland	1	2	50%
Austria	2	35	6%				

Note: Only NUTS 3 regions presenting at least one partnership with another NUTS 3 region for which their expected number of co-participations stood at 30 co-projects or more, and this in both FP6 and FP7 (but not necessarily with the same NUTS 3 region in each FP), could be used in this analysis.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Furthermore, it is important to keep in mind that since NUTS 3 regions had to present a minimum level of co-participation in both FP6 and FP7 to be included in the analysis above, newly integrated regions in FP7 (i.e. new regions co-participating on projects in FP7 that were not co-participating in FP6) could not be incorporated in this analysis and integration of new co-participating regions represent a crucial aspect of increased integration. As can be observed at Table XXXI, which presents the distribution of new co-participating NUTS regions in FP7 when normalised by the total number of NUTS 3 level regions in each country, the countries achieving the highest increases are all smaller countries (e.g. Lithuania, Croatia, Romania, Bulgaria, Greece), which supports the findings regarding the greater integration of smaller countries in FP7 compared to FP6.

Table XXXI Distribution of new co-participating NUTS 3 regions in FP7 by country

Country	No. of new NUTS 3 co-particpating in FP7	Total no. of NUTS 3 in country	% (↓)	Country	No. of new NUTS 3 co-particpating in FP7	Total no. of NUTS 3 in country	% (↓)
Lithuania	3	10	30%	Belgium	5	44	11%
Croatia	6	21	29%	Turkey	9	81	11%
Macedonia	2	8	25%	Austria	3	35	9%
Romania	8	42	19%	Slovenia	1	12	8%
Bulgaria	5	28	18%	United Kingdom	10	133	8%
Greece	9	51	18%	Norway	1	19	5%
Portugal	5	30	17%	Spain	3	59	5%
Hungary	3	20	15%	Finland	1	20	5%
Germany	52	429	12%	France	5	101	5%
Poland	8	66	12%	Italy	4	107	4%
Switzerland	3	26	12%				

Source: Computed by Science-Metrix using CORDA (European Commission) data

10.2 Regional integration within the ERA and the competitiveness of European science & technology

Finding 34	By producing positive outcomes sought by FP7, regional cooperation within the ERA contributes to raising the international competitiveness of Europe

The intervention logic of FP7 indicates that the enhanced regional integration of the ERA resulting from it should raise the innovation capabilities and international competitiveness of Europe, which, in turn, should result in various socio-economic benefits (see logic model of FP7, Figure 2). This section investigates whether the improved regional integration of the ERA resulting from FP7 contributed to raising the international competitiveness of European science and technology, in part through stronger innovation capabilities of the supported projects.

To analyse whether the inter-regional research relations promoted under FP7 have a significant and positive effect on the production of expected outputs/outcomes as laid out in the programme's logic model (Figure 2), regression analyses were performed for each of the bibliometric and survey variables presented in Section 6.3 as the dependents in the implemented models. The regression models that have been implemented incorporate, as explanatory variables, numerous networking dimensions beyond the inter-regional collaboration facet (e.g. the disciplinary and sectoral dimensions) as well as numerous controls such as the number of research publications produced by a given team's members prior to their participation in FP7. Since the number of participants in a project is strongly associated with a greater extent of networking across various dimensions, a number of the networking variables—including the one on inter-regional relations within the ERA (i.e. number of NUTS 3 regions [R = 0.98])—could not be included alongside the number of participants in the model as this would have resulted in redundancy across variables (i.e. multicollinearity). (Note, the Spearman correlation coefficient was used since the data are not normally distributed. It is based on the data for all projects, not just those included in the regression sample.) This is important as too much redundancy in a dataset can lead to spurious conclusions regarding the significance of the regression coefficients and to coefficients of unexpected sign (Zar, 1999). Consequently, where it was necessary to work with a specific networking dimension that is highly correlated with the number of participants—such as inter-regional relations within the ERA (i.e. the number of NUTS 3 regions on a project)—the former variable was used in place of the latter in the model. Refer to the companion methodological annex for details on the regression analysis.

The number of NUTS 3 regions in a project appears to relate significantly and positively with the volume of new knowledge produced (measured by the number of FP7-supported publications produced by the participants). In this case, since both the independent and dependent variables are log-transformed (refer to the companion methodological annex for details on the variable transformations), the regression coefficient (0.19) can be interpreted in terms of elasticity. In other words, a 10% increase in the number of NUTS 3 regions is associated with a 1.9% increase in the number of FP7-supported papers (Table XXXIX).

Table XXXII Relationship between the number of NUTS 3 regions on a project and scientific output under the Cooperation and Capacities specific programmes

Explanatory Variables	No. of papers	Avg. of Rel. Impact Factors (ARIF)	Avg. trans-disciplinarity	Avg. no. of ERA countries per paper	Avg. no. of non-ERA countries per paper
No. of NUTS 3 regions per project	0.189*** (0.040)	0.006 (0.066)	0.025** (0.012)	0.138*** (0.037)	0.029 (0.036)
All other independent and control variables					
R-sq-adj	**0.691**	**0.401**	**0.831**	**0.449**	**0.534**
N	**732**	**250**	**248**	**708**	**708**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All variables presented in this table are log-transformed (natural log) except for the Avg. of Rel. Impact Factors and Avg. trans-disciplinarity of FP7-supported papers. All models are statistically significant at $p \leq 0.05$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Combined with the moderately high adjusted R-square of the model (0.69), this might appear as a very slight effect. However, since the number of publications produced by the project teams prior to their participation in FP7 was included as a control variable, one could assume that this effect is really attributable to the interacting/networking effect of having multiple regions involved rather than to a simple increase in the production capacity of the teams, which would be expected from having multiple people performing some work independently of one another.

The results also indicate that the number of NUTS 3 regions on a project effectively translates into increased collaboration, in the form of international co-publications within the ERA, as measured with the scientific publications resulting from FP7 projects (regression coefficient of 0.14; both the number of NUTS 3 regions on a project and the average number of ERA countries per FP7-supported papers are log-transformed). Note that the model controls for the average number of ERA countries per papers produced by the team participants prior to their participation in FP7.

Altogether, the results of the regression model indicate that the networking that resulted from having multiple regions on FP7 projects leads to FP7-targeted positive outcomes, which are expected to reinforce, at the national level, the innovation capabilities of Europe in the long run.

Numerous case studies have highlighted the policy, economic and integration benefits their project(s) brought to the ERA through inter-regional collaboration. Among them, the AgriPolicy project illustrates a case where strong networks have been created with and between recent Member States, candidate countries and potential candidate countries (21 regions in total). The aim of the project was to support the application of EU agricultural policies in recent EU Member States and Candidate and Potential Candidate States. The project is a rather unusual FP7 project in that the call was identical to an FP6 call except for the inclusion of a wider network of participants. Creating networks between researchers focused on agricultural economic analyses was also one of the prime objectives of the project. Lasting relationships have been created among the project partners and many of them have continued to collaborate in diverse projects after the conclusion of the AgriPolicy project. For instance, the Serbian and the Croatian partners cooperated on the project 'Opportunities to increase marketing of agricultural and food products of family farms' funded by the Ministry of Science in Serbia and the Ministry of Science in Croatia. The project also hired two native English-speaking economists to work on revising and improving the country reports, which provided important competency building for the researchers from the Western Balkans, in particular. By linking a wider range of actors and by involving economists, this project is an example of how FP7 has helped countries' and regions' integration, as well as how it is oriented to increase the competiveness of the ERA and create positive spillovers in neighbouring countries.

The ATLAS project, which involved 10 NUTS 3 regions, fostered the creation of useful S&T tools, which can increase the economic competiveness of Europe. The overall objective of the ATLAS project has been to develop a new laser-based high-throughput technology for analysing protein bindings in DNA that will overcome the current limitations of the applicative research in the field. This technology can be applied in research and in hospital and clinical analysis departments. The outcomes of the project have served as the base for future academic and commercial collaboration. Some of the academic participants from Italy (Seconda Università Degli Studi di Napoli; NUTS: ITF31) and the Netherlands (Stichting Katholieke Universiteit; NUTS: NL226), together with the Swedish SME Sigolis AB (NUTS: SE121), have continued collaborating in BLUEPRINT, another large-scale research project with 41 leading European universities, research institutes and industry entrepreneurs funded by the FP7 programme. This may lead to targeted diagnostics, new treatments and preventive measures for specific diseases in individual patients. ATLAS has also contributed to the advancement of specific new technologies and innovations; namely, the dedicated laser developed by a Lithuanian company (Uzdaroji Akcine Bendrove Moksline-Gamybine Firma Sviesos Konversija; NUTS: LT00A) and the microfluidic system developed by the Swedish company (Sigolis AB; NUTS: SE121). These outcomes are all aligned with the objectives of the Health thematic area where 'increasing the competitiveness and boosting the innovative capacity of European health-related industries and businesses' is key.

10.3 Is there an ideal number of regions in collaboration projects?

Finding 35	The greater the number of participating regions in FP7 projects, the stronger the beneficial outputs/outcomes sought in FP7

In relation to the above findings regarding the effect of international research relations on the production of positive outputs/outcomes, the following question arises: Is there an optimal number of NUTS 3 regions in a project?

To answer this question, the performance of FP7 projects was measured through the use of a composite indicator synthesising the positive outputs/outcomes measured with bibliometric indicators and the survey. This subsequently allowed studying differences in the performance of projects according to a number of dimensions (i.e. the number of NUTS 3 regions) to see whether or not an optimal size exists with respect to these dimensions. The construction of the composite indicator is presented in Section 6.3. Note that this approach only looks at one networking variable at a time and does not include any controls as was done in the previous section on the regression analysis.

As seen in Table XXXIII, there does not appear to be a turning point related to the number of NUTS 3 regions involved in a project where the benefits of adding more NUTS 3 regions decrease or level off. Indeed, there are significant differences across groups for all specific programmes and the mean rank sum increases as the size of the group increases in all specific programmes. This is reflected to some extent in the median and mean scores of groups within all specific programmes, though to a lesser extent under Cooperation. Thus, if there is an optimal maximum with regards to number of NUTS 3 regions on a project, it does not appear to have been reached in the context of FP7 based on this analysis. Here, the higher the number of NUTS 3 regions, the stronger the beneficial outputs/outcomes, though there are likely diminishing returns to scale as the size of group increases as shown in Section 6.3.

Table XXXIII Performance, as measured with a composite measure of positive outcomes, of FP7 projects across networks of varying sizes as regards the number of NUTS 3 regions involved, by specific programme

	Cooperation				Capacities				People		
Descriptive Stats	**(1-8)**	**(9-11)**	**(12-16)**	**(17-48)**	**(1-7)**	**(8-12)**	**(13-16)**	**(17-45)**	**(1)**	**(2-4)**	**(5-10)**
N of Cases	112	129	136	123	28	32	23	28	130	40	39
Minimum	12.0	14.0	13.6	14.8	14.7	16.2	18.7	22.3	11.0	16.5	22.0
Maximum	64.5	50.6	53.5	57.2	72.0	53.4	55.5	64.7	75.7	52.9	65.3
Median	30.7	31.3	31.3	32.9	26.8	29.4	36.0	36.1	25.8	28.0	31.4
Arithmetic Mean	30.8	31.1	31.7	33.2	30.1	30.1	35.5	38.9	27.4	29.1	32.4
Mean Rank Sum*	229	243	251	277	41	45	68	73	64	73	100
Standard Deviation	8.1	6.3	7.6	7.5	10.9	8.1	8.3	10.9	9.5	7.7	7.8
Variance	65.1	39.9	57.6	56.9	119.6	66.2	68.6	117.7	90.1	59.0	60.1

Note: * Significant differences exist between groups for Capacities (p = 0.00) and People (p = 0.00). Nearly significant differences exist between groups for Cooperation (p = 0.07). Tested using a Kruskal-Wallis test.

Source: Computed by Science-Metrix using CORDA (European Commission) data

11 FRAMEWORK PROGRAMMES' CONTRIBUTION TO INTERNATIONAL RESEARCH RELATIONS (SQ6)

Project terms of reference: Based on the assumption that openness to international knowledge sharing is important for innovations and competitiveness of the EU: to what extent does the FP contribute to international research relations between the EU and third countries (patterns by countries and specific research areas)?

Transnationality and mobility over national borders are key objectives of FP7 activities; that is, research projects should be carried out by consortia that include participants from different European (and other) countries (European Commission, 2007). Such international knowledge sharing is assumed to contribute to the competitiveness and innovation capacity of the EU.

Evidence from earlier framework programmes indicates that the interest in international collaboration and competitiveness has been growing with each successive framework programme. For example, in a study on the impact of FP4 and FP5 in the UK, academic and industry participants reported medium to high levels of impact on their organisation's competitive position, both nationally and internationally. This resulted in a recommendation that the Commission redoubles efforts with regard to researching the efficacy of international collaborative research, and in particular to develop meaningful models and case material regarding programme contributions and impact in the wider economy (Technopolis, 2004).

The 2011 review on the long-term impact of the framework programmes notes that one of the novelties of FP5 was the 'mainstreaming' of participation in the framework programmes by third countries, (i.e. those that are neither Member nor Associated States). This partly involved bringing in a range of projects aimed at developing countries and regions outside Europe, and then, in FP6, encompassed growing participation of such countries (especially Russia and China) in core framework programme projects (EPEC, 2011). By the end of FP6, nearly 90% of 'well experienced' framework programme participants (as determined by a large-scale survey) were also categorised as having 'high international R&D cooperation experience' (Idea Consult, 2009).

Continuing in this vein, this study finds that FP7 clearly fostered international research relations, within and beyond the ERA, based on evidence from international co-participation data in FP7, from survey data and from international co-authorships data extracted from framework programme supported publications. It is also worthy to note some advancement from the FP7 Interim Report (2010), which found for international cooperation during the first three years of FP7 that 'not much progress has been made compared to FP6 and the available statistics do not indicate any major change in "Third Country" participation' (European Commission, 2010a).

The evidence in the current report shows that while no major changes from FP6 to FP7 were observed with respect to the overall average number of countries per project, a number of countries (e.g. some former Yugoslav countries and EU members from eastern Europe) are more integrated in the co-participation network under FP7 than they were in FP6. Additionally, it was found that FP7 promotes co-authorship between ERA and non-ERA countries more strongly than FP6, as well as contributes to the increased international integration of countries within the co-publication network of FP7-supported papers relative to the corresponding network established on the basis on the publications produced by researchers prior to their participation in FP7.

Turning to the idea that cross-border knowledge sharing contributes to competitiveness, there is also support in the literature for such an assumption. International collaboration plays a significant role in the innovation process such that over the last several decades (especially for the private sector) there has been a systemic and fundamental shift in the use of external networks to undertake innovatory activities (Hagedoorn, 1996). In addition to scientific benefits of international collaboration such as increased impact (Guerrero Bote, Olmeda-Gómez & de Moya-Anegón, 2013), competitive benefits include cost and risk sharing, skills development, and acquiring knowledge about government standards and regulations of the target markets (OECD, 2011). It may also be that for firms or organisations that are already innovative, stronger innovation performance is associated with capitalising on international collaborative involvement (Ebersberg & Herstad, 2013).

The current study provides some evidence to confirm the logic model's assumptions regarding the strategic outcome of improved competitiveness. It was found that the international cooperation fostered by FP7 contributes to the attraction of internationally renowned scientists, as well as increased production of knowledge. In this regard, if there is an optimal maximum with regards to number of ERA countries on a project, it does not appear to have been reached in the context of FP7; the higher the number of ERA countries, the stronger the beneficial outputs/outcomes, though there are likely diminishing returns as the size of the group increases (Section 10). Thus, it can be said that a clear contribution has been made to strengthening innovation capacities and competitiveness at both the national and European levels.

However, there are well-documented barriers to such cross-border integration. For example, it is organisationally demanding. In order to capitalise on network linkages, resources and routines conducive to partner identification, knowledge assimilation and transformation must be established—no easy task (Ebersberg & Herstad, 2013). Language and geographical proximity may also play a role. Two countries are more likely to collaborate if they are geographically close to each other, if they have a similar technological specialisation and if they share a common language. Being a member of the European Union involves more cross-border ownership, but does not necessarily entail more research cooperation than is implied by the above factors (Guellec et al., 2001).

Similarly, the current study found evidence of barriers to the wider participation of relevant actors that may hinder the integration of countries in FP7. Such barriers include EU immigration laws and travel visa requirements and any lack of transparent, strong project management and coordination.

In sum, while openness to international knowledge sharing fostered through framework programmes has been found to contribute to improved innovation capacity, there is a need to recognise and address potential barriers or issues around international collaboration in order to truly achieve strategic outcomes related to competitiveness.

11.1 Contribution of framework programmes to international research relations

Finding 36	Framework programmes clearly contribute to international research relations within the ERA, and therefore to the integration of European countries

Finding 37	Framework programmes moderately promote international research relations with countries outside the ERA

Finding 38	The growth in non-ERA participation is proportional to the growth of the number of projects from FP6 to FP7

Finding 39	The integration of countries generally did not progress from FP6 to FP7

Finding 40	Yet, a number of the smaller European countries are more integrated in FP7 than they were in FP6 (e.g. the former Yugoslav Republic of Macedonia, Serbia, Croatia, and Bosnia and Herzegovina)

Finding 41	FP7 increased international relations in the form of international co-authorships of scientific papers

The intervention logic of the framework programmes assumes that international cooperation—in the form of cross-country co-participation in framework programme projects—has the potential to facilitate the circulation of knowledge and innovative ideas across national borders within Europe as well as the absorption of scientific knowledge produced by third countries.

11.1.1 Cross-country co-participation in the FP

As a first step towards characterising the extent of international cooperation that took place in the framework programme, data on the national affiliation of project participants in both FP6 and FP7 were extracted from the CORDA database and subsequently cleaned to count the number of countries—from various regions within and beyond the ERA (i.e. EU28, EU15, latest EU members, candidate/EFTA, ERA and non-ERA countries)—that co-participated in projects from both programmes. Note that in comparing the level of cross-country co-participation in the framework programme, some of the specific programmes under FP6 and FP7 were omitted since they were not formally designed to support cooperation, namely People (or Marie Curie Actions) under both FP6 and FP7 and Ideas (or European Research Council) under FP7.

Table XXXIV presents the number of FP6 and FP7 participating countries. All 42 ERA countries (i.e. EU28, candidate and EFTA countries) participated in both framework programmes. The number of projects in which these countries participated increased in FP7 relative to FP6, whereas the average number of countries per project for ERA countries as well as the sub-groups presented here remained roughly stable, showing a slight decrease in FP7 relative to FP6. The extent of cross-country co-participation within the ERA in both FP6 and FP7 shows that framework programmes successfully allowed countries to pool their effort/expertise on projects addressing common scientific challenges. For example, there were, on average, about six ERA countries per project under both FP6 and FP7.

Table XXXIV Number of participating countries in FP6 and FP7

	No. Countries		No. Projects		Distinct countries/project	
	FP6‡	FP7†	FP6‡	FP7†	FP6‡	FP7†
ERA	42	42	5,310	8,861	6.0	5.8
Non-ERA	113	135	1,098	1,732	0.5	0.4
EU-28	28	28	5,249	8,807	5.5	5.2
EU-15	15	15	5,142	8,688	4.5	4.5
Latest EU members	13	13	2,749	3,843	1.0	0.7
Candidate/EFTA	14	14	2,245	3,937	0.6	0.6
Total	155	177	5,331	8,867	6.5	6.2

Note: †FP7 data without People and Ideas as they are not designed to formally support cooperation (which means that a majority of projects from these specific programmes only have one participant).
‡FP6 data without Marie Curie Actions for the same reason as above for People and Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Outside of the ERA, the number of participating countries increased by nearly 20% in FP7 relative to FP6, with the addition of 22 additional countries in the FP7 network (135 in FP7 comparatively to 113 in FP6). Despite the greater diversity of actors in the overall network, the average number of non-ERA countries per project also remained stable between FP6 and FP7. Not surprisingly, the average number of non-ERA countries per project is much smaller than it was for ERA countries, with about one non-ERA country in half of the projects under FP6 and FP7. Though FP7 is larger than FP6 and it is therefore not surprising to see the number of projects with non-ERA countries participants increase (from 1,098 to 1,732), the percentage of projects with no non-ERA countries has actually gone down slightly (from 21% to 20%). Thus, it can be said that framework programmes moderately promote international research relations with third countries and that the growth in non-ERA participation is proportional to the growth of the framework programmes.

Table XXXV presents data broken down by FP7 specific programme as well as by thematic/broad area for Cooperation and Capacities. The data confirm that the specific programmes that have been purposefully designed to support cooperation (i.e. Cooperation and Capacities) have more ERA countries and far more non-ERA countries. This finding reinforces the evidence collected so far that FP7 contributes to international research relations by fostering cross-country co-participation in the projects it funds, especially those that support cooperative projects. Among thematic and broad areas respectively under Cooperation and Capacities, there is some variation in the extent of international cooperation. The thematic areas in which cooperation is strongest both within and beyond the ERA include Environment (including Climate Change), Food, Agriculture, and Biotechnology, and Socio-economic sciences and Humanities. Under Capacities, the broad areas that are the most cooperative include Research Infrastructures and Science in Society. Not surprisingly, the largest proportion of non-ERA countries can be found in the Activities of International Cooperation broad area.

Table XXXV Geographic spread of participating organisations in FP6 and FP7 projects overall, and by specific programme as well as thematic/broad area under FP7

	No. of Projects	Avg. No. of Countries	Avg. No. of ERA Countries	Avg. No. of Non-ERA Countries
FP6 (overall)	**9,781**	**4.3**	**6.7**	**0.38**
FP6 (overall) excluding Marie Curie Actions‡	**5,331**	**6.5**	**6.0**	**0.45**
FP7 (overall)	**21,963**	**3.3**	**5.0**	**0.22**
FP7 (overall) excluding People & Ideas†	**8,867**	**6.2**	**5.8**	**0.40**
COOPERATION	**7,017**	**6.3**	**5.9**	**0.41**
Info. and Comm. Tech.	2,065	5.7	5.4	0.24
Health	977	6.6	6.0	0.66
Nanosci., Nanotech., Mat. and new Prod. Tech.	761	6.6	6.4	0.24
Transport (including Aeronautics)	689	6.4	6.2	0.27
Joint Tech. Initiatives (Annex IV-SP1)	626	3.4	3.3	0.03
Environment (including Climate Change)	443	8.6	7.5	1.06
Food, Agriculture, and Biotechnology	437	8.9	7.8	1.13
Energy	333	6.4	6.0	0.33
Space	240	6.2	5.7	0.52
Security	229	7.2	7.1	0.07
Socio-economic sciences and Humanities	209	8.2	7.5	0.75
General Activities (Annex IV)	8	1.0	1.0	0
CAPACITIES	**1,850**	**5.8**	**5.4**	**0.36**
Research for the benefit of SMEs	905	5.1	5.1	0.02
Research Infrastructures	334	9.5	8.8	0.72
Research Potential	194	1.4	1.4	0.08
Science in Society	162	7.3	6.7	0.51
Activities of International Cooperation	149	6.4	4.3	2.11
Regions of Knowledge	81	4.4	4.4	0.02
Coherent development of research policies	25	3.8	3.8	0
PEOPLE	**9,293**	**1.5**	**1.5**	**0.02**
IDEAS	**3,803**	**1.1**	**1.1**	**0.01**

Note: †FP7 data without People and Ideas as they are not designed to formally support cooperation (which means that a majority of projects from these specific programmes only have one participant).
‡FP6 data without Marie Curie Actions for the same reason as above for People and Ideas.

Source: Computed by Science-Metrix using CORDA (European Commission) data

The cross-case analysis of the case studies revealed one of the potentially many mechanisms through which FP7, by promoting international cooperation, successfully enhanced international research relations: by increasing the cross-country mobility of researchers. All the case studies are examples of projects where partners from different countries worked together and travelled across borders to meet. Though this may appear trivial, it is important to note that FP7 supported in-person collaboration as opposed to being only through technological means centring on information and communication technologies. Stokols, Misra, Moser, Hall, and Taylor (2008) argue: 'Initial face-to-face contact and socialization were found to increase the trust levels among team members, facilitate the formation of social norms, and aid the establishment of group identity. Face-to-face contact early-on may be a prerequisite for successful remote collaboration'.

Survey data have been used to characterise the geographic origin of partners in FP7 projects. With regards to the geographic origin of project partners, almost 90% of the survey respondents stated that more than half of new project partners and of partners known from FP6 came from other European countries. For project partners known from collaborations outside the framework programmes context, this share amounts to slightly more than 70%.

Survey results also suggest that those from international, non-European backgrounds (i.e. all other countries) constitute only a small group irrespective of whether they are new partners, partners known from prior collaborations outside of the framework programmes context or partners known from FP6. More specifically, the large majority of participants—around 85% (new partners) to slightly more than

90% (partners with previous collaborations from FP6)—indicate that the share of international, non-European partners in their projects amounts to less than 5%.

The survey shows that the share of respondents indicating a large participation of non-European partners is higher among new partners (almost 15%) than it is among those already known from previous collaborations in another context (around 10%) or from FP6 (less than 10%). This might explain, to some extent, the 20% increase in the number of new countries from outside the ERA in FP7 relative to FP6.

These survey results confirm the above findings obtained from the characterisation of co-participation data (CORDA) that FP7-sponsored research clearly promotes international research relations within the ERA (i.e. EU28 and FP7 associated countries) as well as between the ERA and other, non-associated, countries, but to a much larger extent for the former than the latter case.

11.1.2 Integration of countries within the co-participation networks of FP6 and FP7

The question of ERA integration is key to the framework programmes, as one of the EC's hypotheses is that by identifying and bridging structural holes, the ERA will be more integrated and EU research more competitive (see project terms of reference, Section 9).

The previous section showed that cross-country co-participation was successfully promoted to a similar extent under both FP6 and FP7. However, this analysis did not account for the co-participation patterns of countries under each framework programme edition. These patterns have a large influence on the integration of individual countries (i.e. the participating ones) within collaborative networks since they determine the structure of those networks. It was shown in Section 9.1 that the co-participation networks of countries under FP6 and FP7 are characterised by a core-periphery structure whereby a few countries are very central—establishing strong ties between themselves—with the majority of countries falling in the periphery of the network where the density of ties—and consequently the flow of knowledge—is reduced. This means that countries are unequally represented in the network, some of them participating in a large number of projects while others are participating rather infrequently. In fact, such networks are characterised by the presence of structural holes between peripheral actors where the lack or sporadic presence of ties hampers the direct circulation of knowledge. The exchange of knowledge between peripheral actors often has to travel through the central actors connecting the different parts of the network's periphery.

To assess whether the integration of different groups of countries generally increased in the co-participation network of FP7 relative to FP6—that is, if the framework programmes filled structural holes—the level of integration of each country within each network was first computed. The level of integration of a country within a collaboration network is reflected by the number of countries to which it is connected, as well as the quality of its collaborations (i.e. the strength of the links measured by the number of co-participations and the importance of the countries to which it is connected in the network); a highly integrated country operates closer to the core of the network (i.e. it is central and highly important to the network's structure). This can be measured using a variety of statistics (e.g. closeness centrality, betweenness centrality, eigenvector centrality). Here, the eigenvector centrality was chosen over other centrality measures since it offers a good appreciation of both the number and quality of an entity's collaborations; indeed, connections to high-scoring countries (which represent hubs in the network) contribute more to the score of a country than equal connections to low-scoring countries (Bonacich, 1987).

The mean (and median) of centrality scores as well as their level of dispersion (i.e. Gini coefficient) in various country groups were compared between FP6 and FP7 to test the hypothesis that the integration of countries within each of these groups increased between framework programmes. The dispersion of centrality scores in a network is important in assessing the level of integration in the network. As mentioned above, it is quite common that centrality is highly concentrated in a network of scientific cooperation with a few hubs (highly important countries to the network structure) having high centrality scores and a majority of relatively underrepresented countries having low centrality scores. When the centrality of a majority of countries is increased (as revealed by the mean/median centrality score) and the concentration of centrality scores is reduced, countries are, on the whole, less centralised and therefore more integrated; in other words, the network is more balanced with smaller inequalities between countries.

The following tables (Table XXXVI, Table XXXVII) show a comparison of the centrality measures for some groups of countries (i.e. ERA, non-ERA, EU28, EU15, latest EU Members and Candidates/EFTA) under FP6 and FP7. A non-parametric test was used to determine whether the differences were statistically significant (Table XXXVI).

The Wilcoxon signed-rank test for paired samples was run for each group of countries independently and tested the following null hypothesis: H_0: The centrality scores of countries based on their co-participation in FP7 did not increase relative to their centrality in FP6. The rejection of the null hypothesis, together with a reduction in the centralisation of the network (i.e. in the dispersion of centrality scores), would be indicative of a significant increase in the overall integration level of countries within each group.

The results of this test (Table XXXVI) show that the integration of countries did not increase significantly from FP6 to FP7 in any of the groups. For instance, generally less than half of the countries in each group, or around half of them, have seen an increase in their ranking based on their centrality score; this ratio is computed by excluding ties—that is, countries whose ranking did not change.

The average/median of the centrality scores in any given group, as well as the concentration of those scores based on the Gini coefficient, did not change much between both framework programme editions. These results therefore suggest that although framework programmes foster international research relations through cross-country participation, the integration of countries generally did not progress from FP6 to FP7 regardless of the groups of countries considered. The most integrated set of countries in both FP6 and FP7 are, in descending order, EU15, EU28, latest EU members, the ERA as whole, candidates/EFTA countries, and the least integrated, not surprisingly, are the non-ERA countries (Table XXXVII). The ranking obtained is consistent with what one could expect given, for example, that the more established EU countries had more time to develop links over several framework programmes.

Table XXXVI Statistical comparison of the distribution of the centrality scores of countries within the co-participation network of FP6 and FP7 for various groups of countries

Country group	% Countries with increased rank	% Countries with increased rank (excluding ties)	Z-Score	p-value†
ERA	8.2%	35.7%	-1.607	0.946
Non-ERA	40.4%	53.6%	-0.753	0.226
EU-28	4.4%	28.6%	-2.004	0.978
EU-15	3.8%	46.7%	0.114	0.545
Latest Members	0.5%	7.7%	-2.900	0.998
Candidates/EFTA	3.8%	58.3%	1.098	0.136
Total	48.6%	49.4%	-1.581	0.943

Note: When the Z value (i.e. [sum of signed ranks]/square root [sum of squared ranks]) is positive, differences tend to be greater than zero (i.e. there is generally an increase in the centrality of countries), whereas when it is negative, differences tend to be less than zero (i.e. there is generally a decrease in the centrality of countries).

Source: Computed by Science-Metrix using CORDA (European Commission) data

Table XXXVII Concentration, average and median of the centrality scores of countries within the co-participation network of FP6 and FP7 for various groups of countries

	Gini Coefficient		Average		Median	
Country groups	**FP6**	**FP7**	**FP6**	**FP7**	**FP6**	**FP7**
ERA	0.55	0.58	0.123	0.118	0.0656	0.0592
Non-ERA	0.82	0.79	0.011	0.010	0.0005	0.0004
EU-28	0.45	0.49	0.172	0.166	0.1118	0.1034
EU-15	0.33	0.34	0.254	0.256	0.1942	0.1868
Lastest Members	0.51	0.54	0.159	0.149	0.0525	0.0488
Candidates/EFTA	0.68	0.71	0.082	0.081	0.0020	0.0021
All Countries	0.87	0.87	0.030	0.029	0.0009	0.0010

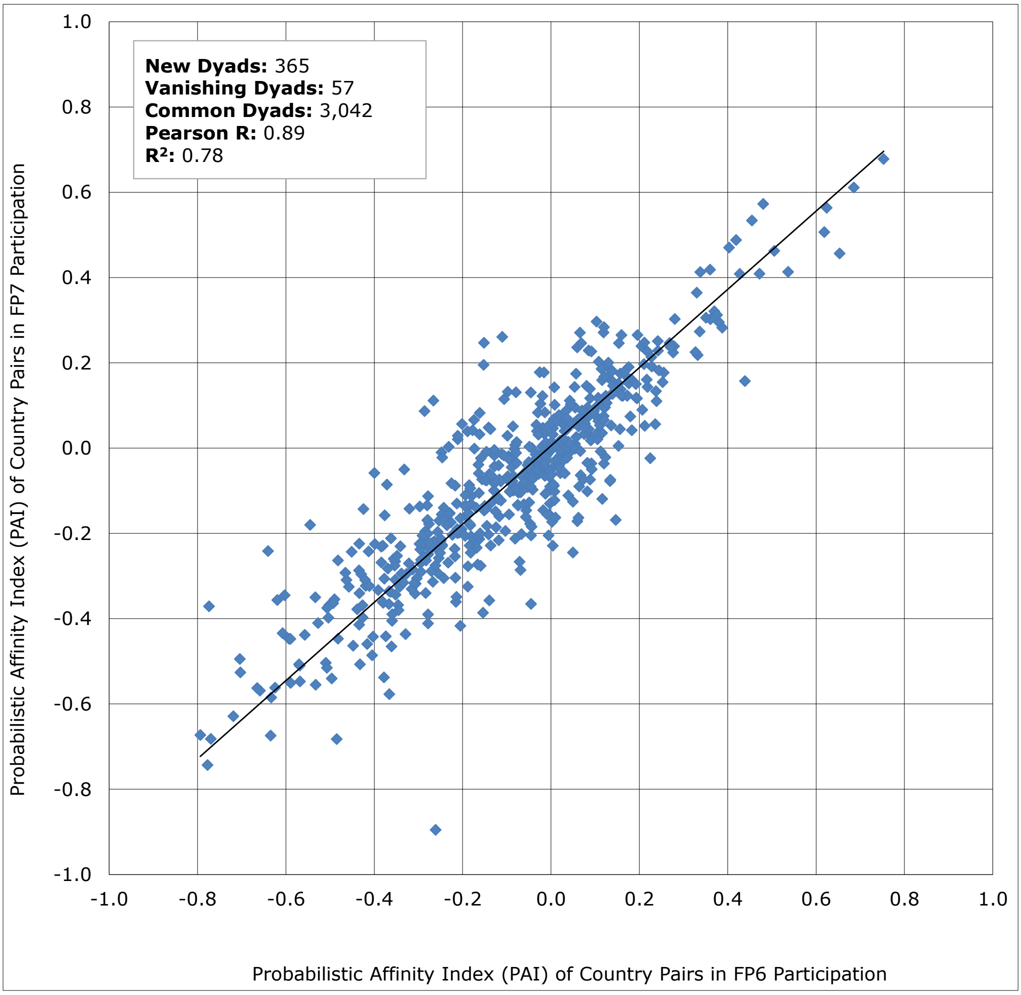
Note: These values were computed on the eigenvector centrality of the countries. The Gini Coefficient represents a measure of concentration; the closer a network is to 1, the less balanced it is.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Note that most centrality measures in collaboration networks are sensitive to scale; that is, in the present case, to differences in the number of projects in which countries participated. In other words, the more a country participates, the more it will be central in the network. Although it is useful to analyse integration by accounting for such differences, it is also of interest to study integration by removing size effects. This can be achieved by computing the affinity of a country to partner with others based on a random assortment of countries, which accounts for the respective participation level of each country in a network. The probabilistic affinity index (PAI) that is obtained in this manner compares the number of co-participations between any two countries to their expected number of co-participations based on their respective shares of all participations in the network. A score above one therefore indicates that two countries preferentially partner with one another, whereas a score below one means the opposite. Note that the scores are transformed so that they are symmetrically distributed between -1 (maximal negative affinity) and +1 (maximal positive affinity). By looking at how the affinities of country pairs changed from FP6 to FP7, it is therefore possible to appreciate whether integration generally progressed between both editions to assess whether or not the framework programme filled structural holes in the network.

In this case, structural holes under FP6 consist of the country pairs with negative affinities. Thus, in a chart where the affinity of each country pair under FP6 is presented on the x-axis and the corresponding affinity under FP7 is presented on the y-axis, if most of the data points lying to the left of the y-axis are above the x-axis (i.e. in the upper left quadrant), then one could assume that the framework programme filled most of the structural holes (i.e. negative affinities under FP6 became positive under FP7). On the other hand, if most data points lay on a quasi-perfect regression line whose regression coefficient is nearly equal to one, then one could assume that FP7 generally reproduced the pattern of affinities between countries found in FP6. This is what the data actually shows in Figure 16. Therefore, FP7 did not fill structural holes at the country level relative to FP6.

Figure 16 Relationship between the affinities of country pairs under the co-participation networks of FP6 and FP7



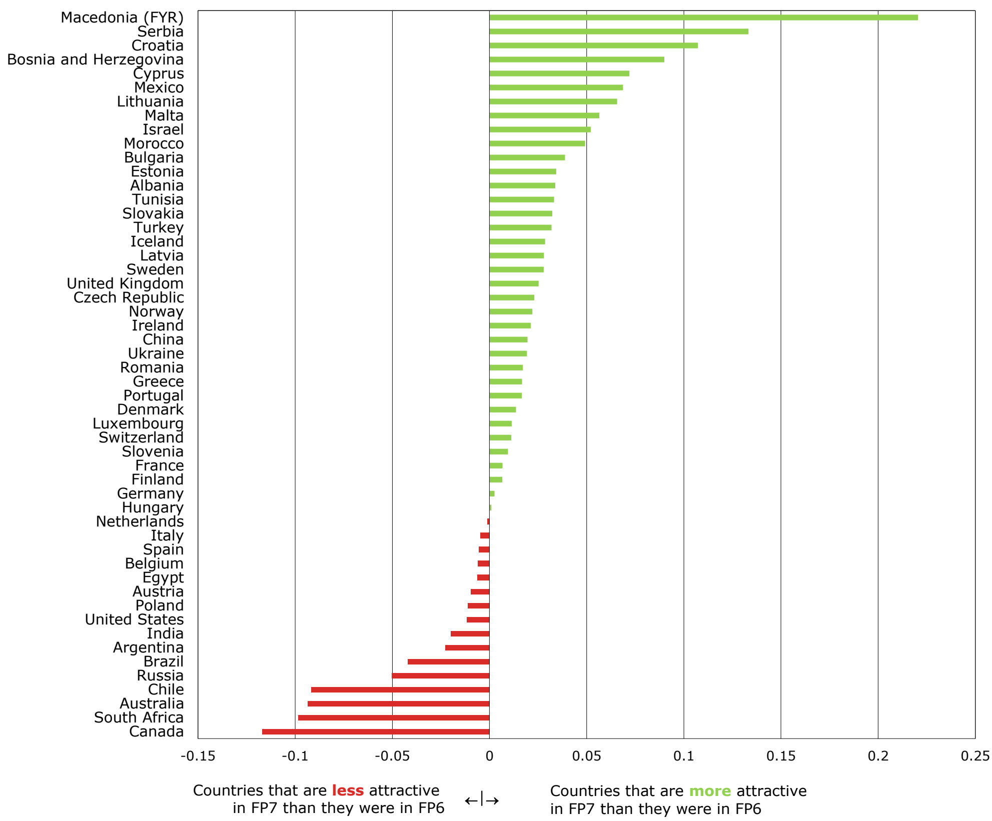
Note: Each point represents a pair of countries; its probabilistic affinity index (PAI) in FP6 is charted on the abscissa, and its PAI in FP7 is charted on the ordinate.

Source: Computed by Science-Metrix using CORDA (European Commission) data

Note that there are nevertheless some outliers in the above charts that may point to some countries whose integration improved from FP6 to FP7. By looking at how the affinities of a country (i.e. its affinities for each of the other countries in the network) changed from FP6 to FP7, it is also possible to appreciate whether it became a more prominent actor in the network taking account of its size (i.e. its number of participations).

Figure 17 presents evidence on the countries that benefitted more systematically than others from changes in affinity—that is, which countries became more preferred as collaborators in FP7 compared to where they stood in FP6. It is very noteworthy that former Yugoslav countries, and in particular the former Yugoslav Republic of Macedonia, Serbia, Croatia, and Bosnia and Herzegovina, were the ones that found new fame in FP7 relative to FP6 (Slovenia's attractiveness changed comparatively little). This is likely to reflect at least in part the application of Croatia for EU membership, which started in 2003, with Croatia becoming an EU Member State in 2013. Many eastern EU Member States increased their attractiveness in FP7 including Bulgaria, Estonia, and Slovakia. In Asia, China gained some ground while India was not in favour as much as it was in FP6. Poland, Austria, Spain and Italy are ERA countries that lost more of their appeal in FP7, while Canada, South Africa, Australia, Chile, Russia, Brazil, and Argentina are those outside the ERA that lost more of their lustre in the new framework programme. These data demonstrate that FP7 has facilitated not only the integration of new EU Member States, but it has also been able to provide greater integration for countries that were on the ERA periphery. It shows that countries outside the ERA are, with a few exceptions, not as attractive as they used to be.

Figure 17 Country change in attractiveness between FP7 and FP6



Source: Computed by Science-Metrix using CORDA (European Commission) data

11.1.3 Cross-country co-publication in FP7 and the integration of countries

To assess the extent that international research relations promoted by FP6 and FP7 in the form of co-participation in framework programmes translated into co-authored scientific publications, an analysis has been carried out using framework programme supported publications (see Section 4). FP6- and FP7-supported publications were first identified by searching publications indexed in the WoS that acknowledged FP6 and/or FP7 financial support through searches for programme names/acronyms, framework programmes' project unique identifiers, project acronyms, and so forth. The retrieved publications were then tagged as either FP6- or FP7-supported depending on the funding acknowledgement. In some cases, publications acknowledged both FP6 and FP7, such that some of them appear under both FP6- and FP7-supported papers. Using those two sets of framework programme supported publications it was then possible to investigate the potential role of framework programmes in translating international cooperation in the form of co-participation in framework programme projects into co-publications in the scientific literature.

Based on the co-publication data of framework programme supported papers, similar findings are obtained to those based on co-participation data for both FP6 and FP7. For instance, when comparing the international co-authorship rates—globally (first set of three columns presenting data in Table III in Section 4)—of framework programme supported publications to those of papers involving at least one ERA country but that were not supported by a framework programme, it is clear that the framework programmes promoted stronger international research relations (intl. coll. rate of about 57% for FP-supported papers compared to about 36% for other ERA publications) to a similar extent under FP6 and FP7. This is, as was the case for data based on co-participation, especially true within the ERA. In terms of co-authorship beyond the ERA, only FP7 facilitated co-authorship between ERA and non-ERA countries to a larger extent than is observed for papers involving at least one ERA country but that were not supported by a framework programme. As was the case for data based on co-participation, the magnitude of effect beyond the ERA remains small (see Table III in Section 4).

To assess whether the cross-country co-publications that resulted from FP7 led to the increased integration of countries, the co-publication network of countries based on FP7-supported publications was compared to the co-publication network of countries based on the publications produced by FP7 participants ahead of their FP7-related contributions. The co-publication network of countries based on FP6-supported publications was not used as the reference to study trends in the integration of countries for two main reasons. Firstly, it has been shown above that both FP6 and FP7 promoted international relations in the form of co-participations and co-publications to a similar extent. Therefore, it is likely that no difference would be observed in the level of integration of countries in both groups of papers. Secondly, many of the participants are new to FP7 and therefore did not directly benefit from FP6. As such, their tendency to collaborate internationally, as well as the integration of countries in their publications, might very well have been increased as a result of their participation in FP7.

Here, the analysis was done using the publication portfolios of researchers who participated in at least one FP7 project. As explained in Section 4, the publication portfolios of researchers who participated in at least one FP7 project were constructed using the WoS. Using these portfolios, FP7-supported publications were identified as those acknowledging FP7 financial support. Publications produced by those researchers ahead of their participation in FP7 were tagged as 'pre-FP7' papers.

For FP7 participants, the international co-publishing rates—globally, between ERA countries, and between ERA and non-ERA countries—clearly increased both within and outside the ERA when comparing their pre-FP7 papers to their FP7-supported papers. These rates and their increase (in percentage points; see 'Delta' column in

Table IV [Section 4]) are also notably stronger than for the ERA as a whole (excluding papers by FP7 participants) over the same period, although to a lesser extent for international partnerships beyond the ERA compared to within the ERA. This indicates that the cross-country co-participations promoted by FP7 contributed to increasing the propensity of participating researchers to produce their research through international partnerships, potentially contributing to furthering the integration of European research both within and beyond the ERA to a greater extent than has generally been observed for the ERA as a whole (i.e. for ERA researchers who did not participate in FP7).

Finally, to test whether the increased propensity of researchers to co-author their papers with international peers indeed translated into a stronger integration of the various groups of countries involved in the scientific literature, a similar approach to the one used above in Section 11.1.2 was implemented. Briefly, a test was performed to assess whether or not the eigenvector centrality of countries (i.e. a measure of integration in collaboration networks) generally increased in the co-publication network of FP7-supported papers relative to the co-publication network of pre-FP7 papers. The test was performed for each of the following groups: ERA, non-ERA, EU28, EU15, latest EU members and Candidates/EFTA countries (Table XXXVIII).

The stronger integration of ERA and non-ERA countries resulting from FP7 is evident when comparing their centrality scores within the co-authorship network of publications produced by participants prior to FP7 to those within the co-authorship network of FP7-supported publications. Indeed, a majority of ERA and non-ERA countries (about 70% in both cases) have seen a significant ($p < 0.05$) increase in their rank based on their eigenvector centrality. For ERA countries, this is mostly attributable to the increased integration of the latest EU Member States (centrality rank increased for 92% of those countries; $p < 0.05$).

Table XXXVIII Centrality scores of countries for pre-FP7 and FP7-supported papers

Country group	% Countries with increased rank	% Countries with increased rank (excluding ties)	Z-Score	p-value†
ERA	14.8%	67.5%	2.419	0.008
Non-ERA	47.5%	70.2%	4.737	0.000
EU-28	10.4%	67.9%	2.095	0.018
EU-15	3.8%	46.7%	-0.057	0.523
Latest EU Members	6.6%	92.3%	3.110	0.001
Candidates/EFTA	4.4%	66.7%	1.177	0.120
Total	62.3%	69.5%	5.133	0.000

Note: The Wilcoxon signed-rank tests whether a significant increase occurred in the centrality scores of specific country groups within the co-publication network of FP7 participants between the period preceding their participation in FP7 and the period while they were supported (only FP7-supported papers, identified using funding acknowledgements, are considered in this period). When the Z value (i.e. [sum of signed ranks]/square root [sum of squared ranks]) is positive, differences tend to be greater than zero (i.e. there is generally an increase in the centrality of countries), when it is negative, differences tend to be less than zero (i.e. there is generally a decrease in the centrality of countries).

Source: Computed by Science-Metrix using CORDA (European Commission) data

SNA results indicate that framework programmes promote international co-authorship for FP6 and FP7 and that at least for FP7 participants (most of which were not involved in FP6 as seen in Section 4) their international co-authorship rate within and beyond the ERA are markedly higher than for the ERA generally, facilitating their integration. While physical proximity remains important in research collaboration and networks, the literature shows that the decreased cost and time of travelling, together with the development of information and communication technologies, may also have contributed to increasing research collaboration at a distance. Furthermore, governments, through various R&D funding schemes, have increasingly encouraged the development of research collaboration and networks at distance with aiming to, including, but not limited to, favouring knowledge transfer and integrating research activities to achieve critical mass, as is the case of the ERA (Adams et al., 2005; European Commission, 2010b).

11.2 International integration of the ERA and the competitiveness of European science & technology

Finding 42	By producing positive outcomes sought by FP7, international cooperation within the ERA contributes to raising the international competitiveness of European countries

Finding 43	EU immigration laws and travel visa requirements can act as a barrier to framework programme projects and hinder international cooperation

Based on the intervention logic of FP7, the enhanced international integration of the ERA resulting from it should raise the innovation capabilities and international competitiveness of Europe, which, in turn, should result in a diverse set of socio-economic benefits (see logic model of FP7, Figure 2). This section investigates whether the improved international integration of European research resulting from FP7—within and beyond the ERA as measured in co-publication networks—contributed to raising the international competitiveness of European science and technology, in part through stronger innovation capabilities of the supported projects.

To analyse whether the international research relations promoted under FP7 have a significant and positive effect on the production of expected outputs/outcomes as laid out in the programme's logic model (Figure 2), regression analyses were performed for each of the bibliometric and survey variables presented in Section 6.3 as the dependents in the implemented models. The regression models that have been implemented incorporate—as explanatory variables—numerous networking dimensions beyond the international collaboration facet (e.g. the disciplinary and sectoral dimensions), as well as numerous controls such as the number of research publications produced by a given team's members prior to their participation in FP7. Since the number of participants in a project is strongly associated with a greater extent of networking across various dimensions, a number of the networking variables—including the one on international relations within the ERA (i.e. number of ERA countries [R = 0.92])—could not be included alongside the number of participants in the model as this would have resulted in redundancy across variables (i.e. multicollinearity). This is important as too much redundancy in a dataset can lead to spurious conclusions regarding the significance of the regression coefficients and to coefficients of unexpected sign (Zar, 1999). Consequently, where it was necessary to work with a specific networking dimension—such as international relations within the ERA (i.e. the number of ERA countries on a project)—that is highly correlated with the number of participants, the former variable was used in place of the latter in the model. Refer to the companion methodological annex for details on the regression analysis.

The number of ERA countries in a project appears to relate significantly and positively with the volume of new knowledge produced (measured by the number of FP7-supported publications produced by the participants). In this case, since both the independent and dependent variables are log-transformed (refer to the companion methodological annex for details on the variable transformations), the regression coefficient (0.12) can be interpreted in terms of elasticity. In other words, a 10% increase in the number of ERA countries is associated with a 1.2% increase in the number of FP7-supported papers (Table XXXIX). Combined with the moderately high adjusted R-square of the model (0.68), this might appear as a very slight effect. However, since the number of publications produced by the project teams prior to their participation in FP7 was included as a control variable, one could assume that this effect is really attributable to the interacting/networking effect of having multiple ERA countries involved rather than to a simple increase in the production capacity of the teams, which would be expected from having multiple people performing some work independently of one another. The size of a project's scientific output also seems to increase with its budget (about 1% increase in output per 10% increase in budget), but with clearly diminishing returns as the size of projects increases.

Table XXXIX Relationship between the number of ERA countries on a project and scientific output under the Cooperation and Capacities specific programmes

Explanatory Variables	No. of papers	Avg. of Rel. Impact Factors (ARIF)	Avg. trans-disciplinarity	Avg. no. of ERA countries per paper	Avg. no. of non-ERA countries per paper
No. of ERA Countries per project	0.116*** (0.042)	0.009 (0.071)	0.030** (0.013)	0.202*** (0.038)	0.021 (0.037)
Project Budget	0.104*** (0.019)	-0.02 (0.032)	-0.010** (0.006)	-0.042** (0.017)	-0.004 (0.017)
All other independent and control variables					
R-sq-adj	**0.684**	**0.401**	**0.832**	**0.460**	**0.534**
N	**732**	**250**	**248**	**708**	**708**

Note: Excerpt from the multiple regression model only for the explanatory variables discussed above. All variables presented in this table are log-transformed (natural log) except for the Avg. of Rel. Impact Factors and Avg. transdisciplinarity of FP7-supported papers. All models are statistically significant at $p \leq 0.05$. *: $p \leq 0.10$; **: $p \leq 0.05$; ***: $p \leq 0.01$.

Source: Computed by Science-Metrix and Fraunhofer ISI using CORDA (European Commission), WoS (Thomson Reuters) and survey data

The results also indicate that the number of ERA countries on a project effectively translates into increased collaboration, in the form of international co-publications within the ERA, as measured by the scientific publications resulting from FP7 projects (regression coefficient of 0.20; both the number of ERA countries on a project and the average number of ERA countries per FP7-supported papers are log-transformed); note that the model controls for the average number of ERA countries per papers produced by the team participants prior to their participation in FP7.

Altogether, the results of the regression model indicate that the networking that resulted from having multiple ERA countries on FP7 projects lead to FP7-targeted positive outcomes, which are expected to reinforce, at the national level, the innovation capabilities of Europe in the long run.

Another means through which international research relations can be fostered besides cross-country co-participation in FP7 projects within and beyond the ERA is by specifically attracting *renowned* international researchers to collaborate with the ERA. In the survey, the following question was asked to assess whether or not this mechanism might have played a role in FP7:

> Has your FP7 project been successful in attracting internationally renowned researchers from outside the European Union and FP7 associated countries from…

…technologically leading nations (e.g. USA, Japan)?

…technologically rising nations (e.g. China, Brazil)?

…technologically developing nations?

Many participants report that renowned international researchers have been attracted. In more detail, 24% of survey respondents reported that such researchers had been attracted from technologically leading nations, 15% reported attraction of researchers from technologically rising nations, while 10% confirmed an attraction of key scientists from developing countries. Although these figures may not seem impressive at first sight, the question explicitly asked about *renowned* scientists and thus intentionally inquired about the (smaller) number of cases in which key experts in a respective field could be persuaded to join a consortium. Against this background, figures like 24% demonstrate FP7's substantial impact on attracting human capital to the ERA, which is highly likely to raise the research excellence and competitiveness of European science.

All 12 case studies include examples where partners from different countries work together and travel across borders to meet. However, EU immigration laws and travel visa requirements were noted as an obstacle in several cases, making it challenging for project participants to attend conferences or meet face-to-face, thus decreasing the effectiveness of international cooperation.

11.3 Is there an ideal number of ERA and non-ERA countries on a project?

Finding 44	The higher the number of ERA countries, the stronger the beneficial outputs/outcomes sought in FP7

Finding 45	The presence or absence of non-ERA countries does not appear to have an impact on the production of the positive outcomes sought in FP7

Finding 46	The lack of transparent and strong project management and coordination can hamper the successful execution of projects

In relation to the above findings regarding the effect of international research relations on the production of positive outputs/outcomes, the following questions arise:

- Is there an optimal number of ERA countries on a project?; and
- Is the presence of non-ERA countries strongly associated with successful outputs/outcomes?

To answer these questions, the performance of FP7 projects was measured through the use of a composite indicator synthesising the positive outputs/outcomes measured with bibliometric indicators and the survey. This subsequently allowed studying differences in the performance of projects according to a number of dimensions (i.e. the number of ERA countries and the presence/absence of non-ERA countries) to see whether or not an optimal size exists with respect to these dimensions. The construction of the composite indicator is presented in Section 6.3. Note that this approach only looks at one networking variable at a time and does not include any controls as was done in the previous section on the regression analysis.

Based on this analysis (Table XL), there does not appear to be a turning point related to the number of ERA countries involved in a project where the benefits of adding more ERA countries decrease or level off. Indeed, there are significant differences across groups for all specific programmes and the mean rank sum increases as the size of group increases in all specific programmes. This is reflected to some extent in the median and mean scores of groups within all specific programmes, though to a lesser extent under Cooperation.

Table XL Performance, as measured with a composite measure of positive outcomes, of FP7 projects across networks of varying sizes as regards the number of ERA countries involved, by sub-programme

	Cooperation				Capacities				People		
Descriptive Stats	**(1-5)**	**(6-7)**	**(8-9)**	**(10-25)**	**(1-4)**	**(5-6)**	**(7-9)**	**(10-26)**	**(1)**	**(2-4)**	**(5-10)**
N of Cases	116	152	122	110	22	27	26	36	133	40	36
Minimum	15.2	12.0	14.9	14.0	14.7	16.2	19.4	26.2	11.0	19.0	22.0
Maximum	64.5	54.2	53.5	57.2	72.0	53.5	55.5	64.7	75.7	52.9	65.3
Median	31.0	31.2	30.7	33.2	27.4	26.4	31.7	37.7	25.7	28.7	31.3
Arithmetic Mean	31.4	30.8	31.7	33.3	29.0	30.5	31.8	39.5	27.3	30.5	31.7
Mean Rank Sum*	241	238	246	282	38	45	52	78	93	120	132
Standard Deviation	7.1	7.3	7.5	7.7	11.2	9.7	7.5	9.2	9.4	7.8	7.7
Variance	49.8	54.0	55.5	59.3	126.1	94.7	56.9	85.1	89.1	61.4	59.3

Note: * Significant differences exist between groups for Capacities (p = 0.00) and People (p = 0.00). Nearly significant differences exist between groups for Cooperation (p = 0.07). Tested using a Kruskal-Wallis test.

Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Thus, if there is an optimal maximum with regards to number of ERA countries on a project, it does not appear to have been reached in the context of FP7 based on this analysis. Here, the higher the number of ERA countries, the stronger the beneficial outputs/outcomes, though there are likely diminishing returns to scale as the size of the group increases, as shown in Section 11.2.

The presence or absence of non-ERA countries in the team of FP7 projects generally does not appear to have an impact on the production of positive outcomes as measured with the composite indicator. Though there is a positive increase in the mean-rank sum for both, there is no statistically significant difference observed across groups for both Cooperation and Capacities. For Capacities, a positive difference in the median and mean composite scores is observed in addition to that for the mean rank sum. The non-significant result might stem from a lack of statistical power due to the small sample size of the group including non-ERA countries (i.e. n = 16). Also noteworthy is that this finding, established at the macro level (i.e. on a regression analysis aiming to infer characteristics of the whole population of projects/participants), does not mean that international research relations cannot be a crucial factor for the success of specific projects at the micro level.

Table XLI Performance, as measured with a composite measure of positive outcomes, of FP7 projects across networks involving or not non-ERA countries, by specific programme

Descriptive Stats	Cooperation		Capacities	
	Absence	Presence	Absence	Presence
N of Cases	348	152	95	16
Minimum	12.0	14.8	16.2	14.7
Maximum	54.2	64.5	72.0	58.6
Median	31.4	31.4	31.6	35.5
Arithmetic Mean	31.3	32.5	32.9	36.7
Mean Rank Sum*	246	260	54	67
Standard Deviation	7.3	7.7	10.0	11.5
Variance	53.3	58.5	100.0	132.0

Note: * No statistically significant difference across groups; tested using a Kruskal-Wallis test.
Source: Computed by Science-Metrix using CORDA (European Commission), WoS (Thomson Reuters) and survey data

Using the same regression models mentioned above, one interesting finding is that among FP7 participants, nominating an individual to oversee the management and coordination of a given project (a control variable in the regression model) appears to be beneficial to the success of international collaboration, at least in the form of international co-authorship beyond the ERA. Note that although this effect is significant, its magnitude is small and only applicable to Cooperation and Capacities, which is not surprising since People and Ideas were not fostering cooperation by design. Furthermore, the regression analysis shows a significant and positive effect of interaction between the number of participants and project coordination on a few positive outcomes such as the breadth of S&T tools creation, and effect on careers. Note that this effect is of a small magnitude and not systematic across all types of outcomes and not applicable to Ideas and People (data not shown). These results therefore suggest that in the absence of proper project management and coordination, the effectiveness of collaboration can be hindered.

Additionally, the cross-case analysis of the case studies reveals that a strong and transparent management structure is critical when dealing with international research, most especially because of potential issues that may arise from cultural differences, geographical distances and language barriers. A project manager must ensure that each partner's purpose for participation is communicated with all partners. Four of the projects held in-person kick-off meetings at the initiation of the project to bring partners together and coordinate proceedings. In two of the largest projects examined, the coordinators and consortia actually devoted the better part of the first two years of the project to networking and engaging all partners. This included the support of various discussion platforms that enabled partners to develop network links without being hindered by geographical or cultural barriers. For example, in one project discussion platforms included more than 20 face-to-face meetings, over 50 telephone conferences, an intranet service, project newsletters, online forums and email exchanges. Interviewees said that this was time well spent, allowing for a common understanding of roles and responsibilities for each partner.

Thus no matter the extent of international collaboration targeted, the variety of contextual factors presented here gives an indication of how the achievement of that collaboration can be greatly influenced within the context of each individual project in the absence of proper project management and coordination.

12 CONCLUSIONS AND RECOMMENDATIONS

The framework programme is likely the largest research and technological development (RTD) experiment the world over. It is the largest laboratory to experiment with international, interdisciplinary, and intersectoral collaboration, and the result is the largest heterogeneous research and innovation network on Earth. It is a bold venture. The report shows this experiment has delivered great results, as thousands of projects yielded knowledge externally validated through publication in peer-reviewed journals, new tools were created, innovations were triggered, and knowledge was transferred to society and to business enterprises. FP7 succeeded in what it meant to achieve, as depicted in the logic model of EC intervention based on the support of networked research (Figure 2). The present study shows that the framework programmes and FP7 have great potential to continue to contribute to increasing the EU's competitiveness in research, but that they also have some limits. Section 12.1 discusses the contribution of FP7 to competitiveness at the organisational, regional and national levels. The report concludes with six recommendations that are made to address current framework programme limits (Section 12.2).

12.1 Contribution of the network approach to the achievement of EU Research Policy objectives (FQ1)

Project terms of reference: How far did the network approach, promoted and implemented by FP7, contribute to the achievement of EU Research Policy objectives?

- What are the effects of networks on strengthening the overall innovation capabilities at local, regional and national levels?
- How have the networks contributed to the improvement of the competitiveness of national economies?

This study shows that networking projects, as supported in FP7, contributes to achieving the objectives they were expected to achieve, and to the extent that more knowledge, individuals, organisations and innovation triggers competitiveness in all these areas, then FP7 has clearly contributed to economic competitiveness at the local, regional, and national levels, as per the logic model presented in Section 3.2. Overall, there is ample evidence that FP7 contributes to EU research policy objectives both directly and indirectly. Aside from knowledge creation, direct and measurable effects include:

- Increased integration of ERA countries
- Increased cross-sector integration
- Inclusion of new participants in research projects with potentially beneficial effects on innovation
- Increased multidisciplinarity, especially in Capacities and Cooperation
- The development of new methods, technologies, concepts, S&T tools, products, and new lines of research that may eventually lead to new disciplines or fields of research

A number of less quantifiable but still tangible benefits are observed via the network approach embodied by FP7:

- Tacit knowledge sharing through networked project participants
- Leveraging of prior knowledge and relationships to overcome project obstacles and apply for new funding. This in turn appears to relate positively to the production of favourable outputs/outcomes such as improvement in increased scientific output, the scientific impact of FP7-supported publications, the breadth of knowledge and S&T tools created, the transfer of research results to the business sector and society as well as career development
- Strengthening of existing mature networks and expansion of new networks
- Fostering researcher mobility

The overall intervention logic of European framework programmes is that innovations by researchers and organisations increase the competitiveness of the localities, regions and countries where they are located. This study has shown that FP7 yielded a large number of positive outcomes and that several projects reported that knowledge was transferred to society and businesses, and that innovations were triggered. Regression analyses revealed that some of the networking variables—such as pursuing a collaboration over framework programmes, having new partners in a continuing relationship, having established links with organisations outside the scope of the project, having a comparatively large average number of regions per project, and the involvement of SMEs in a project—do have a positive and statistically significant effect on innovations triggered and the excellence of knowledge produced [Finding 2, Finding 9, Finding 20, Finding 35]. Thus, this study has provided many indications that networking played a positive role in triggering innovation that benefitted participating organisations. This study has shown that innovation and knowledge transfer commonly occur in FP7 projects, and these outcomes are assumed to lead to increased competitiveness. However, competitiveness as an end goal in itself was not demonstrated directly.

One cannot fully discuss the effects of networking at the local, regional, national and EU levels without first referring to the most direct and basic beneficiaries of the framework programmes: researchers, highly qualified personnel and organisations. Networks and complex innovation systems, such as agglomerations, regions, countries and the like, take on the characteristics of individuals and these are made better, or worse, by emergent, system-level properties that result from their interactions with the local and global environment. Two aspects are therefore essential in considering how the static characteristics changed: the disposition of individuals and organisations including their knowledge, skills and know-how, and how the dynamic effects of their interaction change the more complex, larger-scale systems they are part of.

Coming back to the logic model presented in Section 3.2 of this study, FP7 provided support for researcher mobility, and their career and development. Likewise, the basic programme provided all kinds of support to individuals and organisations to facilitate transnational cooperation, to coordinate the work of regional actors, and to develop and use infrastructures, in addition to non-R&D activities such as dissemination studies. To put it in one word, all these forms of support facilitated *learning* at the individual and organisational levels and by extension at the local, regional and national systems levels.

A programme of the size of FP7 has certainly allowed individuals to learn a great deal, and by making individuals wiser, more knowledgeable, and more skilled, it has improved their competitiveness in an environment where these attributes are key success factors. Perhaps the most important factor to consider is that they have learned to interact and to cooperate and this is especially important in enlarging the benefits of this increased competitiveness to the higher-level, larger-scale, local, regional and national systems.

Learning is an especially important aspect of the framework programme experience. Normally, as a consequence of adding many new participants in a network, the collaboration network density would be expected to drop. This is because network density measures how well each node is connected in a network and the number of possible connections does not grow linearly. If one excludes the Marie Curie Actions from FP6 and the People and Ideas specific programmes from FP7 (because these supported individuals as opposed to projects with individuals from several organisations), the number of supported projects increased from 5,331 in FP6 to 8,867 in FP7—a 66% increase.

The number of potential connections between organisations can be calculated using Metcalfe's law, which stipulates that the number of connections (or edges) in a network is equal to $n(n - 1)/2$, where n is the number of nodes, which are organisations in the present case. In FP7, there were 24,885 organisations participating in the two specific programmes that encouraged networks (Cooperation and Capacities), compared to 20,283 in FP6 (excluding Marie Curie Actions). There were some 450,000 new collaboration pairs in FP7. Although this shows that the number of connections increased faster than the number of organisations, clearly this is much lower than the number of theoretically possible new connections. To completely connect all the organisations in FP6 would have required 200 million edges, and 300 million edges would have been required to directly connect all organisations participating in FP7.

Just like the pioneers who designed the first telephone networks—who realised that connecting each telephone subscriber directly would be cost prohibitive, and that interconnected central exchanges would be much more efficient—social networks self-organise and organisations do play the role of an information central exchange. Occupying this role in a network is advantageous as it allows the more rapid accumulation of knowledge.

This gives rise to a puzzling situation in EC framework programmes. The EC seeks to increase connectedness between organisations and would ideally like them to be closely connected, to have a high network density, and hence few structural holes (see the terms of references of this project at the beginning of Section 9). By having more organisations joining the framework programmes, then clearly it is achieving its objective of having organisations, potentially from all over the ERA, being better connected, as compared to being completely unconnected.

It is impossible to 'wire' each new organisation to all other participants in the network directly—installing 100 million new connections would not have been possible. Thus, just like a telephone network, these new connections reach out to other participants through those who are more established. The puzzling aspect in the framework programme is that while it augments connectedness of previously unconnected organisations, it necessarily decreases network density, creates structural holes, and increases the importance of large 'information exchanges' such as the CNRS, CNR, Fraunhofer, and large prestigious universities, such as Oxford. In this, larger organisations gain more power, as they increasingly play a key role.

Thus, though there is a paradox and the result of the intervention is not necessarily that intended in every respect, it nevertheless helps the competitiveness of Europe by increasing the connectedness of previously unconnected organisations, and increases the strength of its leading organisations in an environment where critical mass confers competitive advantage. In this way, the promotion of the network model increases connectedness and critical mass, but at the expense of high network density and equalitarian distribution of knowledge and the power it confers.

Importantly, the learning effects are significant. As organisations join and remain within the framework programmes, even smaller 'exchanges' start dispatching more information, as they are likely to maintain old connections and make new ones.

Thus, clearly the effects of increased participation in networking in FP7 are twofold. In a context of growing participant numbers, large entities are in a position to increase their capacity to broker knowledge, particularly with the more peripheral entities. Large entities are in a position to become power brokers, and help the ERA by having organisations with critical mass. For peripheral entities, entering the network starts a learning curve. These entities learn to exchange information, and as their connections grow over time, so does their centrality and their capacity to play an important knowledge exchange role in the innovation system.

While the larger players can pick and select their collaborators and with whom they share their information, the peripheral actors are highly dependent, have comparatively little negotiating power, and are frequently left in dark. They are simply not on the preferred information paths. Stamina, repeated participation, and a willingness to increase one's connections are the only way forward to better one's position when on the periphery. Note that being on the network's periphery is a function of not being well connected. This can frequently happen to geographically peripheral entities and smaller organisations, but is not limited to them, nor do small organisations and geographically remote entities necessarily have to be on the network outskirts. For example, large organisations, even those close to the European centre of gravity, can be peripheral if they have only few interactions with the other members of the network.

Despite the possible difficulties of being on the network periphery and of relying on the more central players to relay information, being an autarkist and not participating is a potentially dangerous choice as the network is a large and complex 'nervous system'. Those outside are likely to face even more challenges accessing the information contained in that system.

Though there is no doubt that FP7 succeeded in establishing multidimensional networks, and also that these networks yielded the expected outcomes and hence one can conclude that FP7 was effective, one important question requires further thought: How efficient was this approach? A subsidiary question is whether some of the components of the framework programme approach are actually required and to what extent they should be promoted. In particular, though multidisciplinarity, interdisciplinarity, and intersectorality have been lauded in the innovation policy literature, the present study failed to confirm that they play an important role in the innovation process. Though inter-institutional, inter-regional and inter-country collaboration play an essential role in the building of the ERA, there is a need to openly discuss the evidence and the role of non-essential features as well as how they contribute to the framework programmes' effectiveness and efficiency.

12.2 Potentials and limits of the research network approach (FQ2)

Project terms of reference: What are the potentials and limits of this approach?

The findings of this study support the use of the network approach to generate outcomes such as knowledge transfer from research to industry in order to foster innovation, enhancement of integrated research performance in Europe, and improvement of overall European research capacities. Yet there is room for further improvement and also lessons to be drawn from the more robust aspects of this model, which ought to be preserved and in some cases strengthened to further contribute to the competitiveness of the EU.

In addition to highlighting a number of strengths and limits of networks as used in framework programmes, the present section provides recommendations to further enhance the effectiveness of networking in future framework programmes.

12.2.1 Network continuity

One of the present study's strongest findings is the beneficial effect of network continuity: grounding FP7 projects in work conducted in FP6 leads to well-organised and planned research producing more beneficial outputs/outcomes in the long run [Finding 2, Finding 3]. The renewal of successful projects and/or the promotion of recurring participation are potential avenues favouring the leveraging of knowledge produced in previous framework programmes.

Section 5 has shown that knowledge chaining occurs in framework programmes; that is, there is continuity in FP7 in the use of knowledge created in FP6. The evidence suggests that knowledge chaining yields more scientific papers and these are published in more highly cited journals, and highly cited journals tend to be of high quality. Continuity also increases the breadth of knowledge and tools created in research projects, and increases knowledge transfer to business and society.

The experience in framework programmes and in collaborative research in general shows that past collaborative experiences, particularly when they involved successful projects, have a positive effect on subsequent network performance. The most effective partnerships have a shared history that facilitates collaboration through trust, established routines, and tried-and-true working policies and procedures. Partners have also developed localised or specialised knowledge in the context of previous collaborations and have increased familiarity with members of the other team. Networks that are successful encourage investment in long-term relationships and develop a long-term perspective of the potential of the research conducted, which will eventually allow participants to see the results of the alliance and build on past achievements in an appropriate time frame. A long-term perspective is especially important for participating firms, where the more typical short-term profit perspective may increase their likelihood of leaving the network or stopping the innovation process before the innovation is fully developed.

Recommendation 1	Allow existing networks to receive additional funding in successive calls provided they demonstrate excellence and secure approval in peer reviews

This recommendation echoes the Interim Evaluation of the Seventh Framework Programme, which stated that: 'Another necessity in order to nurture and sustain high quality research is a certain amount of continuity in funding for research that proves valuable, provided that it continues to satisfy excellence criteria and secures approval in peer reviews' (European Commission, 2010a).

12.2.2 Adding new members to existing networks

While the evidence in Section 5 shows the importance of continuity, the evidence shown in Section 6 suggests that having new entrants in projects is also an important factor. This report provides evidence that having new partners increases the breadth of knowledge created and helps trigger innovations [Finding 9]. Case studies have provided evidence that by working with more established organisations and EU12 and EU15 Member States, newer and candidate states have been able to gain experience in international collaboration, further their research capabilities, and develop and strengthen their own networks. New partners should be given the means to benefit from the experience of the more established partners and gain access to the knowledge accumulated in the network. Attracting newer organisations is also a certain way to facilitate the integration of the ERA and Member States.

New entrants, who are more likely to be on the periphery of the networks, also benefit from the continuity of existing networks. In core-periphery networks such as the ones observed in the framework programmes at the national, regional and organisational levels, new entrants are more likely to be located at the outskirts of the network and to be poorly connected, surrounded as they are by structural holes [Finding 29]. Given that 72% of organisations were new to the network in FP7 [Finding 5], these new entrants have to be given means to progressively increase their connectedness, or in network analysis terminology 'to increase their level of centrality'. This also reflects the Interim Evaluation of FP7: [FP7] 'may also have a structuring effect on national innovation and research systems, notably in Member States where they are less developed. But to consolidate these gains and to make impacts enduring, researchers have to be able to obtain repeat funding. This suggests that for excellent scientific outcomes and/or impacts to be capitalised, continuity in framework programmes must be ensured, while avoiding giving "insiders" too easy a ride' (European Commission, 2010a).

While the previous recommendation suggests supporting some of the existing networks to allow them to pursue their work as part of new calls, this should neither be perceived as a right nor as a privilege of established networks. It is not suggested that existing partnerships be given 'too easy a ride'. Rather, they should only be supported when they demonstrate their capacity to evolve, become more dynamic, seek new challenges and—just as importantly and as supported by the evidence presented in the present study—be open to new partners. Networks should not be allowed to become closed and to stall. Conditions do, however, need to be suitable for the renewal of networks in order to foster continuity across successive calls.

Recommendation 2	In the case that an established network is supported in successive calls, ascertain that new members are present

12.2.3 Understanding why so many participants quit

The evidence in the present report shows that FP7 contributed to building the ERA, connected peripheral organisations and regions, and helped the more central ones achieve critical mass. It has achieved this through the promotion of interconnectedness at all scales—researchers, disciplines, sectors, organisations, regions, and countries. FP7 can therefore be considered a greatly successful programme, as were those that preceded it.

Yet considering that framework programmes are so effective, why did so many organisations not continue their participation in FP7? There were 13,434 organisations that participated in FP6 that did not participate in FP7 [Finding 6, Finding 8]. Surely, some of them have disappeared because their priorities have changed. However, for some of them, a decision to quit likely reflected the impression that the benefits of framework programmes were not worth the effort. One possibility is that current procedures are perceived as too complex by participants, as mentioned in the FP7 Interim Evaluation:

> The complaints that the Expert Group has read and heard about the administrative burdens of involvement in FP7, despite the many worthwhile changes adopted since FP6 under the banner of simplification, testify to the continuing frustration in this regard. Too many procedures continue to be unwieldy or disproportionate to the very marginal benefits they provide in terms of control of public spending, and there is strong evidence of a lack of flexibility. The Expert Group concludes that while many of the specific developments are welcome, a much more radical approach is now needed to attain a quantum leap in simplification. In particular, the risk-trust balance needs to be redressed, as the current risk-averse culture inhibits participation and may be undermining the research most likely to result in genuine breakthroughs (European Commission, 2010a).

It is important to explain why only about one third of the organisations that took part in FP6, some 7,360, came back to FP7. Was it because the remainder could not qualify again because they did not meet the excellence criteria? Was it mission accomplished and no more could be learnt through framework programme type activities and interactions? Were they unwanted by their partners and not invited to cooperate again? As mentioned in the report, prior studies on the long-term impact of the framework programme model observed that networks within the framework programmes tend to evolve slowly, with new members being tested and admitted only once they have built trust and old members sometimes falling off the train (EPEC, 2011).

It is essential to understand why these organisations dropped out of the subsequent framework programme. Section 5 has shown how important continued participation is to obtaining positive outcomes and to trigger innovation. Also, as discussed, continued participation by more peripheral organisations is key to them progressively increasing their centrality in the network, thus becoming more important information hubs and gaining greater benefits from networking. Nonetheless, there may be good reasons for this large dropout rate, and it serves as a mechanism for the continuous rejuvenation of framework programmes, avoiding stagnation. As such, this high attrition rate should be understood, as opposed to being decried as a weakness with no consideration for the reasons behind this state of affairs.

Recommendation 3	Perform an in-depth study to explain why nearly two thirds of the organisations in FP6 did not participate in FP7 and investigate why many organisations will not participate in Horizon 2020

12.2.4 Revisit multidisciplinarity, interdisciplinarity and intersectorality

The collective wisdom in building a network and selecting members is that it is important to ensure complementarities of capacity. Capacities can take the form of time, expertise, funds, staff, materials, skilled leadership and other resources or competencies that will help to make the innovation happen. Common sense and the literature tells us that while it is important for members to share similar cultures and orientations, a network should also exhibit a cross-section of members from scientific disciplines and economic sectors that is appropriate for the objectives of the network. Diverse networks enable the sharing and creation of new combinations of technologies and knowledge, raising the likelihood of achieving product or process innovation. However, though FP7 succeeded in linking researchers from fields of science that do not frequently exchange knowledge [Finding 11] and also succeeded in supporting interdisciplinarity [Finding 12], this study failed to find strong evidence to support these claims [Finding 14, Finding 15].

Clearly, there are project management challenges presented by multidisciplinarity and interdisciplinarity [Finding 16]. The fact is that partners in a collaborative network have different organisational and national cultures, work styles, management structures, backgrounds and perspectives, and interests. These differences are sometimes difficult to overcome and may produce adverse, unintended effects. Research shows that ‘proximity’—not just geographical but also organisational, cognitive, and social—is important for the establishment and performance of inter-organisational collaboration. Attempts to ensure alignment of motivations, expectations, values and goals characterise successful networks. Yet framework programmes have encouraged intercultural, interdisciplinary and intersectoral collaboration to such an extent that it is possible to create networks that are ill born and with diversity challenges that exceed the potential benefits.

The present study, like so many before, has shown that ‘homophily’, or the tendency to associate with entities with similar characteristics, is highly prevailing [e.g. Finding 19]. Inherently, and as supported by case study evidence, business enterprises and universities have different cultures and interests—firms need to move fast, obtain results that can be translated rapidly into economic advantages, and appropriate these results privately, whereas university culture stresses the longer-term and open discussion of results, pursuing ever more research projects (‘more research is needed’), and placing results in the public domain. Not addressing these differences upfront is not best practice and can lead to friction down the road.

Hence, networks pose a challenge for adequately balancing academic versus industrial motivations. Academic research is driven by the impact it will have on the global research community, where measures of success are largely based on peer-reviewed articles and publications. Industry research, on the other hand, is driven by the commercial impact, and the measures of success are largely based on the long-term and often the shorter-term value it creates for the company. Such differing motivations can sometimes hinder the integration of partners, even in a mature and well-functioning network. In the absence of adequate coordination, it is possible that conflicting interests might be detrimental to innovation if too many sectors are involved [Finding 24].

This study was unable to find evidence demonstrating that multidisciplinarity, interdisciplinarity, and intersectorality increased innovation and other similar positive outcomes sought by FP7 [Finding 14, Finding 15, Finding 19]. Competing sectoral interests could be but one contributing factor to this, though more research would be needed to tease out such complexities. It is also possible that the size of the data pool available to the present study was not sufficiently large enough to extract more definitive evidence.

Yet the study has presented confirmation that the integration of business enterprises in a network increases the probability that innovations will be triggered [Finding 20]. Likewise, abundant anecdotal evidence has suggested that many problems encountered in research and many societal challenges need to be addressed by diverse teams composed of scholars from varied disciplines and of researchers from different sectors. The conclusion here certainly not is to turn the table and become anti-diversity. The suggestion rather is to better understand how diversity, homogeneity and expertise play different roles in tackling various research problems. A one-model-fits-all approach is unwanted, and requiring diversity for the sake of diversity may be inefficient and even ineffective. As such, and in the absence of supporting evidence that demonstrates their tangible benefits, the presence of interdisciplinarity and of intersectorality should not be mandatory elements in framework programme calls.

Recommendation 4	Interdisciplinarity and intersectorality should not become mandatory elements in framework programme calls

12.2.5 Project success and project management

As mentioned in this report, there are specific management challenges encountered in the multidisciplinary, interdisciplinary [Finding 16], intersectoral [Finding 24], international projects supported in framework programmes. This study, like several before, also found that the lack of transparent and strong project management and coordination can hamper the successful execution of projects [Finding 46]. Some studies suggest that effective networks integrate monitoring and evaluation processes into network activities from an early stage. These processes may include, for example, performance reviews or the periodic surveying of members and stakeholders. The results inform quality-control mechanisms and procedures and the ongoing orientation of the network.

The management literature comprises endless prescriptions on project management for research partnerships. The literature suggests that successful networks are management intensive. Regression analyses conducted for this study revealed that nominating an individual to oversee project management and coordination is beneficial to the success of international collaboration, at least in the form of international co-authorship beyond the ERA. Regression analysis also shows effective project coordination can have significant impacts on positive outcomes in Cooperation and Capacities, such as breadth of S&T tools creation, and career development.

A cross-case analysis confirmed that a strong and transparent management structure is critical when dealing with international research, most especially because of potential issues that may arise from cultural differences, geographical distances and language barriers. A project manager must ensure that each partner's purpose for participation is communicated with all partners. Four of the projects in the case studies held in-person kick-off meetings at the initiation of the project to bring partners together and coordinate proceedings. In two of the largest projects examined, the coordinators and consortia actually devoted the better part of the first two years of the project to networking and engaging all partners. This included the support of various discussion platforms that enabled partners to develop network links without being hindered by geographical or cultural barriers. For example, in one project discussion platforms included more than 20 face-to-face meetings, over 50 telephone conferences, an intranet service, project newsletters, online forums and email exchanges. Interviewees said that this was time well spent, allowing for a common understanding of roles and responsibilities for each partner.

While all projects (except those under the ERC) must have a project coordinator, survey results indicated that researchers were sometimes undertaking project management duties themselves and that the assigned project coordinator role was nominal. It is also worth noting that there is a significant difference between an inexperienced or multi-tasking project coordinator and an effective, motivated and dynamic project manager. Visionary, boundary-spanning, entrepreneurial project managers, particularly those with links to diverse groups or networks, help to foster strategic alliances. More formal bodies, such as a board of directors, can also strongly influence the gains to be made from network participation. Essential contributory factors for effective network management include a clear structure and hierarchy of partnership agreements, a clear division of labour, and an open and participatory decision-making process.

Considering the evidence on the challenges of managing the types of projects supported by framework programmes, and knowing that effective project management increases the likelihood of achieving positive outcomes, making use of best-practice project management would be a worthwhile investment.

Recommendation 5	Require that coordinators have demonstrated project management skills and networks have a clearly stated project management approach

12.2.6 Optimal project size and project mix

Studies suggest that an important determinant of the success of networks is that they have an appropriate number of partners and participants (not too few and not too many), given the particular nature and objectives of the joint venture. An optimal number of members enables participants to work more smoothly together and mitigates coordination issues.

This study has not been able to confirm the existence of optimally shaped collaborative research networks. For example, there does not seem to be an ideal number of sectors in a project [Finding 21], or an ideal number of international partners. In fact, given the feature size of the projects tested, positive results were associated with growing sector diversity [Finding 20] and a growing number of international participants [Finding 41, Finding 42]. When asked if they had to start anew, would participants prefer having fewer, the same number, or more collaborators, most of the respondents preferred having the same, or more, but some would have had fewer collaborators.

This study has shown that finding an ideal number of participants, disciplines, sectors, NUTS 3 regions or countries is elusive [Finding 10, Finding 17, Finding 21, Finding 35, Finding 44]. Either there is no clear effect of size on results, or continued increases do not curtail the capacity to obtain results. In all cases, the tests conducted only allow the study to provide insight on effectiveness—that is, the capacity to obtain outcomes. This does not mean that increasing scale or complexity does not come at a cost in terms of efficiency—that is, the capacity to produce specific outcomes with minimum expense and/or effort.

Considering the available evidence, there is a need to communicate clearly as part of calls that the constitution of teams should reflect the understanding of the team of the best way to address the specific problems of the project. This stance is in contrast to attempting to optimise the number of organisations, the level of interdisciplinarity, the level of intersectorality, the number of regions, and the number of countries in a joint proposal in such a way as to meet unspecified, untold norms by the European Commission. This reflects discussions held at the workshop where FP7 participants mentioned perceived unwritten rules that supposedly were taken into consideration in the adjudication process. While this feedback is anecdotal, it nonetheless represents the candid opinion of past programme participants and therefore merits addressing to clarify expectations for the benefit of all parties.

Recommendation 6	Produce clear guidelines for calls that mention the Commission’s expectations and absence thereof regarding selection criteria, such as number of participating organisations, level of multi/interdisciplinarity, level of intersectorality, number of regions, and countries, wherever relevant

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This report examines the effectiveness of the Seventh Framework Programme's network approach in achieving EU research policy objectives and fostering Europe's international competitiveness in Science & Technology. It summarises the findings of an in-depth analysis of FP7 participation amongst research networks and presents 46 findings and six recommendations. In investigating the potentials and limits of the network approach, the study examined the effects of multidisciplinary, interdisciplinary, intersectoral and international collaborations on achieving the positive outcomes sought in FP7. This was one of several preparatory studies for the overall ex-post evaluation of FP7, which is to be carried out over two years following completion of the Programme.

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