Universidade do Minho
Escola de Economia e Gestão

Miguel Nuno Linhares Pinheiro

From perfect strangers to research partners: A study of relationships, resource sharing and perceived benefits within R&D cooperation networks

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Doctoral Thesis in Marketing and Strategy

Conducted under the supervision of
Professor José Carlos Martins Rodrigues de Pinho
Professor Cândida Manuel Ribeiro Simões Lucas

August 2015

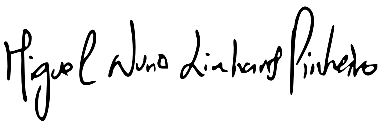
ii STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, 7th of August 2015

Full Name: Miguel Nuno Linhares Pinheiro

Signature: 

iii ACKNOWLEDGEMENTS

This thesis represents the end of a 5-year journey. I cannot look back and say, “I’ve made it”, without acknowledging some of the most significant contributions that made this work possible.

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iv TITLE AND ABSTRACT

Title:

From perfect strangers to research partners: A study of relationships, resource sharing and perceived benefits within R&D cooperation networks

Abstract:

The present thesis aims at providing guidelines for researchers and managers of R&D cooperation networks as to maximize value creation, by taking into account partners' relationships, shared resources and perceived benefits.

Based on a combination of qualitative and quantitative methodologies, data for this study was collected through interviews and a large survey of researchers involved in R&D cooperation networks within the Biological Sciences domain.

The main results of the present thesis show that:

1. Social Network Analysis (SNA) is a relevant tool to examine and understand the establishment and maintenance of University-Industry (U-I) relationships within R&D cooperation, at both personal and organizational levels. This research approach differs from measuring just tangible R&D outcomes at the end of a project, unlike found in most literature to the day;
2. Understanding and influencing R&D partners' initial interactions seems key to promote functional and successful cooperating networks, as there are relational disparities between early and established ties;
3. Members with different roles within R&D consortia perceive benefits differently and have diverse centralities within the cooperation network. Disparities in the perception of benefits could indicate different realizations of the valuable opportunities generated by R&D networks. This requires managing relationships by taking into consideration the differences in expectations according to each role. Also, a core-periphery structure was observed in partners' relationships within R&D projects, which should have direct implications at the level of innovative capacity;

4. Social Capital dimensions were important predictors of Resource Sharing among R&D partners, although to a different extent. Prior Ties impacted resource sharing in about half of the projects studied, while a Shared Vision of the project success contributed positively in 50-75% of the projects. Trust did not contribute positively to Resource Sharing, while Commitment was the strongest and most prevalent predictor of Resource Sharing. Social Capital dimensions were more relevant for Resource Sharing than attribute-based variables and modelled network effects. This highlights how the structure of partners' relationships within R&D consortia is crucial for effective collaboration, maximizing the use of tangible and intangible available resources for generating mutual value.

The implications of the present thesis extend beyond the dyads and triads directly involved in R&D tasks. In particular, this thesis provides guidelines for Universities, R&D project coordinators and for the European Commission to ensure both maximum performance and value creation in future R&D ventures. Finally, this work presents its contributions for theory as well as identified opportunities for future research.

Keywords:

University-Industry links; R&D cooperation; Inter-organizational networks; Social Network Analysis; ARA model; Social Capital; Relationship Marketing; Biological Sciences

v TÍTULO E RESUMO

Título:

De perfeitos desconhecidos a parceiros de investigação: um estudo das relações, partilha de recursos e benefícios percecionados em redes de cooperação em I&D

Resumo:

A presente tese tem como objetivo fornecer linhas orientadoras para investigadores e gestores de redes de cooperação em I&D de forma a maximizar a criação de valor, tendo em conta as relações entre parceiros, os recursos partilhados e os benefícios percecionados.

Tendo por base uma combinação de metodologias qualitativa e quantitativa, os dados para este estudo foram recolhidos através de entrevistas e de um inquérito a investigadores envolvidos em redes de cooperação em I&D no domínio das Ciências Biológicas.

Os principais resultados da presente tese mostram que:

1. A análise de redes sociais é uma ferramenta relevante para examinar e entender o estabelecimento e manutenção de relações de cooperação em I&D entre Universidades e Indústria, tanto a nível pessoal como organizacional. Esta abordagem de investigação não se foca apenas em medir os resultados tangíveis de I&D no final de cada projeto, ao contrário do que se observa na maioria da literatura atual.
2. Compreender e influenciar as interações iniciais de parceiros em I&D parece ser essencial para promover redes de cooperação funcionais e bem sucedidas, já que se observam disparidades relacionais entre laços recentes e antigos;
3. Membros com papéis diferentes dentro de consórcios de I&D percecionam os benefícios de forma diferenciada e têm centralidades distintas na rede de cooperação. Estas disparidades na perceção de benefícios podem indicar diferentes concretizações relativamente às oportunidades de valor que a rede de I&D proporciona. Isto requer uma gestão de relações que tenha em conta as diferentes expectativas associadas a cada papel. Além disso, observou-se uma estrutura de núcleo-periferia nas relações entre parceiros nos projetos de I&D, que deverá ter implicações diretas ao nível da capacidade de inovar.

4. As dimensões do Capital Social foram importantes antecedentes da Partilha de Recursos entre parceiros em I&D, embora em diferentes proporções. Os Laços Prévios impactaram a partilha de recursos em cerca de metade dos projetos estudados, enquanto que a Visão Partilhada contribuiu positivamente em 50% a 75% dos projetos. A Confiança não contribuiu positivamente para a Partilha de Recursos, enquanto que o Compromisso foi o antecedente mais forte e prevalente da Partilha de Recursos. As dimensões do Capital Social foram mais relevantes para a Partilha de Recursos do que as variáveis com base em atributos dos atores e do que os efeitos de rede modelados. Isto evidencia a forma como a estrutura das relações entre parceiros em consórcios de I&D é crucial para uma colaboração efetiva, onde é maximizado o uso de recursos tangíveis e intangíveis disponíveis de forma a gerar valor mútuo.

As implicações da presente tese estendem para lá das díades e tríades diretamente envolvidas nas tarefas de I&D. Em particular, esta tese fornece linhas orientadoras para Universidades, coordenadores de projetos de I&D e para a Comissão Europeia, de forma a assegurar simultaneamente o máximo desempenho e a criação de valor para futuras iniciativas de I&D. Finalmente, este trabalho apresenta os seus contributos para a teoria bem como as oportunidades identificadas para investigações futuras.

Palavras-Chave:

Ligações Universidade-Indústria; Cooperação em I&D; Redes inter-organizacionais; Análise de Redes Sociais; Modelo ARA; Capital Social; Marketing Relacional; Ciências Biológicas

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ARA	Actors–Resources–Activities
ATLAS	R&D cooperation experiment at CERN involving roughly 3,000 physicists
B2B	Business–to–Business
CCDRN	Comissão de Cooordenação e Desenvolvimento Regional do Norte
CEO	Chief Executive Officer
CERN	European Organization for Nuclear Research
CIS	Community Innovation Survey
CORDIS	Community Research and Development Information Service
DB	Database
DGEEC	Direção Geral de Estatísticas de Educação e Ciência,
EC	European Commission
ERGM	Exponential Random Graph Models
EU	European Union
EUA	European University Association
FCT	Fundação para a Ciência e Tecnologia (Portuguese Research Funding body)
FP(s)	Framework Programme(s) for Research and Technological Development
FP1	First Framework Programme
FP7	Seventh Framework Programme
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GPEARI	Gabinete de Planeamento, Estratégia, Avaliação e Relações Internacionais
IMP	Industrial Marketing and Purchasing
KED	Knowledge Exploiters, Knowledge Developers and Promoters
— DEV	Knowledge Developers
— EXPL	Knowledge Exploiters
— PROM	Promoters
LRQAP	Logistic Regression Quadratic Assignment Procedure
MEC	Ministério da Educação e Ciência
MRQAP	Multiple Regression Quadratic Assignment Procedure
OECD	Organization for Economic Co-operation and Development
QAP	Quadratic Assignment Procedure
R&D	Research and Development
RCD	Research Centre Director
RJV	Research Joint Venture
SCOPUS	Elsevier Bibliographic database
SEM	Structural Equation Modelling
SME	Small and Medium Enterprise
SNA	Social Network Analysis
SPSS	Software for statistical analysis
TTO	Technology Transfer Office
U-I	University-Industry
UCINET	Software package for SNA
US	United States of America

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CHAPTER 1 GENERAL INTRODUCTION

This thesis focuses on the relationships between partners involved in R&D cooperation, which is a research topic which has attracted increasing interest since the mid-twentieth century, and in particular over the last two decades (Arranz and Arroyabe 2008; Brod and Shivakumar 1997; Caloghirou, Tsakanikas, and Vonortas 2001). Cooperation between partners is a very broad concept ranging from informal relations to fully formalized strategic alliances, encompassing a set of antecedents for success, which depend on context, the type of partners and the type of interactions. In the Marketing field, this topic can be framed within Relationship Marketing, where trust and commitment are portrayed as important antecedents of successful cooperation

(Morgan and Hunt 1994). Overall, this research topic aims at achieving a deeper understanding of the various types of relationships among organizational partners (Frasquet, Calderón, and Cervera 2011; Ekici 2013; Macmillan et al. 2005; Mora-Valentin, Montoro-Sanchez, and Guerras-Martin 2004; Plewa, Quester, and Baaken 2005). However, it should be noted that very few studies addressed the relationships between R&D cooperating partners, as well as their positions within the network of interactions. That research should allow a better understanding of the major drives leading to strategic resource sharing and consequent creation of value.

Within the framework of University-Industry (U-I) links, the vast majority of studies centred on technology transfer processes, such as licensing, transference of explicit knowledge and patenting (Agrawal 2001), which act as *ex post* R&D cooperation indicators. Several studies showed the relevance of explicit and implicit knowledge transfer (namely through spillovers) in generating the innovation needed by companies to maintain their competitive advantage (Lehrer 2007; Powell, Koput, and Smith-Doerr 1996; Rosiello 2007). However, from a relational perspective, innovation evolves as a consequence of significant business interactions (social and non-social), as well as the combination of both tangible and intangible resources (Landry, Amara, and Lamari 2002), instead of being a technological solution to a particular problem/market need. Accordingly, the importance of establishing successful partner relationships to improve innovation processes has already received some attention in past studies (see for instance Acworth (2008) and Pérez-Luño et al (2011)). In that sense, companies need to be integrated in knowledge networks that allow them to acquire strategic assets and resources, enabling them to innovate continuously (Powell, Koput, and Smith-Doerr 1996; George, Zahra, and Wood 2002). These knowledge networks must include research institutions because they hold high quality R&D skills, both in fundamental and applied sciences. Moreover, these institutions are less prone to the conflicts of interests typically found in industrial partnerships (Santoro and Betts 2002). Despite these advances, the literature specialized on U-I links over the past two decades did not properly address the relationships established within these strategic partnerships. Concomitantly, as recognized in the work of Plewa and Quester (2007), there is no established framework to address these relationships. In this regard, the present thesis aims at progressing in that direction through a combination of organizational networks theories, such as the ARA model and Social Capital, complemented with the important findings of Relationship Marketing Theory.

Research Background

The European Union (EU) research policy had, in the last decades, significant implications in the available funding through the implementation of various Framework Programmes. These programmes generally affected the scientific outcomes of, namely, the University-based research units or other such public institutions. Reports from the European University Association (2012; 2014) revealed considerable changes on the total budgets of public funded universities during the global economic crisis, between 2010 and 2013. While some universities saw their budgets slightly increased in this period, mainly in central and northern Europe, the periphery countries were challenged with a steep decrease of resources. In particular, Portugal experienced a decreased of 26% in that period. Given that R&D performed in Portuguese universities and research units is 83% to 86% dependent of public funds (GPEARI 2011a; DGEEC-MEC 2014), the sustainability of this relevant activity is a growing challenge. Additionally, there is growing awareness that the research-funding strategies of the past can no longer be used. This is based on the need to improve significantly the competitiveness of European industry through a fast and intense input of innovation. This is produced mostly at the level of research units and therefore, the new funding policies favour applied and innovative research in detriment of the European traditional fundamental scientific production. In this context, universities quickly shifted towards searching for alternative ways to monetize the knowledge and capacity of their research centres (Baaken (2003) cited in Plewa and Quester (2007)).

Consistent with the above scenario, it is possible to observe the growing negative effects of globalization on companies with little capacity to innovate. In order to survive increasing competition, companies need to rely on their in-house knowledge capability, or decide to acquire new knowledge through R&D networks (Carayannis, Alexander, and Ioannidis 2000). Research on inter-organizational networks revealed the importance of interactivity between partners in the mobility of their strategic resources and consequent development of sustained competitive advantage (Håkansson and Snehota 1995). Resource sharing has been suggested as the keystone of efficient networks (De Wever, Martens, and Vandenbempt 2005). However, the willingness to share these strategic resources increases with the promotion and development of trustful relationships (Collins and Hitt 2006). Therefore, further studies are required to examine the causal relationship between inter-organizational ties, resource sharing, and the opportunities created for network partners, which can be measured by relevant indicators, like the level of innovation or value-creation.

The research stream on inter-organizational networks developed by the Industrial Marketing and Purchasing (IMP) Group serves as the structural base for the present research, allowing a better understanding of the cooperative action of actors and addressing the following concerns: (1) the competitive advantage of companies based on the acquisition of new knowledge/resources and, on the opposite side, (2) the financial sustainability of research units that support companies in generating new products and services. Additionally, with direct relevance to this study is the work of Nahapiet and Ghoshal (1998), whom proposed the three dimensions of Social Capital (structural, relational and cognitive). These authors defined Social Capital as "the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit" (1998, 243). This definition is central to the present thesis because of the importance attributed to the resources embedded and shared (both tangible and intangible) in an organizational network, while accounting for individual and collective benefits. Specifically, this study expects to combine the contributions from both research streams — IMP and Social Capital — into a coherent theoretical framework that could help explaining and quantifying the importance of partners' relationships towards the success of U-I R&D cooperation.

Research Problem and Questions

Relying upon the literature gaps and research background described above, this thesis focuses on addressing the following research problem:

> *How can R&D cooperation networks maximize value creation, taking into account partners' relationships, shared resources and perceived benefits?*

This research intends to describe the patterns of relationships and resource sharing among partners within R&D networks in order to promote opportunities for value creation, and enhance the perception of benefits obtained from cooperation. The present study should raise foundations allowing future research towards the patterns of strategic resource sharing that lead to an increased capacity to innovate within a network, consequently improving actors' performance.

The research problem identified above was unfolded into research questions, which serve as guidelines for this thesis:

RQ1: How should U-I relationships be approached in order to capture and describe the interdependencies between partners, and the diversity of ties within cooperative R&D projects?

RQ2: How do U-I R&D relationships evolve over time with regard to partners' motivations, shared activities and resources, mutual interests, trust and commitment?

RQ3: To what extent do the roles performed within R&D cooperation networks affect members' perceived benefits and centrality within the network?

RQ4: To what extent do Social Capital dimensions (structural, cognitive and relational) contribute to resource sharing within R&D cooperation networks?

The link between the above questions and the thesis structure will be detailed at the end of the present chapter.

Research Scope

The statistics available on the Portuguese scientific funding, independently of the reduction in full university budgets mentioned above, reveal stagnation in national R&D spending since 2008. The historical maximum funding of 1,58% of the national GDP was observed in 2009, enclosing 47% of private funds (DGEEC-MEC 2015). However, the amount of R&D investment differs significantly between economic activity sectors, with Engineering & Technology sector leading the allocation of funding. According to data from 2008, among the 100 largest companies financing extramural R&D activities, only 6 worked in the broad domain of Biological Sciences[1], and the amount of funding averaged at 0.6% of the total R&D investment of those companies (GPEARI 2011b). Since micro-enterprises along with SMEs represent over 99% of the private sector in

[1] *Bial – Portela & Cia, SA; BluePharma - Produtos Farmacêuticos; Grupo Águas de Portugal; Grupo Heineken; Grupo RAR; and Sanofi Aventis – Produtos Farmacêuticos.*

Portugal (IAPMEI 2010), the challenges to invest and thrive by innovating without cooperation are very substantial. Therefore, the present study was based on the following reasoning:

1. Wines, included in the more general sector of agro-food industries, biotechnology and environmental technologies (including climate change, impact analysis, ecosystem sustainability, among others) are key strategic sectors for the Portuguese economy (CCDRN 2014);
2. The potential that information originating from the Biological Sciences domain has to be effectively integrated into current business activities namely within any of these economy areas, improving national competitiveness, is very high;
3. No data on U-I relationships is available despite that Portugal has many firms capable of absorbing research results and innovating in those areas with the help of universities;
4. According to Plewa et al. (2005), research that gathers data from all activity sectors where U-I relationships occur may loose the necessary detail to understand the nuances of relationships between specific partners in a given industry type.

This thesis follows these premises, and focuses on detecting the key aspects for managing U-I relationships within the Biological Sciences domain involving Portuguese partners.

Expected Contributions

In light of the current macroeconomic scenario that the EU faces with notorious implications in science financing, universities have increasingly focused on finding new ways to monetize the knowledge and capabilities of its research centres. One increasingly accepted way to circumvent this challenge is R&D cooperation between research centres and companies, strongly backed by European science funding programmes. Concurrently, business innovation is becoming less associated with isolated events or the transfer of technical components. Instead, research has shown that innovation depends both on explicit knowledge as well as tacit, and its transfer results from social network-driven interactions (Landry, Amara, and Lamari 2002; Ouimet, Landry, and Amara 2004). Based on this rationale, the present thesis focuses on cooperation networks involving universities and companies, along with the resource sharing activities facilitated by the relationships among partners. It aims at understanding the role of those relationships towards value creation opportunities fostered within the cooperation network.

Based on this research setting, practical contributions of the present thesis might include: (i) an empirical recognition of the importance of social networks as drivers of resource sharing among partners leading to more successful ventures, (ii) a better understanding of the relational factors that influence the success of R&D networks involving companies and universities within by the Biological Sciences domain and (iii) a set of strategic orientations for the major actors involved aiming at promoting opportunities with enhanced value creation in the perspective of all stakeholders. Likewise, the present thesis should include a set of relevant contributions for theory in the domains of marketing and strategy. Specifically, if the methodological approach to U-I relationships to be developed in this thesis adequately captures the diversity of ties within cooperative R&D projects, this work could contribute with a demonstration of the use of Social Network Analysis (SNA) to address relational issues involving engaged partners. Also, if R&D partners' relationships evolve over time, this study could capture some of the resource and activities that drive that change and could call for a comprehensive and longitudinal approach to these relationships in order to detect potential points of success (and failure) along the relational evolution. These contributions could help strengthen the creation of a U-I relationships stream, as suggested by Plewa and Quester (2007). Moreover, this research could contribute with a better understanding of the R&D opportunities interface between commercial and non-profit actors, which are driven by distinct objectives and value creation conceptions. Finally, a contribution could be expected for the literature on inter-organizational networks as a consequence of the integration of Social Capital, Relationship Marketing and the ARA model. The synergies obtained in the process could further highlight the role of these theoretical frameworks to understand partners' cooperation dynamics involving resource-sharing leading to innovation.

Thesis Structure

The present thesis encompasses an article-based structure, with each of the four articles leading the construction of its own chapter. The complete list of publications can be found in Appendix A1. Chapter 2 deals with the first research question above mentioned, by presenting SNA as the adequate methodology to capture and describe the interdependencies between partners and the diversity of ties within cooperative R&D projects. It presents an illustrative case of SNA applied to data on close work relationships within a FP7 project. These data are part of the larger survey of FP7 participants used more extensively in chapters 4 and 5.

Chapter 3 focuses on the second research question by addressing the relational evolution of U-I partners with regard to their motivations, shared activities and resources, mutual interests, trust and commitment. The study is based on data collected through a series of interviews with Portuguese researchers from the Biological Sciences domain. The interview script can be found in Appendix A2. The theoretical contributions of the ARA-model and Social Capital were combined into a single framework and applied to the interviews data, highlighting the different relationship levels (individual *versus* organizational), the disparities between early and established ties, and the interplay between low and high investment activities underlying researchers' relationships.

Chapter 4 addresses the third research question and examined FP7 members' perceived benefits and centrality within the network as a function of the roles performed within the R&D consortium. A new classification of project members, the KED roles, was developed according to the way in which members where implicated towards knowledge-sharing, instead of using their economic principal activity. The data used is based on a large survey involving more than 1,000 participants of FP7-funded projects on Biological Sciences. The survey template used for collecting data can be found in Appendix A3. Results showed significant differences among project participants regarding their perceived benefits and positions frequently occupied in each R&D network. The results of this chapter created the conceptual support for studying the role of Social Capital within FP-funded networks at project level.

Chapter 5 follows the work of previous chapters and addresses the last research question of the thesis, which aimed at assessing the role of Social Capital dimensions (structural, cognitive and relational) towards resource sharing within R&D cooperation networks. The data were analysed with two different SNA methodologies: Logistic Regression Quadratic Assignment Procedure and Exponential Random Graph Models. Results showed that all Social Capital dimensions helped to explain Resource Sharing among partners, although to a different extent, which contributed to a better understanding on the diversity of partner relationships within R&D projects.

CHAPTER 2 SOCIAL NETWORK ANALYSIS AS A NEW METHODOLOGICAL TOOL TO UNDERSTAND UNIVERSITY-INDUSTRY COOPERATION

The contents of this chapter were published in the International Journal of Innovation Management, Volume 19, Issue 01 (February 2015), 1550013 [22 pp.] — DOI: 10.1142/S1363919615500139

ABSTRACT

Purpose: This work tests the use of Social Network Analysis (SNA) as a new methodological approach to better understand University-Industry (U-I) relationships in the context of R&D cooperation networks for innovation.

Methodology: Following a thorough review of the literature on U-I links from the last two decades, focusing on methodologies, Social Network Analysis (SNA) was applied to data on work relationships, obtained through a survey of the participants from University and Industry, engaged on a FP7 project.

Findings: SNA is suggested as a useful and relevant tool to understand and examine U-I R&D cooperation at both personal and organizational levels. In support of this statement, several examples and an empirical illustration are provided. The assessment of the processes underlying the establishment and maintenance of U-I relationships within R&D cooperation with SNA suggested that interpersonal relationships are crucial for the establishment of successful cooperative activities. Unlike other tools, SNA allows the recognition of preferential relationships between institutions, and reveals asymmetries from within the U-I R&D network.

Originality/value: This paper addresses the interactional dynamics embedded in U-I links. Most studies regarding U-I links focus on describing the downstream processes associated with technology transfer and commercialization. This study applies SNA to understand the ex ante establishment and maintenance of U-I relationships within R&D cooperation. The high volatility of these relationships, in view of the importance of the expected outcomes, justifies the need to understand the fundamentals of successful cooperation.

Keywords:

Innovation, University-Industry links, R&D cooperation, Social Network Analysis, research methodologies, technology transfer

INTRODUCTION

Understanding U-I links assumes in today's environment an increasing importance in the need to strengthen global economic competitiveness. This paper assesses the extent to which Social Network Analysis (SNA) has been used to study University-Industry (U-I) relationships, and proposes SNA as a relevant tool to further understand linkages within Research and Development (R&D) cooperation ventures.

The effects of external knowledge sources on company growth and performance have been addressed (Cassia, Colombelli, and Paleari 2009; Svetina and Prodan 2008). These studies have shown that U-I cooperation generates important external knowledge for company growth, and that a company's in-house learning mechanisms are not sufficient to develop radical innovations. Additionally, several authors maintain that knowledge is an important component in explaining the formation of U-I linkages, because companies that enhanced their knowledge base through their absorptive capacity (Cohen and Levinthal 1990) developed better capabilities to reinforce their competitive advantages (Giuliani and Arza 2009). George *et al.* (2001) also stressed this point, arguing that the capacity of a company to absorb knowledge could be determinant for both growth and performance. Additionally, other authors claim that the combination of heterogeneous sources of knowledge can lead to an increase in radical innovation (Gilsing and Nooteboom 2005; Tödtling, Lehner, and Kaufmann 2009) and lower R&D costs for both U-I parties (George, Zahra, and Wood 2002). As Caloghirou and Vonortas (2001) pointed out, when collaborating with universities, companies primarily aim at "achieving research synergies, keeping up with major technological developments, and sharing R&D costs" (p. 160), resulting in knowledge creation and improvements in production processes.

The topic of U-I cooperation has been approached in the literature from different perspectives (Agrawal 2001; Plewa and Quester 2007; Tijssen 1998), although it mostly addresses companies' innovation, technology and knowledge transfer processes, together with cooperative relationships as described above. Innovative activities, from a company perspective, depend on a variety of links to sources of innovation, knowledge, technologies, practices and human and financial resources (OECD and Eurostat 2005). Each linkage ties the company to a stakeholder in the innovation system, such as government laboratories, universities, policy departments, regulators, competitors, suppliers and customers (OECD and Eurostat 2005), enabling access to its unique resources (Mowery, Oxley, and Silverman 1996). When these links are aggregated in a network, the unique contribution of each partner may be shared amongst members, thus giving the network a competitive edge in a certain knowledge domain (Rycroft and Kash 2004).

Resources required for innovation are often found amid institutions rather than inside them (Powell, Koput, and Smith-Doerr 1996). Therefore, identifying the right partners, capable of supplying relevant knowledge, technology and tacit information to foster innovation seems key to succeeding in networked U-I cooperation. Prior research has identified a variety of factors that act as transactional indicators to measure successful cooperation outcomes, such as technology and knowledge transfer (Mowery, Oxley, and Silverman 1996; Siegel et al. 2001; Vonortas 2012). In the literature, technology transfer is frequently measured through proxy variables, such as the submission of joint patents and the citation of publications (Balconi and Laboranti 2006; Kumaramangalam 2005). These incorporate transactional perspectives, which disclose very little about the relationships among co-authors. According to Rycroft (2004), understanding learning processes is key for innovation networks, a reason why the study of R&D cooperation should focus on the diversity of relationships within that cooperation.

Notwithstanding the value of transactional outcomes, such as patents, a number of studies have shown that R&D partners value other forms of cooperation (Bekkers and Freitas 2008; D'Este and Patel 2007) that involve deeper social interaction (Landry, Amara, and Lamari 2002), which are based on relationships of trust, common representations and shared norms and values (Beaudry and Kananian 2013). Building on this point, Yli-Renko *et al.* (2001) claimed that over the last decade there has been an important research stream, demonstrating that innovation is not just the result of technology transactions and patenting. Instead, it is said to be the result of knowledge sharing, derived from relationships. This relies on the fact that U-I links involve high-risk activities, and in most cases results are not guaranteed. Therefore, similar to other authors (Mora-Valentin, Montoro-Sanchez, and Guerras-Martin 2004), the present work holds that cooperative R&D relationships tend to take place between trusting and committed partners.

U-I links typically involve a diversity of actors working on different projects (Protogerou, Caloghirou, and Siokas 2012) and forming a vast number of complex interactions inside and outside a specific social structure. With this in mind, it is important not to assume that relationships among actors are all alike, as if membership in a project included a known level of *a priori* interaction or closeness. In fact, this work challenges the idea that an R&D project acts as a clique, where all members are equally connected to each other (Vonortas 2012). As members of an R&D consortium strengthen or weaken their ties, different structural configurations may arise. This is an interesting phenomenon to study, as the output of R&D networks may derive from its pattern of interactions. Therefore, the methodology to study these configurations should take into account the diversity of each person's interactions as well as the pattern of links within the whole network (Vonortas and Okamura 2013). Connections that are unique to specific actors (individual or organizational) allow access to singular resources and opportunities that are valuable, rare, imperfectly imitable, and difficult to substitute, therefore providing the conditions to gain value (Barney 1991; Vonortas and Okamura 2013). If we combine this view with the previous argument that relates social interaction with U-I cooperative arrangements, it is expected that the nature and composition of certain ties may contribute to higher efficiency in sharing explicit and tacit resources, leading to greater innovation. This may be even more so when projects are long and require significant multidisciplinary cooperation. Based on these arguments, the present study aims at:

1. Assessing the extent to which SNA has been used as a method to study U-I relationships in the context of R&D cooperation;
2. Illustrating the use of SNA as a relevant tool to understand the diversity of relationship patterns within R&D projects, using data collected through a survey to members of a project funded by the Seventh Framework Programme (FP7) of the European Commission.

SNA has been mostly used to analyse journal citations and patent databases. On the other hand, U-I links have been mostly addressed by traditional research methodologies, based on the item response theory *i.e.,* Structural Equation Modelling (SEM), Factor Analysis, Regressions and others. SNA high flexibility can be used to analyse relationships at the individual, research group and institutional levels (Wasserman and Faust 1994), enabling a distinction between individual ties formed between researchers, local exchange networks and formal inter-organizational links. In this sense, SNA may contribute to a better understanding of the interactional dynamics among different actors, as well as the implications, with regard to sharing resources and achieving innovation. In the present work, the SNA methodology is presented in the context of U-I cooperation, followed by an illustrative case of U-I relationships. Furthermore, the different perspectives on U-I links are reviewed, and the U-I cooperation, seen as a relational perspective, is analysed. Finally, several limitations of this approach are discussed, and future research is proposed.

Different perspectives on U-I cooperation literature

In recent decades, the role that universities can play in enhancing innovation is a topic of growing interest, not only from a practitioner's perspective, but also from an academic point of view. This statement is echoed in studies that have shown the relevance of transferring knowledge, both explicitly and implicitly, to generate the innovative outcomes that companies need to maintain their competitive advantage over competitors (Lehrer 2007; Powell, Koput, and Smith-Doerr 1996; Rosiello 2007). A growing number of studies have shown how these links can be approached from different perspectives. There is a stream focused on the characteristics of organizations that influence the probability of forming U-I linkages (Giuliani and Arza 2009; Tödtling, Lehner, and Kaufmann 2009). Another stream has significant interest in the regional and spillover effects of collaboration (Kauffeld-Monz and Fritsch 2013; Gallié 2009), or even the short- and long-term benefits for companies and universities (George, Zahra, and Wood 2002; Hemert, Nijkamp, and Masurel 2012). Some researchers focus their attention on the role and characteristics of individual scientists at universities (Boardman and Ponomariov 2009; D'Este and Patel 2007) to understand the outcomes of R&D cooperation, whilst others look at the co-authorship of papers and patents (Baba, Shichijo, and Sedita 2009; Kumaramangalam 2005), or R&D spending (Hyvärinen and Rautiainen 2007), as indicators of innovative performance. Most studies appear to see innovation as driven by knowledge and technology transactions, modelled by the characteristics and achievements of universities, companies or other partners. These include patents, publication rates and competitive funding, amongst others. However, there is a growing body of literature concerning the relational and social part of innovation (Alguezaui and Filieri 2010; Landry, Amara, and Lamari 2002; Pérez-Luño et al. 2011), changing the study focus towards the contribution of each individual. In this perspective, the whole is greater than its parts (Protogerou, Caloghirou, and Siokas 2012).

In order to deepen the understanding of the above-mentioned streams, we searched for articles published in the last two decades, focused on U-I R&D cooperation. The search was performed using the SCOPUS database, with combinations of keywords such as 'academia', 'university', 'business' 'industry', 'collaboration', 'cooperation', 'R&D', 'partnership', and 'alliance'. The choice of SCOPUS was based on the broader range of scientific titles available when compared to

Web of Science (Falagas et al. 2008). The result in Figure 1 compares the number of published papers by year with the inner number of such articles mentioning 'network' in the title, abstract or keywords. As can be observed, the number of articles on research cooperation increases over the years, as well as those referring to the existence of networks (grey bars). A sub-set of these (not shown) is based on the concepts of Social Capital and network resources.

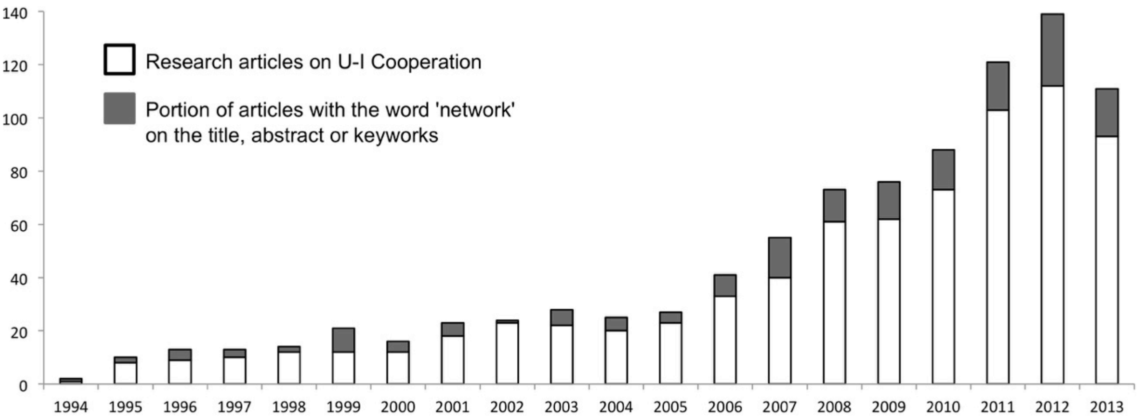

Figure 1. Number of articles published on the topic of University-Industry R&D cooperation between 1994 and 2013 (20 years)

The numbers were retrieved from SCOPUS database[2]. Each bar represents the yearly sum of articles found using the query presented below. They total 920 papers. The grey segments (totalling 173 papers) represent the articles with the word "network" on the abstract, title or keywords.

The majority of the articles in Figure 1, with more than 10 citations per year, are based on the utilization of traditional methodologies, *i.e.,* data analyses based on attributes and not network data. The most frequent research tools are based on Item-Response-Theory and include a variety of statistical techniques such as SEM (Zeng, Xie, and Tam 2010), Factor Analysis (Bierly, Damanpour, and Santoro 2009), regression analysis of various types (Choonwoo Lee, Lee, and Pennings 2001; Belderbos, Carree, and Lokshin 2004; Belderbos et al. 2004; Tödtling, Lehner, and Kaufmann 2009; Tether and Tajar 2008), econometric models (Fontana, Geuna, and Matt 2006), analysis of co-variance (George, Zahra, and Wood 2002) and descriptive statistics (Keeble et al. 1999; Bianchi et al. 2011). Exceptionally, Ponds *et al.* (2009) uses a regression model

[2] *Scopus Query: TITLE-ABS-KEY(universit* OR academi*) AND TITLE-ABS-KEY(enterprise OR business* OR industr* OR company*) AND TITLE-ABS-KEY(r&d OR research*) AND TITLE-ABS-KEY(innovat*) AND TITLE-ABS-KEY(collaboration* OR cooperation OR partnership OR alliance) AND PUBYEAR > 1993 AND PUBYEAR < 2014 AND (LIMIT-TO(DOCTYPE, "ar"))*

together with attribute and network data. All these studies have merit, but traditional methodologies are unable to identify important aspects of these networks, such as the effects of brokerage and social capital (Burt 2005; Murray 2004). These were shown to be relevant in innovation studies (Kauffeld-Monz and Fritsch 2013; Pérez-Luño et al. 2011). The few articles using SNA methodology within the grey bars of Figure 1 are mentioned in Table 1. Most were published in the past five years. Moreover, it is possible to see in Table 1 that the data sources and study focus of these articles are not very wide in scope, mostly consisting of database analysis, as mentioned above.

U-I R&D cooperation with a relational perspective

The advantages of U-I cooperation are evident for companies, but also extremely important for the university. While universities are primarily driven to create and disseminate knowledge, they stand to benefit in economic terms from U-I cooperation, frequently securing financial support for future research (Plewa and Quester 2007). As D'Este and Patel (2007) observed, academic researchers who interact with industry through a wide set of mechanisms are more likely to build the capabilities necessary to bridge the gap between scientific research and its commercialisation. The main outcomes of U-I collaborations are bi-directional knowledge flow and learning gains, providing important competitive advantages for a knowledge-based economy.

The capacity to assimilate the know-how produced at universities "can be built through cooperative agreements with science institutions" (Veugelers and Cassiman 2005, 362) in order to achieve a higher probability of success in R&D cooperation activities. This is particularly difficult because of the inherent differences between organizations. Lee (1996) acknowledged that academics value and encourage such cooperative activities, while recognizing the limitations of such interaction, since they need to pursue their research in a context of intellectual freedom. As such, U-I cooperation can sometimes be incompatible with the pursuit of sound scientific knowledge. This is relevant because U-I links may not be valuable *per se*, and outcomes will vary with partner involvement. Linking the needs of both universities and companies constitutes an important driving force in the formation of these cooperative networks, aiming at creating reciprocal value (Carayannis, Alexander, and Ioannidis 2000).

Table 1. Articles from Figure 1 that used Social Network Analysis (SNA) as a methodological framework

Authors, Year	Country	Journal	Method / Data source	Unit of analysis / Study focus
Gauvin, (1995)	Canada	Group Decision & Negotiat.	Patent Database (DB)	R&D alliances via patent co-authorship
Orsenigo et al, (1998)	Worldwide	J. Manag. & Govern.	R&D agreements DB	R&D networks
Balconi & Laboranti, (2006)	Italy	Research Policy	Interviews & Patent DB	R&D alliances via patent co-authorship
Cantner & Graf, (2006)	Germany	Research Policy	Patent DB	R&D alliances via patent co-authorship
Olmeda-Gómez et al, (2008)	Spain	Information Research	Papers DB	R&D collaboration via paper co-authorship
Ponds et al, (2009)	Netherlands	J. Economic Geography	Patent & Papers DB	R&D collaboration via co-authorship
Chen & Guan, (2011)	China	Scientometrics	Patent DB	R&D collaboration via patent co-authorship
Zoss & Börner, (2011)	Worldwide	Scientometrics	Awards DB	Collaboration & Co-funding networks
Lander, (2012)	Canada	Scientometrics	Papers DB	R&D collaboration via paper co-authorship
Vonortas, (2012)	Worldwide	J. Technology Transfer	R&D Projects & Patent DBs	R&D projects & patent co-authorship
Protogerou et al, (2012)	Europe	J. Technology Transfer	R&D Projects DB & Survey Data	R&D networks via research projects
Beaudry & Kananian, (2013)	Canada	Industry & Innovation	Patent, Papers and Funding DBs	Academics funds, patents and papers
Kauffeld-Monz & Fritsch, (2013)	Germany	Regional Studies	Survey of Network Relationships	R&D alliances
Islam & Ozcan, (2013)	Worldwide	IEEE Trans. Eng. Manag.	Patent DB	R&D collaboration via patent co-authorship
Vonortas & Okamura, (2013)	Europe	Econ. Innov. & New Tech.	R&D Projects & Patent DBs	R&D projects & patent co-authorship

When assessing U-I cooperative relationships, it is worth emphasising the importance of communication, trust, commitment and a common vision between partners. Despite the existence of organisational arrangements, interactions are ultimately about people. Consequently, interpersonal networks are important channels for the dissemination of knowledge (Cantner and Graf 2006). Literature shows how relationships embracing the dimensions of trust and commitment are becoming the cornerstone of successful cooperation (Frasquet, Calderón, and Cervera 2011; Plewa and Quester 2007). As R&D collaboration networks lower the barriers for knowledge sharing, these relational resources must be present in order to build up the network's social capital and to enhance the flow of resources (Tödtling, Lehner, and Kaufmann 2009).

In line with the purpose of the present work, the methodology chosen to study these relationships inevitably influences the nature of the extracted information. For instance, Frasquet *et al.* (2011) and Plewa and Quester (2007) have studied U-I cooperation, and modelled trust into structural equation models, having found that trust is a determining variable for successful cooperation. Notwithstanding this approach, trust is a relational resource that builds up in individual relationships and, when studying network phenomena, it should be assessed for each single tie where partners report trusting each other. Asking about the level of trust, as a general question regarding all the partners in the cooperation limits the ability of understanding the actual role of trust in a network of interactions. The same argument could be made for commitment, shared values or communication. These are all variables that ultimately build up over dyads. Therefore, in order to understand how these affect cooperation within a network, the measurement and analysis should take into account the structural positioning of the actors (Tsai 2001) and the natural flow between them caused by pre-existing relationships (Gulati and Gargiulo 1999).

As mentioned above, the use of SNA to study U-I R&D relationships has been limited in scope. Most studies in the literature analyse citation or publication networks, via articles or patents (as most references in Table 1). These analyse the tangible outcomes of R&D cooperation between parties, and not the interactions and intangible outcomes that precede them, such as resource sharing, trust development or learning processes. These studies reveal shared achievements of companies and research institutions, telling us very little about the interactions and innovation process that took place in order to reach those outcomes. This is true also for the studies using SEM, Factor Analysis, or Econometric Models. Very recently, analysis of databases of R&D projects using the same methodologies revealed relevant patterns of connections between a multitude of projects, funding programmes and their shared members (Vonortas 2012; Vonortas and Okamura 2013; Protogerou, Caloghirou, and Siokas 2013; Yokura, Matsubara, and Sternberg 2013; Barber, Fischer, and Scherngell 2011). Research should address the antecedents of cooperation, activities inside the project and the respective outcomes from the perspective of each partner, instead of simply modelling the tangible outcomes. Relationship patterns, brokerage and social capital must underlie the establishment of interpersonal relationships that enable R&D cooperation outcomes. The need to investigate the diversity of roles played by the partners has already been proposed by Lundberg and Andresen (2012). At the network level, trust and commitment, which allow surpassing the level of single transactions, should be measured using a methodology that distinguishes individual relationships, such as SNA. Social Network Analysis is a tool suitable for examining multiparty interaction and cooperation, having evolved from different scientific fields such as Sociology, Psychology and Anthropology (Wasserman and Faust 1994). The development of theory within Social Network Analysis (SNA) is directly tied to the nature of actors' relationships and the context in which they occur. SNA represents the development of several theories, including Social Capital. This encompasses the obligations and expectations, information channels and social norms within the social structure (Coleman 1988). The "strength of weak ties" (Granovetter 1973) and "structural holes" (Burt 1995) are popular conceptualizations of Social Capital that have great potential for application in U-I R&D relationships. In short, SNA methodology seems appropriate insofar as it distinguishes between different actors by their specific network roles, such as information providers, knowledge exploiters or bridging institutions.

Social Network Analysis methodology

The study of social networks grows from the assumption that actors (members of the network) are interdependent in their activities and environments, thus influencing each other's access to information and other resources. Furthermore, the exchange of resources is assumed to occur through different types of links (or relationships) among actors. SNA assumes that the network structure provides both opportunities and constraints to its members (Marin and Wellman 2011; Wasserman and Faust 1994). Moreover, these relationships of dependency lead to the notion that the social structure among actors is pivotal for the outcome of a network, more than actors' individual attributes. The following paragraphs explore all the outcomes and implications of applying SNA in the context of relationships within U-I R&D projects. Each step reflects decisions regarding (i) the types and units of analysis, (ii) the relationship contents, (iii) the data collection methods, and (iv) the measurement and data analysis (Carrington, Scott, and Wasserman 2005; Scott 2000; Wasserman and Faust 1994). Finally, an illustration of network data from a relationship inside a U-I R&D project is provided.

(I) TYPES OF ANALYSIS IN SOCIAL NETWORKS

Ego-network vs. Whole network

Ego-network analysis focuses on existing relationships from the perspective of a focal actor, *i.e.* the direct connections of an individual (also called alters), such as the relationships a project coordinator might have with his peers inside an R&D project. Therefore, the goal is to study the number of links, and the types of relationships, each of these may have. The further analysis of the connections between alters (*e.g.* members) and beyond is not frequent but is possible. This approach is useful when the network is vast, or its boundaries are not clearly defined. Whole-network data focuses on all the relationships within a given network with defined boundaries. In such cases, all members should participate in the study. Whole-network analysis is very useful in understanding the flow of resources among several network members, as well as assessing the indirect access that actors might have to each other. These actors have potentially different relationships between them (such as funding, lending equipment, attending conferences together, joint publications, etc.) and this approach helps determine which type of relationship is associated with distinctive types of individuals (e.g. company senior researcher, junior university researcher, principal investigator, etc.). Furthermore, according to Marin and Wellman (2011, 20), "ego-network data can be extracted from whole network data by choosing a focal node and examining only nodes connected to this ego", which could be useful in surveying R&D networks with many members, such as those in the ATLAS or CERN experiments (Boisot et al. 2011)

In the specific case of U-I R&D project relationships, because the boundaries are known (actors that participate and those who do not), whole-network data was used. Although individual researchers could alternatively have been sampled, to participate in an Ego-network study as focal actors, without the need to survey all the researchers in that university and/or company, which was not tried.

One-mode vs. Two-mode networks

A 'mode' is a set of actors. A one-mode network is composed of a single set of actors. In one-mode networks the analysis could be focused, for example, on which actors are linked through supplier-customer relationships and the strength of that tie. A two-mode network is composed of two sets of actors. One-mode networks can originate from two-mode networks by using the relationships that consist of co-authorship, co-membership, co-attendance at meetings and conferences or others. In the specific case of U-I, both approaches are equally possible, depending on the variety of the types of actors and on the objectives of the network. Within a single R&D project, such as the one analysed in this work, the typical analysis would be one-mode.

Units of analysis in SNA

SNA has three units of analysis, all of which can be used to measure U-I relationships (Wasserman and Faust 1994). The major unit is the dyad (the tie-level). The data collected at this level is relational by nature and reflects the content shared between pairs. The variables selected for this analysis are properties of relationships between network pairs. In the case of a U-I R&D study, those could be *e.g.* the resources shared, the participation in joint R&D activities, or the trust between peers. All these variables are a function of the dyad and not exclusive of a single actor. Thus, each dyadic variable is presented in an actor-by-actor matrix of values with cells representing the relationship value for each pair, within which the relationship is interdependent.

The second unit of analysis is the monadic level (the actor-level). Variables are represented in an actor-by-attribute matrix, where each actor is a case and the measurement of individual variables is presented along a vector (usually a row-vector). Examples of variables can be attributes such as the age of the researcher, the number of published articles or the number of patents, but there can also be network variables such as the number of ties to industrial partners, the number of members in her/his research team or even the amount of money received for cooperative R&D activities.

Finally, the highest level of analysis is the network (the group-level). The data collected at this level represents whole groups of actors and the ties between them. This level is useful to understand, for example, the level of connectedness or centralization within the network (measuring how much a network depends on a single or a small group of members). In this case, each variable has one value per network.

(II) CONTENT OF NETWORK RELATIONSHIPS

The conceptual framework of the study relies on *a priori* empirical considerations. The establishment of U-I relationships depend, before anything else, on human interaction networks, which ultimately rely on the ability to establish or have a prior personal relationship. Underlying this major premise, people establish relationships based on subjective concepts such as who trusts whom, who is considered trustworthy, as well as the ability for example to communicate (e.g., who works closely with whom and how frequently they meet) and the ability to cooperate (e.g., who shares information, who consults with whom). In this work, SNA is applied to study such types of variables, as suggested by the list of relationships in the work of Wasserman and Faust (1994, 25:37). The structure of the R&D network is determined based on the relationships chosen by researchers, and all of its concepts must be defined relationally.

(III) COLLECTING AND MEASURING NETWORK DATA

Network data can be collected using the same tools as are used for other research, that are not SNA, as long as the items are developed in terms of actor relationships. The choice of the appropriate technique has a lot to do with the access the researcher might have to the data as well as its nature. As an example, joint patents can be a type of relationship to consider in U-I links, but the researcher has to have access to the archive of such data (see for example the study by Balconi and Laboranti, (2006), or others in Table 1). On the other hand, the level of trust between researchers is a variable that can be collectable through a survey or an interview. Besides, while collecting relational data, researchers can include questions to collect attribute data that can help categorize different types of actors. Examples of attribute data in U-I links can comprise actor affiliation, years of experience in U-I links, age, tenure or hierarchical position in the institution. Moreover, network relationships to be measured can be directed or undirected, valued or binary. Directed ties go from one actor to the other, unlike undirected ties. As an example, the flow of samples or advice seeking are examples of directed ties while co-authorship of patents and co-attendance at project meetings are considered undirected. If a directed tie exists in both directions (e.g. both actors call each other), then the relationship is reciprocal. These directed and undirected ties can also be measured as valued or binary relationships. Binary represents the existence or absence of a tie (e.g., attendance at a meeting or money transferral), while value relations represent the strength of a given tie (e.g., the level of trust, amount of money).

(IV) ANALYSING NETWORK DATA

The most popular programs to analyse network data are UCINET (Borgatti, Everett, and Freeman 2002) and Pajek (Nooy, Mrvar, and Batagelj 2005). A comprehensive list of SNA software can be found in Scott and Carrington (2011). Regardless of the software used, there are a handful of indices that should be calculated in order to get an analytical sense of the network's social structure. In the particular case of U-I relationships, crucial indices would be centrality measures, network density, strength and reciprocity of ties, clustering and core-periphery structures. For example, centrality measures can help predict actors' levels of power in the network, despite organizational boundaries; strength and reciprocity of ties could act as a proxy for the amount of resources (financial, equipment, knowledge, advice or others) shared between any pair of actors; clusters and core-periphery structures make it possible to perceive closely related actors in contrast to the remainder of the network. The representation of information in SNA can be achieved in matrices or in graphs (as in Figure 2). The direction of the ties is also relevant when analysing links, as it may change the role of the actor in the network.

The use of SNA to study U-I R&D Relationships was tested using as a case study the network from a FP7 research project, funded by the EU - Cooperation programme, in the area of Biological Sciences. The data is part of a larger set obtained in a survey of all the 29 project members, collected by e-mail during the summer of 2013. Non-respondents were later contacted by telephone. A total of 23 valid responses to a single question were collected from key informants in each institution. The chosen question was: “Within ...(name of the consortium)... I worked closely with the following partners:”.

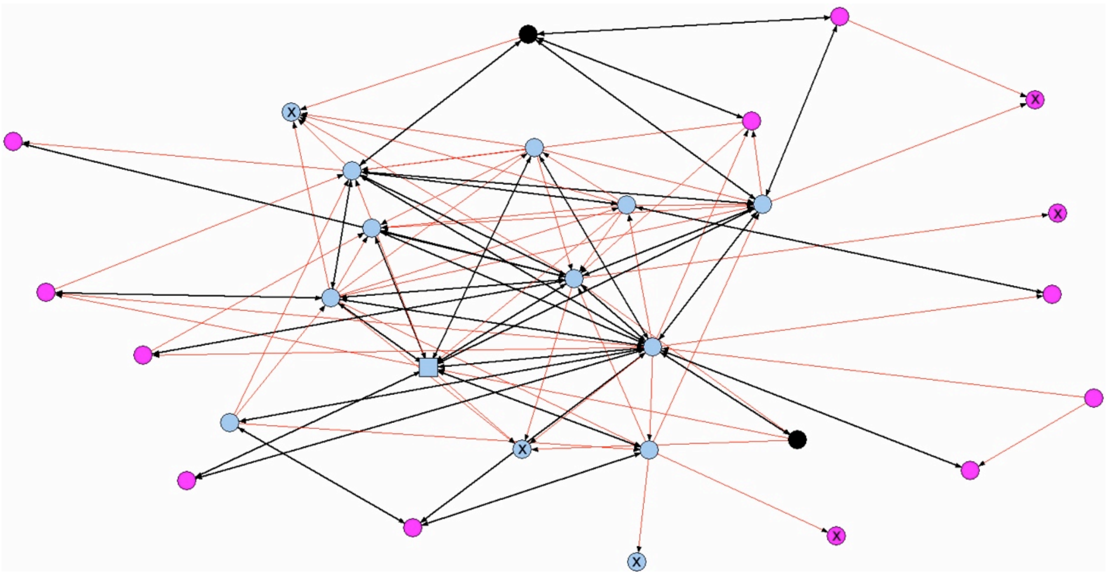

Figure 2. Network of reported close working relationships between 29 partners within an R&D project funded by the FP7

Project members are identified by a circle, and the coordinator by a square. Blue nodes are public or private research institutions; pink nodes are private or public companies; black nodes are other type of institutions (e.g.: funding bodies, city councils, interest groups, international associations, and the like). Ties between nodes are black if both members claim to work closely and red otherwise. Nodes marked with ‘x’ did not respond to the survey but are present in the network because other members have reported having closely worked with them in the project. Graph produced using NetDraw, in UCINET (Borgatti, Everett, and Freeman 2002)

Patterns of connections and core-periphery structures are well explored in the SNA literature (Gulati and Gargiulo 1999; Salavisa, Sousa, and Fontes 2012), but there is not yet a substantial body of knowledge applied to U-I R&D networks. In Figure 2, the blue nodes are universities and research organizations (public and private), while the pink nodes are public or private companies hoping to benefit from the application of the knowledge and technology produced by the former. The pink nodes are mostly found on the network's periphery. Pink nodes relate preferentially to blue nodes, and have few connections to other pink nodes - companies. This suggests an interesting phenomenon of companies preferential linkage to research organizations. However, the blue nodes mostly connect with other blue nodes (called homophilic relationships). Again, research organizations connect preferentially with each other. This asymmetry is also evident in the quantification of ties between groups, as shown in Table 2. Importantly, in spite of all partners being equally embedded in the network, sharing values, objectives and knowledge, the institution type ultimately influences each partner's position and interplay. Concurrently, some pink nodes are linked to the network by only one or two ties. These nodes are more likely to be constrained in terms of information access, exposing their dependence on other more central actors.

Table 2. Number of ties within and between groups of institutions and average degree for each institution type

	Public and Private Companies (N=13)	Research Institutions (N=13)	Other institutions (N=2)	Average degree for each institution type (in-degree / out-degree)
Public and Private Companies (N=13)	2	16	2	1.92 / 1.54
Research Institutions (N=14)	21	75	4	6.93 / 7.14
Other institutions (N=2)	2	6	0	3.00 / 4.00

To our knowledge, this is the first time that these asymmetries in U-I R&D work relationships are recognized and analysed, and they will be further explored in the future, namely so as to understand their possible consequences in distinct innovation processes within R&D networks. Asymmetry in tie reciprocity in U-I R&D cooperation was mentioned in the work of Fritsch and Kauffeld-Monz (2010), however its implications were not taken into consideration. Another important observation of the above example is that, despite the missing data from six organizations, the network density is much lower than a clique - 16%, similar to the value reported by Fritsch and Kauffeld-Monz (2010). This emphasises the mentioned asymmetry, further showing that the different types of organizations/nodes also have different degrees or sub-group densities (Table 2).

Concluding, this work, while rather preliminary in nature, provides an illustration of how SNA can be useful to study relationships within R&D projects. In particular, SNA exposed the degree and directional asymmetry in connections between the different types of partners, and suggests these types of projects might have densities much lower than a clique. In our opinion, further research is necessary to understand and explain these unequal relationships, since all the mentioned factors have significant implications on the network structure (see Figure 2). As said before, most previous studies did not take into account the human relationships underlying inter-organizational ties, focusing on collaborative outcomes. Otherwise, we analysed the *ex ante* relationships. Moreover, SNA served the purpose of extracting relevant information from relational processes between actors, a reason why it should be used in future research to explore the effect of R&D network structures on cooperation outcomes. In line with previous studies (Alguezaui and Filieri 2010; Landry, Amara, and Lamari 2002; Pérez-Luño et al. 2011), the present work suggests that innovation may depend on interpersonal relationships, and is not *a priori* guaranteed by the characteristics and achievements of the institutions' candidate to partner U-I R&D projects. Questions regarding network structures and R&D cooperation outcomes will be further addressed in future research, along with the dynamics of network governance and activities leading to relationship development.

Finally, our research limitations and challenges are presented. The bibliometric analysis, by forcing the combination of a high number of keywords, limited the amount of results, possibly excluding studies that did not use all those terms. The search conditions were therefore tentatively relaxed. The resulting pool of articles further included many unrelated studies, skewing the data in the bibliometric analysis.

Several challenges associated with using SNA to study U-I relationships can be recognised. The most straightforward concerns collecting relational data, particularly from a "complete network" perspective, since SNA utilization requires statistically significant rates of response. Previous studies focused on existing databases, usually avoiding the need to ask researchers how they cooperate. Additionally, the procedures of collecting network data lead to some exposure of the individuals surveyed. In rare instances, participants reported that they were sharing somewhat sensitive information, partly due to competition between institutions. In order to ensure greater participation, we guaranteed anonymity and caution in the use of the collected data.

This study is essentially limited by the single project analysis it embodies. Therefore, although the conceptual basis of the work is rather solid, the main concepts addressed at the end of the last section cannot be generalized. The work offers an illustration of the potential of using SNA methodology to assess U-I networks. Further research is necessary to sustain generalized use of SNA in the R&D context, and validate potentially fruitful results originating from it. Nevertheless, the present work contributes to highlight the centrality of relational asymmetries shaping the innovation process within U-I R&D projects.

CHAPTER 3 THE OUTSET OF U-I R&D RELATIONSHIPS: THE SPECIFIC CASE OF BIOLOGICAL SCIENCES

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ABSTRACT

Purpose: This paper draws insights from the ARA-model and Social Capital literature to identify relevant activities shared by University-Industry (U-I) actors prior to R&D cooperation.

Methodology: Based on a qualitative methodology, a series of interviews were carried out with researchers from the Biological Sciences domain.

Findings: This study found that, at the outset of U-I links, companies' motivations are strongly organizational, while academics are motivated at a personal level. The interactions grow from low-risk activities to partnerships on complex tasks, and depend on relational resources framed within the ARA and Social Capital theories. Results showed that shared interests are present at the outset of U-I links and grow thereafter. Trust and commitment were not ubiquitous at the outset, but rather at later stages of the cooperation, as a result of the developed interdependencies.

Research implications: The combination of the ARA-model and Social Capital in U-I links highlighted the different relationship levels (individual *versus* organizational), the disparities between early and established ties, and the interplay between low and high investment activities underlying researchers' relationships. Several managerial contributions are presented for Universities to promote greater integration with industry partners.

Originality/value: A new direction of research is presented towards lower levels of U-I cooperation, taking into account the relational resources and the activities shared in each level. This work distinguished the different actors' motivations and clarified the role of trust and commitment at the outset of U-I links. This first assessment of Portuguese U-I interactions within the Biological Sciences provided valuable insights for both academics and practitioners.

Keywords:

Inter-organizational networks; ARA-model; Social Capital; University-Industry links; Biological Sciences, Portugal

INTRODUCTION

Understanding University-Industry (U-I) links assumes an increasing importance in the need to strengthen company's sources of competitive advantage when operating in turbulent environments. This study assumes that innovation is not exclusively dependent on the internal capabilities of a company, such as its R&D skills and its capacity to absorb external knowledge (Cohen and Levinthal 1990; Hagemeister and Rodríguez-Castellanos 2010) but can emerge and be built in the thin layer of actual exchange and knowledge-sharing between actors (Powell, Koput, and Smith-Doerr 1996). In other words, it depends on the networking and knowledge flow between all players involved (Ouimet, Landry, and Amara 2004). The business context in which a company develops its activity can greatly affect its success and growth (Håkansson and Snehota 2002) in a sense that better collaborations (in the qualitative sense) may foster improved outcomes for the actors involved (Mora-Valentin, Montoro-Sanchez, and Guerras-Martin 2004; Raesfeld et al. 2012). Consequently, networking activities allow R&D partners to acquire innovation-prone tacit and explicit knowledge, crucial for competitive advantage (Gilsing and Nooteboom 2005; Story, Hart, and O'Malley 2009). This perspective is particularly relevant for most knowledge-intensive economic activities, such as those relying on Biological Sciences (Gertler and Levitte 2005). It is also important to notice that "studies of networking have mainly focused on private sector organisations and have mostly used an organisational perspective ignoring collective network-level views" (Lundberg and Andresen 2012, 429).

On the other hand, universities around the world are increasingly eager to collaborate with external partners. The academic mission of teaching and advancing fundamental research continues to be the major priority for which there is a growing need of external funding (Y. S. Lee 2000; Plewa 2005). Yet, universities are expected to impact on society and economy at regional and national levels. R&D cooperation with business partners is instrumental in this regard (Kauffeld-Monz and Fritsch 2013), and universities can be valuable partners for companies, as they are usually not competing counterparts of their research activities (Santoro and Betts 2002; Welsh et al. 2008). Moreover, the combination of heterogeneous sources of knowledge can lead to an increase in radical innovation (Gilsing and Nooteboom 2005; Tödtling, Lehner, and Kaufmann 2009), as well as lower R&D expenses for both parties (George, Zahra, and Wood 2002).

The resources required to promote collaborative innovation can be financial, intellectual and physical, as well as social capital (Lundberg and Andresen 2012), each having a distinct role in the development pipeline. However, the availability of resources *per se* does not guarantee successful cooperation. Actors involved in the process must be able to exchange and combine the different resources to achieve novelty beyond results obtained individually (Håkansson and Snehota 1995). In this sense, university and industry actors need to allow their partners access to each other's resources, expecting that activities derived from their use will generate synergy. This particular aspect of resource sharing is key in R&D cooperation. R&D involves high-risk activities, in most cases with no guaranteed results (Blomqvist, Hurmelinna-Laukkanen, and Seppänen 2005). This way, cooperative relationships tend to take place between trustworthy and committed partners (Mora-Valentin, Montoro-Sanchez, and Guerras-Martin 2004; Frasquet, Calderón, and Cervera 2011), where it is fundamental to be able to depend on and trust each other, in view of the commercially sensitive and tacit nature of the knowledge involved (Santoro and Saparito 2003; Bruneel, D'Este, and Salter 2010)

Considering the previous arguments, and in order to reach a successful U-I cooperation, partners need to mutually develop their relationship prior to sharing their resources. The activities that precede the level of R&D cooperation can be crucial to align their interests, deriving from different organizational objectives (Plewa and Quester 2007). Moreover, trust and commitment between partners can contribute to overcome functional conflicts, leading to the accomplishment of mutually valuable outcomes (Morgan and Hunt 1994; Frasquet, Calderón, and Cervera 2011). In our view, the interactions that shape U-I R&D cooperation should be approached as a continuous and developing relationship, with various common activities and resources invested throughout time. Moreover, neither relationships nor organizations exist in isolation but rather depend on each other (Hagedoorn 2006; Håkansson and Snehota 1995). These arguments provide the basis for our choice of the Actors-Resources-Activities (ARA) model (Håkansson and Johanson 1992), along with key concepts from Social Capital theory, to understand the interactions between U-I partners at the outset of an effective R&D cooperation. Although both theories have been discussed together previously (Lundberg and Andresen 2012; Finch, Wagner, and Hynes 2010), these have not yet been applied to the outset of U-I R&D relationships. Hence, this article attempts to identify relevant activities shared by U-I actors prior to research cooperation, as well as the importance of relational resources (trust, commitment, shared interests) in the process towards joint R&D activities. Data used in this study was collected by means of interviews with researchers from the Portuguese Biological Sciences community. Importantly, this preference for qualitative data (Cassell and Symon 2004) rests on the fact that it allows a deeper understanding of the language shared by R&D partners, provides a richer context insight, as well as an assessment of their common conceptual construction of the developing relationship.

We proceed by first presenting the literature review, followed by the research methodology. Next, the data collection and analysis is presented. Then, the major findings are analysed followed by discussion and implications for both theory and practice.

From dyadic transactions to network relationships

U-I cooperation and its impact on innovation has been a long-standing topic of analysis in many fields of knowledge, ranging from Management, Economics and Sociology to Science Policy (Bozeman 2000; Agrawal 2001; Leydesdorff and Meyer 2003; Brimble and Doner 2007; Perkmann and Walsh 2009). In recent decades, much research has been carried out on the processes of technology transfer, in order to measure innovation performance and its impact at regional and national levels (Mowery, Oxley, and Silverman 1996; Siegel et al. 2001; Hemert, Nijkamp, and Masurel 2012; Thornhill 2006). Several authors emphasised the relevance of transferring explicit knowledge in order to generate the innovative outcomes that companies need to maintain their competitive advantage (Lehrer 2007; Powell, Koput, and Smith-Doerr 1996; Rosiello 2007). Nonetheless, there is a growing body of literature addressing the relational and social side of innovation aiming at understanding the relational investments and processes that institutions go through in order to reach innovative outcomes (Landry, Amara, and Lamari 2002; Alguezaui and Filieri 2010; Pérez-Luño et al. 2011). This putative change of paradigm implies that U-I links are treated less as transactions and more as relationships, which are built up over time, and can be leveraged to access critical resources. In a sense, the developing relationship itself becomes a unique and valuable resource that competitors cannot access or copy, requiring investment to be maintained (Lavie 2006; Lundberg and Andresen 2012). The use of this unique resource should enable a positive feedback loop, continuously improving the quality of the interaction between the partners and increasing their relational interdependence.

Another key aspect of U-I cooperation is the fact that actors can be involved in simultaneous relationships with different partners (D'Este and Patel 2007; Protogerou, Caloghirou, and Siokas 2012). Research on networks of co-authorship and project membership showed that university and industry have very diverse networks with multiple stakeholders (Vonortas 2012; Beaudry and Kananian 2013). Moreover, for any given institution, each link has the capacity to positively or negatively influence every other existing or potential link, embodying the opportunities and constraints promoted by network interactions (Baraldi and Strömsten 2009; Rowley 1997). As resources are limited, institutions can only invest in selected relationships, which forces the study of U-I relationships to consider the network effects and the structural dependence of actors, moving away from dyadic studies, often based on the relationship with the main partner (Plewa and Quester 2008; Morgan and Hunt 1994). Concurrently, when a network is formed, the ARA-model and the Industrial Marketing and Purchasing (IMP) group research stream advocate a structural and relational dependence between the actors (Baraldi et al. 2007; Ford et al. 2008). Three layers that involve the network of interactions describe this dependence in the ARA-model: the Actors, the Resources and the Activities (Håkansson and Snehota 1995). Actors share bonds between them, through which resources flow and activities are performed, creating mutual value. The exchange and combination of Resources are tied to relationships developed in dyads, embedded in wider networks. The progress of a dyadic relationship is not transferable between actors, representing the relational interdependence of the network. Activities have links between them and reinforce the bonds between actors. Likewise, when two actors perform a joint activity using their resources, it may limit the execution of that same activity with other actors in the network, revealing the structural interdependence of the network. These actor bonds grow from simple, low involvement interactions between institutions to mature relationships when the partners feel confident to invest further, in order to secure the benefits of a greater integration (Trkman and Desouza 2012). Just as in B2B networks, actors' structural and relational dependence can be observed in U-I links (Lundberg and Andresen 2012), impacting the type of activities and resources available from the outset and throughout the development of the relationship between actors.

Inter-organizational links and activities prior to R&D cooperation

U-I relationships can easily be perceived as inter-organizational links. The most immediate requirement is that two institutions provide a bridge for their researchers to foster and maintain the collaboration. In the IMP literature, these bridges were described to develop because organizations acknowledge they need external partners for their everyday activities, without whom their opportunities for development become limited (Anderson, Håkansson, and Johanson 1994; Håkansson and Ford 2002). Consequently, the structural links driven by organizational motivations should empower joint activities and resource sharing. The interdependence between actors on the two sides of the bridge is regarded as an opportunity for cooperation, as it facilitates knowledge-sharing, and allows partners to build their competitive advantages (Baraldi, Gressetvold, and Harrison 2012).

There are diverse motivations to initiate an inter-organizational link towards R&D cooperation. Companies enjoy lower risks and lower R&D costs, a favourable public image and reputation, and easier access to frontier knowledge and skills. For their part, Universities are motivated by the need for external funds to support their research activities, as well as producing positive effects on society through improved regional, economic development, education, and the exploration of new ideas for future projects (Lundberg and Andresen 2012; Veugelers and Cassiman 2005; López-Martínez et al. 1994). Based on their own mission-based organizational motivations, U-I partners are expected to seek one another and, similar to B2B links (Ganesan 1994; Dwyer, Schurr, and Oh 1987), collaboration could start with low-investment low-risk activities, such as service-provision or buyer-seller exchanges. This starting process most likely contributes to clarifying the orientations and goals of each organization, and the establishment of a common ground for future collaborative works, as actors may be more receptive to each other's ideas and therefore more willing to invest further if there are shared interests and mutual value. As acknowledged by Jaakkola and Hakanen (2013, 48) value derives "from the benefits and sacrifices perceived by the actor in the offering and the related exchange".

R&D literature acknowledges several activities used to foster U-I links (D'Este and Patel 2007; Bekkers and Freitas 2008), but it is not clear as to which one/s ensure/s the relationship development. This entails greater dependence between actors, which may shift from considering themselves each other's clients to being partners as well. In this line, do the activities also change along with the relationship? Would that mean that mutual service provision continues, despite more complex collaboration? The literature seems clear that the significance of the shared resources and the consequent level of the actors' dependence evolve with the relationship (Mouzas and Ford 2012), making it more likely that the degree of complexity of the activities changes as well. This work proposes that this change encompasses adding more shared tasks with consequent increased partner reliance, and not substituting service provision by other tasks. Thus, supplier-customer activities may continue while more complex tasks are added to the relationship. To the best of our knowledge, in addition to the limited data on how the interaction between actors tends to start, in particular in the Biological Sciences domain on which the present work focuses, there is little research evidence on how the relationship development affects the activities performed by U-I actors. All things considered, the following research propositions are built:

Proposition 1: *Organizational motivations of both university and industry actors are the main promoters of the activities at the beginning of a U-I relationship.*

Proposition 2: *Low-investment and low-risk activities at the beginning of a U-I link will continue throughout the relationship, while more complex tasks are added as the relationship matures.*

The role of relational resources prior to R&D cooperation

The IMP research stream, through the ARA-model, supports the theory that, in any relationship, resources are essential for each actor to develop activities. As resources and activities become more complex, the capacity for a single actor to manage them becomes more limited, requiring the inclusion of further actors for collective leverage (Cantù, Corsaro, and Snehota 2012). The capacity to do this is dependent on the actor's capability to engage in interactions that generate joint gains (Mouzas and Ford 2012). This was suggested for inter-firm cooperation, but it should also be true for any other knowledge-based activities, such as those within U-I partnerships.

IMP focuses on the exchange and combination of financial, intellectual and physical resources, and less often on relational resources, such as social capital. According to Batt (2008), Social Capital is underexplored in B2B marketing, which it should usefully contribute to with key insights into many of the IMP concepts. As Partanen et al. (2008) observed, while the IMP-driven research tends to focus mainly on organisational actors and business networks, Social Capital research tends to consider the individual's social relationships. Similarly to Batt (2008, 488), we view Social Capital as "the mobilization, use and benefits gained through accessing present and future resources" through social, intra- and inter-organizational networks. Common features exist between these research streams, encompassing constructs such as commitment, trust and shared interests, amongst others. In the context of business networks, IMP has acknowledged the role of these relational resources in cooperation, as engaged actors develop mutual orientation and commitment over time, gradually assuming a higher degree of interdependence (Håkansson and Snehota 1995). Concurrently, trust and dependence were considered elementary qualities in customer-supplier relationships within networks, with actor interdependence increasing as the relationship develops (Laaksonen, Pajunen, and Kulmala 2008). As such, in time, actors are more aligned with their partners' interests and objectives, and their resources can be leveraged for mutual strategy formulation (Baraldi et al. 2007). Similar phenomena are expected in a U-I setting, as actors increasingly share research interests and resources in their cooperation, despite their organizational differences (Lundberg and Andresen 2012).

In the context of U-I links, the combination of relational resources embedded in actor bonds, such as trust, commitment and shared interests, could be directly tied to the successful execution of tasks. In the case of inter-firm links, the successful development of R&D cooperation is simultaneously dependent on trust and formal contracts (Blomqvist, Hurmelinna-Laukkanen, and Seppänen 2005). However, unlike contracts, trust is more far-reaching in the relationship between actors. Trust can be viewed as the belief that a potential partner is honest, fair and reliable, irrespective of the ability to monitor or control the other party (Mayer, Davis, and Schoorman 1995). Thus, a trustworthy relationship provides the conditions for assessing the predictability of future actions based on past interaction and promises, and mainly reduces the perception of risk, associated with opportunistic behaviour (Dwyer, Schurr, and Oh 1987; Morgan and Hunt 1994). In view of the high-cost high-risk character of research, even if applied in nature, trust should be present from the outset in U-I relationships in order to enable greater integration and resource sharing. According to Blomqvist (2005), within inter-firm R&D cooperation, a base level of trust is required to initiate any cooperation or to even draft a contract. This work expects to understand if U-I relationships behave similarly.

University and industry actors have different organisational cultures, namely regarding secrecy vs. free dissemination of knowledge, which might jeopardise effective alliances (George, Zahra, and Wood 2002; Plewa and Quester 2007). Asymmetries of an identical degree can be found in inter-firm collaborations (Blomqvist, Hurmelinna-Laukkanen, and Seppänen 2005). This could have a significant and direct impact on the development of trust, commitment and interdependence. Therefore, partners need to find compatible matches to foster adequate cooperation. Despite the acknowledged differences between academia and industry, it is possible to deal with those differences through close and direct involvement, progressively closing the gap generated by cognitive distance (Rosiello 2007). Intuitively, U-I cooperation could consider sharing any type of resources, namely information, tacit or explicit knowledge, technology, materials or samples. However, in order to reach this exchange level, partners should be comfortable working together and committed to their shared tasks. Specifically, commitment is often referred to as an attitude of attachment and an intention to continue a relationship (Dwyer, Schurr, and Oh 1987; Morgan and Hunt 1994). As previously mentioned, investments in relationships enhance parties' credibility, reducing uncertainty and the risk of opportunism (Achrol and Gundlach 1999). Whilst past works have shown that both trust and commitment are constructs present in U-I relationships (Frasquet, Calderón, and Cervera 2011; Plewa 2005), little evidence was found on how those relational resources are present at the outset of the relationship. In successful relationships, both constructs are expected to grow as relationships progress, even if conflict is present (Morgan and Hunt 1994). Based on these arguments, the following research propositions are proposed:

Proposition 3: *Shared interests should be identified at the outset of the U-I link and grow alongside the relationship, allowing increasing resource sharing.*

Proposition 4: *Trust and commitment are required for the outset of U-I links and should increase alongside the relationship, allowing greater partner interdependence.*

Following the explanation of the methodology used in the present work, the research propositions are contrasted with the collected data from the interviews.

METHODOLOGY

Research background

Given the fact that the objectives of the study were more related to understanding than assessing, the outset of U&I relationships are analysed using a qualitative methodology. The logic behind this approach is to place emphasis on theory development as a process, based on interviews with a semi-structured script, instead of assessing or testing pre-defined hypotheses. Furthermore, the focus of this study — Biological Sciences community in Portugal — was chosen according to several criteria. The Biological Sciences provide knowledge and technology to many different industries, such as medical, food, environment, agriculture and pharmaceutical industries, as well as industrial processes, such as plastics or beverages production, making it a relevant area of study in terms of the amount of opportunities for U-I cooperation. Additionally, the research units in Portugal that work in this broad scientific field enclose 46% of the total Portuguese research FTEs (Full Time Equivalent) working on non-Humanities and non-Social Sciences units (FCT 2014). The choice of narrowing the study to the Portuguese scientific community is based on the exceptional way Portuguese R&D activities evolved over the last 20 years. During that period, and according to data from Eurostat and the Portuguese Science and Technology Foundation (FCT), the number of FTEs and the associated scientific production increased exponentially, from the very low base level of 1.04 FTE /1,000 inhabitants in 1994 (50% of the EU average in 1993) (Eurostat 2013; FCT 2014). Unlike other countries in the EU, Portugal has a very young scientific community. This configures the field of Biological Sciences in Portugal as very dynamic, providing a good population to understand the outset of U-I relationships.

It is worth noting that, according to the latest European Community Innovation Survey (CIS 2010 data in FCT, 2012), in terms of collaboration partners for R&D tasks, Portugal compares unfavourably to the EU average. When compared to EU figures, the potential partners that Portuguese companies least search for are universities and other institutions of higher education, along with private consultancies and research laboratories (FCT 2012, 223). Moreover, U-I cooperation within the EU members relies considerably on European funding. Each year, there are projects funded by European framework programmes, supporting sound research proposals from U-I consortia. Nevertheless, there is no information in the literature on how these consortia came to be, and what steps partners went through in order to reach such an involvement towards a funding opportunity. At national level, similar funding programmes exist, though the degree of funding is much smaller, and they are less frequently committed to the U-I interplay, with less than 1% of total funding allocated to projects submitted by industrial parties (FCT 2012, 187).

Sampling process and sample size

The key criteria underlying the selection of individuals for our study was relevance rather than representation (Perry 2000). This study adopted a theoretical sampling in order to gain a deeper understanding of the outset of U-I R&D relationships. Specifically, this sampling proceeds not in terms of a sample of a specific group of individuals, but in terms of concepts, their properties, dimensions and variations (Corbin and Strauss 1990). Accordingly, academic participants were selected from research centres in Portuguese universities that had been recently distinguished in the Times World University Ranking (Region: Europe). The sample included 11 academics from five research centres working within the Biological Sciences domain covering a wide range of experiences in research collaboration (Table 3). Nine university researchers and the two research centre directors (RCD) were contacted and agreed to participate in our study. One of our academic interviewees was both a university researcher and founder of a biotech SME, therefore providing a more comprehensive view of both sides of the relationship. Subsequently, four researchers from the private sector were contacted for an interview regarding the relationship already described by the university party, but only two of them were available for our study.

Research instrument and unit of analysis

Our data was collected using a semi-structured script developed from relevant literature, as recommended by Eisenhardt (1989) and Yin (1994). A guideline for face-to-face interviews was established, accommodating concepts from the IMP research stream with contributions from Social Capital. The procedure was developed in order to give interviewees the ability to describe his/her reality free of constraints with regard to each question. University participants were encouraged to select one or more successful collaborations ongoing between 2008 and 2012, as long as these included at least one private sector partner. In the interviews, university and company researchers were asked to (a) describe the outset and evolution of the relationships with their R&D partners; (b) detail how trust and commitment developed and why these elements were important; (c) identify the resources (supplied and received) and how they affected the relationship.

Face-to-face interviews averaging 45 minutes were conducted between June and October 2012. The collected data consisted of nine independent cases of self-reported U-I links. The corresponding unit of analysis is the cooperative relationship from the perspective of its participant(s). Additionally, the interviews with the two RCDs gave a further contextual view of the importance of U-I links in the overall activities of the research centres. The number of interviews (Table 3) was not higher because a clear level of data saturation was reached (Bowen 2008), in accordance with the guidelines of four to ten cases, as proposed by Eisenhardt (1989).

Data collection and analysis

Nine participants allowed the audio record of the interviews, while extensive note taking was used for the remaining interviews. The recorded audio data was transcribed *verbatim* and compared to the notes of the other interviews. The contents of the transcripts (from notes and audio) were then analysed following three concurrent stages, as proposed by Miles and Huberman (1994): (1) data reduction, (2) data displays and (3) conclusion verification. The results were grouped according to the four research propositions, in order to facilitate the assessment of data match with our theoretical propositions.

Table 3. Information from interviewees of the present study.

#	Profile of the Interviewee	Area of Research	Experience in U-I links
I1	Technical Director of SME	Agricultural Biology Services	Mostly services and small projects with universities in the Lisbon area.
I2	R&D Laboratory Manager of SME	Molecular Biology Services	Service provision and research collaborations with national and international universities. Participant in R&D projects funded by national and international agencies.
U1	Tenure Professor – University in Lisbon	Biotechnology	Research collaboration with companies mostly in national projects (service provision and R&D with shared students)
U2	Tenure Professor – University in Lisbon	Biotechnology	Over 20 years of research collaboration with companies, mostly in service provision projects
U3	Tenure Professor – University in Lisbon	Biotechnology	Over 15 years of research collaboration with several companies, mostly in national projects (service provision and R&D)
U4	Tenure Professor – University in Lisbon	Biotechnology	Over 10 years of continuous collaboration with a limited number of companies, mostly in national projects (service provision and R&D)
U5	Tenure Professor – University in Lisbon	Molecular Biology	Over 10 years of research collaboration with few companies, both in national and international projects (service provision and R&D with shared students).
U6	Senior Research Fellow affiliated with a University in Porto	Molecular Biology	Over 10 years of interaction with multinational companies, mostly in licencing deals from products developed by a University team.

(Table 3 continuation)

#	Profile of the Interviewee	Area of Research	Experience in U-I links
U7	Tenure Professor – University in Braga	Biotechnology	Over 20 years of research collaboration with companies in national and international projects (service provision and R&D)
U8	Tenure Professor – University in Braga	Environmental Biology	Limited experience with companies, recent R&D services for a multinational company.
U9	Tenure Professor – University in Braga & Founder of a biotech SME	Biotechnology	Over 20 years of research collaboration with companies in national and international projects (service provision and R&D with shared students).
RCD1	Research Centre Director – University in Lisbon	Biotechnology	Overview of centre's U-I activities
RCD2	Research Centre Director affiliated with a University in Porto	Molecular Biology	Overview of centre's U-I activities

Note: Research area and U-I experience data collected during the interviews.

FINDINGS

Organizational motivations at the outset of U-I links (Proposition 1)

From the literature review, U-I links are promoted first and foremost by organizational motivations. Whilst academics seek industry in line with the university's mission for education, research advances and regional development, industry contacts the university driven by a quest for easier access to frontier knowledge and skills to foster innovation. The interviews conducted with researchers from both groups evidenced diverse motivations, but not only organizational.

The two research centre directors (RCDs) interviewed acknowledged the capacity of their research centres to attract industrial funding, mostly through service provision derived from frequent requests for their research competences and equipment. As the national public funding of research centres is progressively reducing, both directors looked at research services as a strong drive fostering U-I links, as the resulting external funds allowed keeping their fundamental research activity alive. In parallel with these reports, both industry researchers (I1, I2 in Table 3) mentioned the importance of university knowledge for their activities. Since their university partners (U3, U5 in Table 3, respectively) were working in complementary areas to their business activities, the knowledge produced was identified as a sector-specific and innovation-prone resource. These partners were willing to start a relationship based on matching motivations. Likewise, the majority of academic interviewees described similar alignments. However, in several unsuccessful cases reported by researchers (U1, U2, U3, U4), companies expected universities to develop new products without any compensation (financial or otherwise), showing no interest for the university's motivations. These unsuccessful cases were not deeply explored in the interviews. Nevertheless, they contributed to highlight that common organizational motivations are needed to establish successful cooperation. Alongside these strictly organizational drives, nearly every interview revealed interpersonal history underlying the initiation and maintenance of a U-I link. These links elaborate from more to less interpersonal contacts as follows:

- A colleague and a family member introduced U9 to its future industrial partners.
- U5 knew the CEO of the company personally before any work was shared.
- U2 and U3 had several on-going U-I links based on personal acquaintances that facilitated the commencement of several master and doctoral theses.
- U7 started the link from a personal contact developed during a workshop.
- U1 and U4 described relationships driven by contacts established by former graduation students working at companies.
- U6 developed a close work relationship with the industrial partner from a sustained buyer-seller interaction.

In this sense, while inter-organizational motivations were recognized as important promoters of U-I activities, they are not the main drivers underlying the outset. Accordingly, most academic researchers pinned the success of their cooperation to the establishment of interpersonal links, rather than to the alignment of organizational drivers. In the words of U1: "*the link to the company would not be so easy if there was not a previous, almost personal, relationship* [with the former student working there]." Moreover, academics referred more often to personal motivations, such as funding for their research, opportunities for career development and individual recognition. Thus, our Proposition 1 - organizational motivations are the main drivers of the outset of U-I links - was not confirmed in the interviews. Quite the opposite, these data suggest that interpersonal links are the main drivers.

The evolution of shared activities as U-I relationships mature (Proposition 2)

Consistent with the literature on B2B links, U-I actors are expected to start their collaborations with low risk and low investment activities, in order to clarify their own orientations and goals, as well as assessing the quality of each other's work. More complex tasks could be added over time, as the relationship matures. This was confirmed from the perspective of both U and I researchers. Industry researcher I1 had previous contacts with U3, related to mutual service provision, and this had recently evolved into the development of a doctoral thesis, expected to result in innovative services to be provided by the firm to the market. In the meantime, mutual service provision persisted whenever specific laboratory analyses were needed. On a similar note, industry researcher I2 reported the following: *"In this case [of the relationship with U5], they were our clients, using services that we provide, therefore in a supplier-customer relationship. (...) We are now trying collaboration not as supplier-customer but as partners [sharing R&D tasks in a funded project]. The relationship evolved, which does not mean that we will not keep each other as suppliers in other situations. (...) It evolved into a partnership because we got to know them. (...) A deeper relation in non-client-to-customer terms came from going along with each other. There were synergies"*.

Likewise, academic researchers recognized this relational evolution, tied to the level of investments and risks in activities. All successful experiences reported by U1 started with service provision and then evolved into the development of master theses, with part of the work conducted in close collaboration with company members. U9 started a U-I link from smaller tasks of interest to a company partner, and through continuous interaction over time started engaging in common projects, which ultimately led to a shared doctoral student working in the company environment. Researcher U4 had a similar account: *"The idea of working together came from the company, because they wanted a service that we could provide. In 2001, in Portugal, very few people were working in that area (...). We then proposed to add something beyond the service provision so we could go a bit further (...) that led to the master thesis and now the doctoral thesis of one of my students"*. While it is not transcribed, in U4's experience, simultaneous service provision and research tasks for both master and doctoral theses lasted several years. Finally, the most recent experience of U7's in U-I links was the participation in a project funded by the FP7-SME programme, which consisted mostly of service provision activities of interest to SMEs spread throughout Europe. Within the project tasks, U7 interacted mostly with one of the SMEs, but did not produce any research papers, which was presented as a significant drawback. The benefits for U7 consisted mostly of available funds for scholarships and attending conferences. In the interview, U7 referred being available for further work with this company, as long as some academic outputs could be ensured, namely through research that was less focused on problem-solving for a single company.

All taken, the majority of the studied cases (6 out of 9) evolved from supplier-customer relationships to sharing post-graduation and/or doctoral students, which necessarily involved more human resources, time, money and laboratory supplies to keep the cooperation alive. In some cases, but not all, interviewees kept low and high investment activities going at the same time. In line with the interviewees' accounts, Proposition 2 - low-investment low-risk activities, characteristic of the outset of U-I links, may last and occur simultaneously with other more mature types of cooperation - was confirmed.

U-I shared interests and resource sharing (Proposition 3)

U-I institutions have distinct roles and objectives in society, and their mutual engagement should only be explored if shared interests and mutual benefits can be acknowledged. Given their putative ability to complement each other in knowledge creation, development and exploitation, it is expected that interactions grow towards cooperation with greater mutual benefits, as a result of significant sharing and a combination of strategic resources.

Successful U-I links reported by interviewees were undoubtedly dependent on the identification of shared interests and mutual gains. This important step was echoed throughout the interviews with academic and company researchers, as well as RCDs. Academics described interest in knowledge outputs, such as theses, papers, ideas for future projects, and patents (by decreasing order of mention frequency). Companies identified the U-I link as beneficial to their national reputation, as well as to their capacity to develop new services/products. According to I2, co-authoring research papers, for example, served the interests of both parties, as long as that research could later be turned into a market application. Moreover, researcher U3 saw the work of previous master theses in collaboration with companies grow into two independent R&D project applications for national funding with companies being partners. U4, on the other hand, expanded a series of service provision tasks to a research project, whose expected results were of interest to the company, reason why it was willing to invest more financial and physical resources. Finally, U9 explicitly reported another level of growing interest in the collaboration with industrial partners. Their joint work led to a new research line at the university, and a new spin-off company based on products developed within the scope of a shared doctoral thesis. This way, Proposition 3 is confirmed - shared interests were identified at the outset of successful U-I cooperation, and frequently grew as a result of partners sharing more complex tasks, implying increasing resources.

Trust, commitment & partner interdependence (Proposition 4)

In the interviews, trust and commitment were referred as *sine qua non* conditions for R&D cooperation by the interviewees, except for the two RCDs with whom the issue was not discussed. Academics and company researchers very clearly distinguished the level of trust inherent in cooperation activities from the level inherent in mere service provision. The latter was considered much lower, and was associated with lower engagement or commitment. Actually, some interviewees (U1, U3, U6, U8) reported that initial service provision activities were often associated with distrust, which could only be overcome with the positive and significant national or international reputation that the company had in the marketplace at the time of their first interaction. From experience, U3 pointed out that trust, or lack of it, is the single most significant barrier to more frequent U-I cooperation in Portugal, since both universities and companies frequently have a mutual *a priori* sense of distrust in their first interactions. Furthermore, U1 and U3 explained that, from the university's perspective, distrust comes from the feeling that the company will not fulfil its promises, which often included not paying for the research services provided by academics, despite the contracts signed beforehand. This statement aligns with Luhmann's (1979, 72) definition of distrust as a "*positive expectation of injurious action*". Similar findings were reported by Seppänen and Blomqvist (2006) on inter-firm relationships.

When addressing their successful experiences, academics and company researchers did not describe trust as blind confidence in the correct execution of programmed tasks, but rather as an expectation of fulfilment that was accompanied by mutual supervision. The definition cited previously (Mayer, Davis, and Schoorman 1995) was less dependent on this capability. This suggests that Portuguese researchers end up trusting their partners in the long-run, while being aware of each other's self-interests, similar to what has been described as calculative trust (Doney and Cannon 1997). This *calculative trust* was useful in cases of research issues and minor conflicts reported by U3, U4, U7, U8, U9 and I2. Supervision helped partners become aware of, and resolve issues with further and closer collaboration. This type of functional conflict was frequently associated with growing trust and commitment, because partners acknowledge a mutual effort in trying to accomplish the promised activities. The majority of interviewees, with the exceptions of U1, U2 and U7, experienced an increase of trust and commitment throughout their relationships. Researcher U9 explained that mutual trust and commitment to shared activities were instrumental for relationship continuity and partner dependence. This was important for both parties because it allowed investments in future opportunities, such as applications to funding calls at the European level. Likewise, as U3 explained, "*service provision and research outsourcing can be used as opportunities for companies to know the universities and vice-versa and to establish trust for other types of projects*". Currently, their expectation is that on-going national research activities with companies might one day pave the way for more integrated, internationally funded projects.

Summing up, at the outset of U-I links, it is not consensual that trust is present, while commitment to shared tasks was mostly enforced by signed contracts, since distrust was significant, and only softened by the partner's reputation. Furthermore, at the level of R&D cooperation, the presence of trust and commitment is nearly unanimous, with partners acknowledging significant resource interdependence. Proposition 4, in line with previous research (Seppänen, Blomqvist, and Sundqvist 2007; Plewa 2005), considers that trust and commitment are mandatory for the outset of U-I collaborations, and should increase during activity development along with partner interdependence. However, according to the results in the present work, U-I collaborations start even without trust and commitment, although these must grow in order for the collaboration to progresses to shared R&D activities. Therefore, Proposition 4 was only partially confirmed, in that trust and commitment are mandatory for partners' growing interdependence and project success, but not for the outset.

DISCUSSION

This section reviews the most salient findings and explains the activities and resources involved at the outset of University and Industry (U-I) R&D cooperation relationships. In the literature, these relationships are mostly addressed from the point of view of the aftermath innovation and economy achievements. These are the final outcomes of dynamic, complex and long-lasting networks which nodes are both organizations and individuals. In that context, the IMP Group focused on the inter-organizational links through the use of the ARA (Actors, Resources and Activities) model, which has been mostly explored in the B2B context (Cantù, Corsaro, and Snehota 2012; Håkansson and Snehota 1995). Lundberg and Andresen (2012) explored the ARA-model in U-I R&D cooperation with the inclusion of further actors, like governmental bodies, financiers and facilitators, while acknowledging that established interpersonal relationships are important for cooperation between different actor categories, improving communication and lowering cultural barriers.

Relying on both the ARA model and Social Capital theory the present work aims at understanding the outset of the relationships that enable effective U-I cooperation. The comparison between the interviews and the literature led us to develop a diagram representing the evolution of the actors' activities as a function of the investment of relational resources, such as trust, commitment and shared interests (Figure 3). Both axes of the diagram include more than one construct. The horizontal axis should be read as a gradual though non-quantitative increase of relational resources shared among actors, while the vertical axis should be read as an increase in mutual value created as a result of growing actor bonds, resource ties and activity links (ARA model premises). This diagram was used in support of the discussion that follows.

In line with recent contributions, the increasing availability of relational and non-relational resources led U-I actors to participate in activities of greater interdependence and integration accruing value in a network context (Jaakkola and Hakanen 2013). The increase in non-relational resources (financial, physical and intellectual) as actors became more interdependent, is not portrayed in the diagram. However, the present work found that the accomplishment of more complex activities (towards the right side of Figure 3) demands not only high levels of resources and capabilities but also a combination of these into a number of activities, similarly to previous contributions of the IMP Group in the B2B context (Cantù, Corsaro, and Snehota 2012; Mouzas and Ford 2012). These dynamics reflect the findings of Proposition 3 in which increased resource sharing derives from maturing relationships.

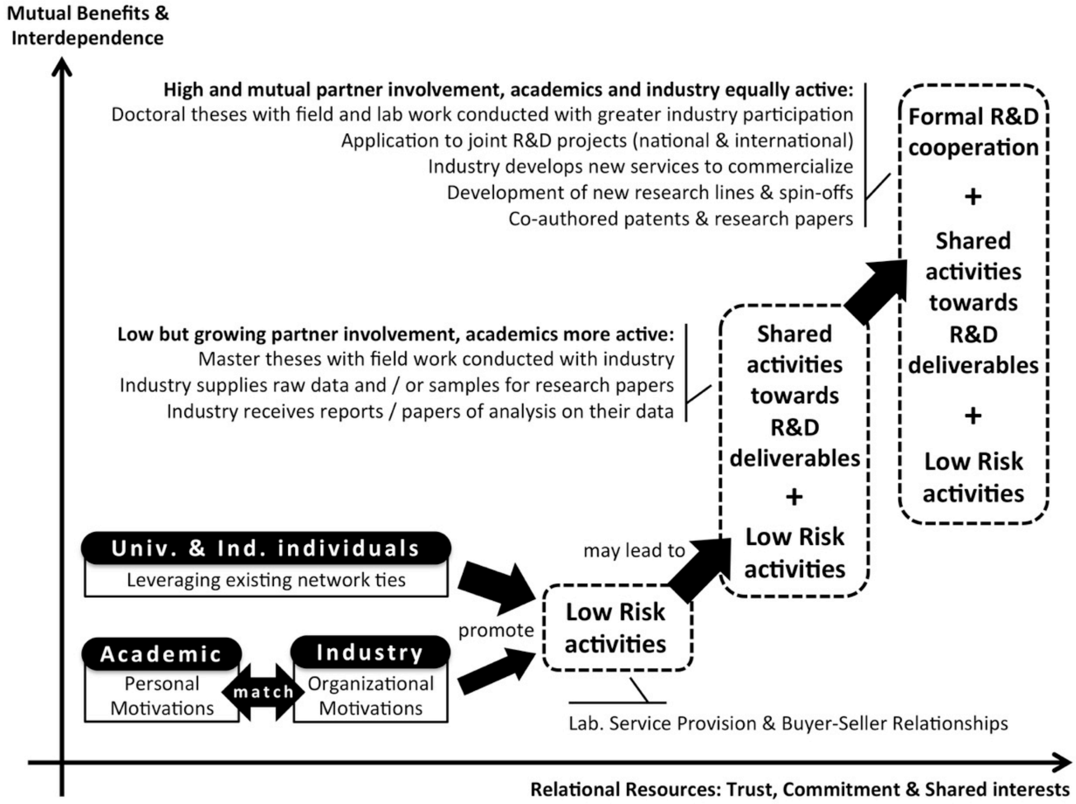

Figure 3. Diagram of the Cooperation continuum – the evolution of U-I actors shared activities and mutual value as a function of the investment of relational resources

In Figure 3, the extent of U-I cooperation was divided into three levels representing the overall dimension of the actor bonds. Nevertheless, these levels are not to be understood as strict stages of the process. From the analysis, cooperation was realized as a continuum rather than a stage driven process. While advancing to a higher level of cooperation, actors may keep engaged in low-risk tasks, as these activities also contribute to a constant improvement of their relationship and resource ties. Proceeding to the next level of activities is suggested to be dependent upon good execution of previous ones, as mentioned frequently by interviewees, highlighting the role of activity links from the ARA-model. Proposition 2 is in accordance with this rationale.

As mentioned above, the findings of the present work did not confirm Proposition 1. Much the opposite, the process to develop a U-I work relationship starts with two main outset activities: (1) leveraging of existing personal direct or indirect network ties, and (2) matching inter-organizational and interpersonal motivations. Concerning the first outset activity, ties can originate from formal acquaintances within the participating organizations (co-workers or other research teams) or from informal relationships developed elsewhere (family, common friends or others). It is important to highlight that the interviewees mentioned that without the first activity (i.e., leveraging of network ties) the relationship is much harder to start. Consequently, the amount of relational resources (or social capital) available is lower and it appears to slow down (but not impede) the development of long-term U-I relationships. In what concerns the second outset activity, failure to find a match between each party's motivations ceases the link. Interviewees described unsuccessful cases like this. It was found that companies and their employees usually understand very well their institutional motivations and objectives towards U-I cooperation. In particular, it was perceived that companies seek universities, or research groups, or even an isolated researcher. This was most often associated with an organizational initiative. However, this was different from the academic end. Ultimately, it was never the university as a whole that approached a company, but rather the research group or, more frequently, the individual researcher that took the initiative. As such, the major drivers from the academic side were mainly individual motivations, and the development of interpersonal relationships, which do not collide with the university's mission. Depending on the private sector (i.e., companies) or the university's end of the exchange, there is often an uneven, individual and organisational weight driving the outset of U-I connections. These observations stress that research of developing U-I links should be able to encompass analysis at both individual and organizational level, in order to truly capture the nature of outset U-I relationships, particularly when numerous formal and informal interactions are in place.

The successful execution of outset activities (either with or without previous ties) promotes the advance to low risk activities, such as laboratorial service provision and engaged buyer-seller relationships. Other types of activities could be included in this stage, but the interviewees did not mention them. It is relevant to notice that these activities are not limited to strict transactions bound to terminate at some point in time, but instead represent an initial interplay that might allow future higher levels of collaboration. At this point, partners learn about each other's work and conduct and assess the extent to which their future interests in this relationship might be compatible with their partner's interests. A successful combination of interests generates 'shared interests' that can be leveraged, along with trust and commitment, to lower the perception of risk and opportunism. This allows proceeding to higher levels of cooperation where more resources become available to the partnership, as presented in the findings underlying Propositions 3 and 4. In the second level of cooperation represented in Figure 3, the activities described in the findings (shorter term theses that may lead to faster publications) tended to benefit academics more immediately. The industry interviewees concurred. The industry can only benefit from these activities if the results within the deliverables are beneficial to their commercial activity. As such, an asymmetry exists in the involvement of actors at this level, similar to asymmetries in B2B links involving actors of different dimensions (Blomqvist, Hurmelinna-Laukkanen, and Seppänen 2005). Academics are more engaged in the activities at this level because they value deliverables *per se*, while industry parties can only gain if the deliverables can be converted to commercial advantage. In Figure 3 the level of engagement of each type of participant is not represented, just their relational interdependence.

At the highest level of U-I collaboration, formal R&D cooperation activities are added, leading to joint R&D projects, shared PhD students and co-authored papers or patents, or even the creation of spin-offs. When the relationship progresses to this highest level of interdependence in the cooperation continuum (right-hand side of Figure 3), strong actor bonds are observed and several value-added activities are performed, many of which are extensively described in the literature (D'Este and Patel 2007; Bekkers and Freitas 2008). At this level, trust assumes a crucial role in relationship building. Specifically, it represents the basis for interpersonal interaction with U-I partners being more willing to engage in exchanges and cooperative activities when levels of trust are high (Ring and van de Ven 1992; Powell 1996; Morgan and Hunt 1994). According to the interviewees, only a fraction of all cooperation experiences ever reach this high level of interdependence. Nevertheless, most of the literature on U-I driven innovation only addresses this last, less frequent but very successful level of cooperation. This bias does not allow understanding how this level is reached, and more importantly, why it may not be reached. As depicted in Figure 3, the levels of lower interdependence are very rich in interaction and partner matching, and are indispensable to reach the highest level. Also, the lower levels have relational challenges that may not be as frequent in higher levels but that significantly impact on continuity, such as opportunism, distrust, and inefficient communication, among others (Seppänen and Blomqvist 2006; Achrol and Gundlach 1999; Santoro and Saparito 2003). Finally, by studying the whole cooperation continuum it is possible to identify key points for managing the relationship and pinpoint the attributes or events that lead to a successful or unsuccessful relationship, in view of future application in the establishment of more successful networks.

To conclude, this research contributed to a better understanding of the activities and relational resources involved at the outset of successful R&D cooperation activities. Companies' motivations at the beginning of U-I links are strongly organizational, while academics are mostly motivated at a personal level (Proposition 1). These interactions grow in a cooperation continuum from low-risk, low-investment activities, such as service provision and buyer-seller exchanges. As the relationship grows, actors consider themselves partners instead of clients and more complex tasks are added to the existing link, namely the development of students' dissertations and shared R&D activities (Proposition 2). All these activities are supported by relational resources, explained by the IMP and Social Capital theories, that are crucial for the relationship, i.e. shared interests, trust and commitment. This work shows that shared interests are present at the outset of U-I links and grow alongside the building of the relationship, leading partners to increasingly share resources and complex activities, such as applying joint proposals for funding, submitting patents or launching a spin-off (Proposition 3). Finally, trust and commitment were not found to be ubiquitous at the outset of U-I links, but rather at later stages of cooperation, as a result of developed interdependence between partners (Proposition 4).

THEORETICAL CONTRIBUTIONS

Over the last decades, R&D cooperation studies have mostly focused on understanding the role of universities (and other knowledge producers) and companies in technology / knowledge transfer (Bekkers and Freitas 2008; Agrawal 2001), along with the impacts towards regional and national innovation systems (Fritsch and Kauffeld-Monz 2010; Ozcan and Islam 2014). However, a new approach addresses the social and relational side of innovation, focusing on the relationship between actors and its impact on innovation (Landry, Amara, and Lamari 2002). Instead of justifying this as a function of R&D performance indicators, the actors' diversity and their relationships are recognized as *ex ante* drivers of innovation (Pérez-Luño et al. 2011). The present work followed this trend through a qualitative approach, and showed how activities and relational and non-relational resources change throughout the whole cooperation continuum between U-I actors. This was done within the framework of the Portuguese Biological Sciences scientific community. The results of this work focus on efficacy of U-I relationships at their starting up level, at the source of their first interaction, when crucial interactions may allow or impede further developments. As such, this work presents a new direction of research towards understanding the lower but indispensable levels of the cooperation continuum. Throughout the continuum, and to the extent of our knowledge, the concrete roles of trust, commitment and shared interests towards U-I actors interdependence are yet to be fully understood, reason why the current study enriched our understanding of this phenomenon. Specifically, understanding the role and evolution of each relational resource (trust, commitment and shared interests) in the developing U-I link, should help explain to what extent each one contributes to more interdependent and valuable relationships.

From a theoretical perspective, the activities at the outset of U-I relationships seem to be distinct from previous accounts of B2B marketing literature. In particular, the IMP research has a substantial focus on inter-organizational networks and bonds between actors at the institutional level. According to the present results, relationships in the U-I context are simultaneously important at the organizational and individual level, from the outset onwards. This limits the capacity of the IMP approach to capture the whole range of data underlying the establishment of links between researchers. The combination of the Social Capital concepts, as proposed by Batt (2008), proved to be very useful in the present paper in a sense that it enabled a broad understanding on the outset of U-I links. The strength and relative importance of the interpersonal and inter-organizational ties towards the success of shared activities were not compared in this study, however, they are expected to have different contributions to cooperation, given that university interviewees considered the role of their interpersonal networks and benefits more important. The present work should positively contribute to the IMP group stream by extending the scope of resources frequently under study.

As previously reported in the literature, each academic researcher promotes their own interpersonal network, despite organizational boundaries, and there is significant value to such an approach (Beaudry and Kananian 2013; Baba, Shichijo, and Sedita 2009). Interpersonal ties with external partners, as opposed to the inter-organizational level, constitute an important network resource (Gulati 2007), and an important form of social capital. Accordingly, this study demonstrates that social capital reinforces the value derived from each network, based on trustful relationships among actors. Consistent with previous studies, trust is the basis for knowledge-related interactions, such as exchange, integration, cooperative problem-solving and constructive dialogue (Powell 1996; Morgan and Hunt 1994). Previous research on inter-organizational networks also identified the need for new relational models that may contribute to explain the processes and contents of relationships (Håkansson and Ford 2002; Håkansson and Snehota 1995). While this work did not propose a new model, it discussed relevant aspects that should positively contribute to advance the ARA-model in the framework of U-I links: (1) the different levels of analysis (individual *versus* organizational), (2) the relational disparities between early and established ties, and (3) the interplay between low and high investment activities underlying researchers' relationships.

MANAGERIAL CONTRIBUTIONS

Universities and research institutions that want to promote greater integration and cooperation with industrial partners need to focus on the researchers that are motivated for engaging in U-I links. From the perspective of interviewees, Portuguese universities do not yet have the capacity to systematically foster these relationships, and the current scenario mostly consists of casual meetings between parties that eventually lead to cooperation, without the academic institution being a key active member in the relational development. Typically, the involved researchers are in charge of defining the strategy and negotiations of contacts and ongoing activities, while University officers are mostly involved in drafting contracts or other documents required for the R&D cooperation agreements. As shown in this study, the relationship starts much earlier and the university should manage it from the outset, not just during the late stages of knowledge sharing and cooperation. The challenges to initiate a successful cooperation continuum are amplified at the outset of relationships, when distrust seems to be most significant. Overcoming this natural mutual suspicion, connected to the perception of a partner's trustworthiness, should promote relationships and turn easier the subsequent more engaged levels of the cooperation.

On top of all major actions, universities, through their Technology Transfer Officers (TTOs), should develop and implement mechanisms that motivate all partners to participate in collective actions. Specifically, TTOs should be actively engaged in promoting networking activities and informal meetings that could spark the cooperation, even if this only goes as far as mutual service provision. Additionally, universities have to develop the capacity to communicate their researchers skills in a language that companies value and understand, acting as facilitators of the cooperation (Lundberg and Andresen 2012). To implement/improve these strategies is particularly important in view of the decreasing national and European scientific funding mentioned by RCDs and described in the literature (European University Association 2012). Moreover, less R&D cooperation will derive from skipping significant lower engagement parts of the relational development, as partners may not be prepared to deal with the more demanding activities of the higher levels of cooperation. For example, given the importance of the funding aimed at joint R&D initiatives of European consortia, understanding and influencing partners' initial interactions seems key to promote functional and successful cooperating networks.

LIMITATIONS AND FUTURE RESEARCH

Focusing the study on the Portuguese Biological Sciences R&D community revealed important findings. Assuming that cooperation relies mainly on interactive and social processes, the geographical concentration of actors in a relatively small territory should facilitate the process of learning-by-interacting (Gertler and Levitte 2005). Concurrently, studying actors within the same location may be beneficial as they are under the influence of the same socio-cultural, economic and political constraints. On the other hand, the results may not be generalizable to other regions within the EU, which configures a limitation *per se*. Another limitation could come from the interviewees' perspective in which both successful and unsuccessful experiences have implications in shaping partners' expectations and motivations at the outset of new relationships. However, this study focused mostly on successful cooperation ventures, possibly generating a bias towards positive findings and conclusions. Future research on unsuccessful experiences is particularly adequate to understand the interactions at the lower levels of the cooperation continuum, where there is likely more opportunity to improve relationships success rates.

Despite the use of the concepts within the ARA model and Social Capital, this study was designed in a way that did not allow exploring the structure of interviewees' network. The existing connections between academics in the same research centre, and between universities in similar research domains, were not explored. Interviews focused on extensive details of one or two cooperation experiences with business partners. Although the interplay between personal and organizational networks was not foreseen before data collection, it should be regarded as an opportunity for this research area, as this work highlighted the role of interpersonal ties to promote formal U-I links. Moreover, considering how U-I organizations and researchers differ in motivations and objectives (López-Martínez et al. 1994), it could be beneficial for future studies to consider an additional dimension of Social Capital in order to model these interactions. Future researchers may wish to consider examining the direct and indirect effects of different social capital dimensions along different stages of the cooperative relationships (Tsai and Ghoshal 1998; Nahapiet and Ghoshal 1998). Specifically, a cognitive dimension could encompass (1) the shared languages and terminology that enable effective U-I communication and (2) the shared vision of partners towards cooperation opportunities of mutual value (Tsai and Ghoshal 1998; Nahapiet and Ghoshal 1998). Finally, in our view, the complex interaction framework under which U-I links develop, further justifies the use of Social Network Analysis as a method to model different types and levels of relationships (Wasserman and Faust 1994).

CHAPTER 4 EXAMINING THE PERCEIVED COOPERATION BENEFITS AND THE NETWORK CENTRALITY OF MEMBERS WITHIN EUROPEAN R&D CONSORTIA

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Abstract

The present study shows that the analysis of the roles performed within an R&D consortium enables a better understanding of perceived benefits and relationships among project participants. It assumes that, to assess the diversity in perceived benefits (Satisfaction, Cooperative learning, Continuity, New R&D ideas) and network centrality, classifying institutions by their principal activity is inadequate. Thereby a new classification is proposed and validated. Project members were grouped according to the knowledge-sharing roles performed: *Knowledge Exploiters*, *Knowledge Developers* and *Promoters* – KED roles.

The study is based on a large survey involving participants of Biological Sciences funded projects from the 7th Framework Programme. Results indicate that (1) *Knowledge Developers* (public or private research organizations) perceive higher benefits than firms in the role of *Knowledge Exploiters*; (2) *Developers* are more central to the network, reporting fewer Close Work Ties with other roles, and (3) *Exploiters* avoid collaborating with other *Exploiters*. Consequently, the traditional clique and star network models do not mirror consortia structure. KED roles appear more suitable, although individual motivations to select work ties within R&D consortia need deeper assessment. The present work creates the conceptual basis for future exploration of the role of Social Capital within FP-funded networks at project level.

Keywords:

Managing International Projects; Benefits Management; Social Network Analysis; Europe; Framework Programmes

INTRODUCTION

During the past three decades, the European Commission (EC) has promoted successive Framework Programmes for Research and Technological Development (FP1 through FP7) as a tool to improve Europe's international competitiveness, and to maintain member states in the forefront of the knowledge-based global economy (European Commission 2013; Protogerou, Caloghirou, and Siokas 2012; Caloghirou, Tsakanikas, and Vonortas 2001). These programmes are based on highly competitive and peer-reviewed funding calls for proposals, submitted by consortia of public and/or private institutions. Each funded proposal, presented by partners from three or more countries, constitutes a Research Joint Venture (RJV). To date, the EC financed thousands of RJVs involving a wide range of participants including companies, universities and research centres, industrial associations, municipalities and government agencies, citizen and interest groups (European Commission 2013; Arranz and Arroyabe 2008). Surprisingly, despite the large amount of funding and the variety of institutions involved, there is little research on the perceptions and relationships among project participants (Caloghirou, Tsakanikas, and Vonortas 2001; Mothe and Quélin 2000). The majority of studies available otherwise focus on analysing the vast inter-project networks, and attempt to understand the networks' structural properties and their implications in knowledge diffusion across regions and innovation systems (Kastelli, Caloghirou, and Ioannides 2004; Ortega and Aguillo 2010; Pandza, Wilkins, and Alfoldi 2011; Protogerou, Caloghirou, and Siokas 2012; Vonortas and Okamura 2013; Avedas 2009). These are very important topics for European Science & Technology policies. However, there is an increasing awareness that research at the level of the aggregated network, or based solely on the perceptions of the project managers, does not cover the complexity of the associated reality (Avedas 2009; Mothe and Quélin 2000; Ebers and Maurer 2014). Current literature on Framework Programmes has failed to capture the micro-foundations of partner interaction and their relationships within a RJV, as well as the extent of members' perceived benefits such as cooperative learning and satisfaction with R&D outcomes. The pattern of ties within an R&D project might be associated with resource sharing and task dependence among partners and this should be relevant to the perception of organizational benefits, which vary substantially across institutions performing different roles within the RJV. Both should significantly impact on RJV's performance and continuity towards future projects (Olk and Young 1997; Shamdasani and Sheth 1995; Wahyuni, Ghauri, and Karsten 2007).

From the perspective described above, the following research questions are formulated:

1. To what extent does the role performed by each member within a RJV affect its perceived benefits accrued from cooperation?
2. To what extent does the role performed by each member within a RJV affect its centrality within the cooperation network?

As a means towards this end, a new classification system for members of RJVs was used to test differences in perceived benefits. This considers three categories / roles, based on how partners in a consortium are involved in the process of sharing knowledge, and oppose a simpler view that only distinguishes between *Coordinator* and *Partners*. The three roles are *Knowledge Developers, Knowledge Exploiters*, and *Promoters* bridging the other two. This classification is hereafter designated as KED roles, acronym for Knowledge Exploiters and Developers. The consequent premise is that these three knowledge-sharing roles form a web within each consortium, supporting and regulating the circulation and availability of new knowledge from *Developers* to *Exploiters* through *Promoters*. The KED classification was further used to study the centrality of each role through Social Network Analysis (SNA). Therefore, to respond to the research question above, a survey addressed to more than 1,000 participants of FP7-funded RJVs in the scientific domain of Biological Sciences was implemented and more than 750 responses were collected and analysed.

Classifying institutions in European Framework Programmes

Analysis performed by the European Commission, as well as past studies on EC-funded RJVs by other players rely most of their conclusions on the classification of participants according to the type of institution (Avedas 2009; Pandza, Wilkins, and Alfoldi 2011; Protogerou, Caloghirou, and Siokas 2012; European Commission 2013). Generally, the categories adopted in previous studies include SME's, research organizations, government entities and hospitals among others, mostly disregarding the classification proposed by the OECD's Frascati Manual (OECD 2002). This manual was created to become the standard practice for surveys on R&D activities, and includes four categories: *Business Enterprises* and *Higher Education*, *Government* and *Private Non-Profit Institutions*. Within the literature that covers European funded projects, the use of this standard classification is not widespread, whereas ad-hoc typologies are relatively common (Breschi and Cusmano 2004; Caloghirou, Tsakanikas, and Vonortas 2001; Pandza, Wilkins, and Alfoldi 2011; Protogerou, Caloghirou, and Siokas 2010a; Mothe and Quélin 2000; Mothe and Quelin 2001). Nevertheless, the Frascati classification should be relevant in allowing, namely, to understand the contribution of public funds to private R&D spending, the frequency of participation of each type of institution, and the categories of institutions more frequently located at the core of the networks formed within FPs (Lööf and Hesmati 2005; European Commission 2013; Protogerou, Caloghirou, and Siokas 2010b). However, these typologies still have one major hindrance, which consists in relying on the participants' institutional background, economic activity, or 'principal activity' (as per the Frascati Manual), and not on the role the participants actually play within R&D consortia.

Previous research attributed importance to considering the different roles played within RJVs, though these have been very often restricted to the distinction between *Coordinators* and *Partners* (Pandza, Wilkins, and Alfoldi 2011; Mothe and Quélin 2000; Breschi and Cusmano 2004). Past studies revealed how frequently certain institutions occupy the role of coordinator (Breschi and Cusmano 2004; Pandza, Wilkins, and Alfoldi 2011), the countries that are recurrently assigned to this role (Pandza, Wilkins, and Alfoldi 2011; Ortega and Aguillo 2010), and the organizational attributes more often associated with it, such as reputation, experience and efficiency to perform the task (Avedas 2009). However, this classification addresses a single member in each RJV — the *Coordinator* — while the rest of the participants are indistinguishably grouped into a single category — *Partner* —, which does not take into account the variety within. This variety is both in type and role. For example, a SME is a well-recognizable type of institution that in an FP-funded project could either perform research for other members, or manage the consortium and dissemination activities, or even be the end-user of a new technology to develop new products. In sum, institutional arrangements based on the type of institution or the roles of *Coordinator / Partner*, both fail to adequately match the type of project member with the role it performs within the project. Moreover, type-based classifications also do not connect the way in which participants are involved with the output knowledge, nor do they explain how it will impact their future activities. To the best of our knowledge, the closest alternative in the literature is the work from Vonortas and Okamura (2013). These authors distributed the roles of the participants from a large cohort of FP-funded RJVs into seven categories that reflect their contribution to the network structure and the connectivity between members in multiple shared projects. These seven roles were grouped in 3 categories of hubs and 4 categories of non-hubs. Hubs and non-hubs were differentiated by their respective large or small number of ties within the overall network, as well as the proportion of ties across network communities, which are highly connected clusters within the network. This classification, for example, distinguished Peripheral Nodes (non-hub), which have a small number of participations with the majority of ties within their community, from Kinless Hubs, which have a higher number of participations with the majority of ties spread across several communities. Interestingly, the authors found that universities represent over half of the hubs. Since the present work deals only with the structure within each single RJV this hub-based classification is not useful. Therefore, the roles will be described taking into consideration the project tasks, and not as a function of the number of ties within the project or the links across several RJVs.

The KED classification

In light of the above, this study contributes with a new classification system based on the roles performed by participants within their R&D projects, avoiding both the concentrative model of two categories (*Coordinator* and *Partners*, albeit mostly focused on the *Coordinator*) and the distributive model of seven categories (Vonortas and Okamura 2013) that ultimately identifies the actors that keep the network connected in order to ensure diffusion of knowledge across several RJVs and towards actors that participate few times on these programmes. Instead, to differentiate partners according to their role, the KED classification assumes that consortium competitiveness depends on both knowledge exploration and exploitation strategies (Levinthal and March 1993), building upon the framework of organizational learning suggested by March (1991). The exploration strategy refers to the development of new knowledge and capabilities and is commonly associated with both radical innovation and long-term framing (Levinthal and March 1993). On the other hand, the exploitation strategy refers to the deployment of current capabilities and is associated with knowledge consolidation and incremental improvements to existing products and processes, while being more short-term focused (Bierly, Damanpour, and Santoro 2009; Pandza, Wilkins, and Alfoldi 2011). Studies at the project level involving exploration and exploitation strategies are not yet common in the literature (Tiwana 2008; Eriksson 2013), although the advantage has been recently recognized (Michelfelder and Kratzer 2013). Hoang and Rothaermel (2010) applied the exploration-exploitation framework to study pharmaceutical R&D projects and found that internal exploration associated with external exploitation benefited R&D project performance. All taken, three categories of KED's knowledge-sharing roles are proposed: the *Knowledge Developers*, the *Knowledge Exploiters* and the *Promoters*.

The major role of *Knowledge Developers* is to perform research tasks and advance the state of fundamental and applied knowledge that can benefit the consortium (Hoang and Rothaermel 2010). These entities, public or private, profit-driven or not, are mainly concerned with undertaking an exploratory strategy, motivated to push forward discovery beyond the boundaries of current science. Universities, research centres and SMEs performing R&D services fit this role.

Knowledge Exploiters contribute to the consortium with knowledge on the state-of-the-market and customers' needs, fostering the opportunity to develop new products, services and processes. These institutions tend to develop businesses towards end-users by offering new products/services, and are not in the business of performing R&D tasks for other companies.

Therefore, this role is mainly exploitative in the sense that the entities thus classified, namely firms, seek to leverage their existing capabilities in areas such as distribution, sales or marketing, despite their internal R&D activities. Typically, SMEs and large firms perform this role by fostering the commercial exploitation of the knowledge developed within the consortium. This is what Grant (1996) assumed to be the primary role of firms.

Finally, *Promoters* nurture a knowledge-sharing environment within the consortium, ensuring the greatest benefits to the larger group, including external stakeholders that could be impacted by the R&D outcomes. This very diverse group of partners may include consultants for R&D activities, public or private entities that administer consortium activities, non-profit associations that assist or represent the interests of end-users, regional or industrial sectors, as well as Government agencies or municipalities that regulate / supervise the sectors and activities targeted by the consortium. The role of *Promoters* is not especially driven by an exploitative or explorative strategy. Instead, these act as mediators between the two previous roles.

The present study makes use of a large set of data, collected through a survey to participants of FP7-funded RJVs in the scientific domain of Biological Sciences, and links the roles of *Knowledge Developers*, *Knowledge Exploiters* and *Promoters* in a network-like structure of project members according to their corresponding tasks. This way, associating partners according to their KED roles is more appropriate for describing and explaining the pattern of collaboration and perceived benefits within R&D projects.

Members' perceived benefits from R&D cooperation

This study assumes that entities performing different roles value differently some of the benefits deriving from R&D cooperation. Past studies addressing cooperative benefits associated with FPs have mainly emphasised organizational and social benefits (Caloghirou, Tsakanikas, and Vonortas 2001; Larédo 1998). However, a more detailed analysis is required to understand how different members perceive benefits like (a) cooperative learning, (b) the generation of new ideas that can be explored in future projects, (c) the satisfaction with project outcomes, and (d) the willingness to participate in future R&D activities with members of the consortium (continuity). These are valuable concepts in the long run to evaluate the success of a funding programme.

(I) COOPERATIVE LEARNING

Cooperation favours learning through positive and negative past experiences, and nourishes the process of joint knowledge creation through shared resources, such as skills, proficiency and technology (Katz and Martin 1997; Defazio, Lockett, and Wright 2009; Espinosa and Soriano 2014). As a result, due to a different availability of resources (Lundberg and Andresen 2012), the overall learning experience achieved in cooperation can be substantially different from the one achieved individually (Xia, Zhao, and Mahoney 2011; Espinosa and Soriano 2014; Håkansson and Snehota 1995). Moreover, the process of learning, and the perception of learning opportunities, may differ depending on the assigned project tasks i.e., the role in the collaboration. This study therefore analyses potential similarities in the perception of cooperative learning as a function of the role within a consortium, considering it provides opportunity for sharing resources. Accordingly, the following hypothesis is proposed:

> *H1: Members from different KED roles report a similar perception that their learning experience would be impossible to achieve without cooperation.*

The hypothesis will be compared to what would be obtained using instead the more common *Coordinators / Partners* classification.

(II) GENERATION OF NEW R&D IDEAS

Learning processes, either individually or collectively, can lead to the generation of new ideas for future research (Kastelli, Caloghirou, and Ioannides 2004; Perkmann and Walsh 2009). However, the recognition of the value in those new ideas may vary across participants, depending on their tasks, their receptiveness to new ideas, and their assimilation of the available knowledge, based on the concept of Absorptive Capacity (Cohen and Levinthal 1990), which is promoted by internal R&D capabilities. Accordingly, this study analysed whether recognizing value in the ideas generated within the project may differ according to the member's role, hypothesizing the following:

> *H2: Knowledge Developers report more often than other KED roles that the participation in the project resulted in new ideas for future R&D projects.*

As above, this hypothesis will be compared to what would be obtained using the *Coordinators / Partners* classification. R&D performing institutions and *Coordinators* should be *a priori* more receptive to recognize and value new ideas.

(III) SATISFACTION WITH PROJECT OUTCOMES

Satisfaction with R&D projects refers to the degree of a partner's overall affective evaluation of the on-going relationships, and the quality of interactions with regard to the expectations of performance and outcomes (Shamdasani and Sheth 1995; Wahyuni, Ghauri, and Karsten 2007). In that sense, satisfaction in a RJV is intrinsically related with the potential benefits (economic and non-economic) in the perspective of each member (Hatfield and Pearce 1994; Olk and Young 1997; Wahyuni, Ghauri, and Karsten 2007; Chol Lee and Beamish 1995). Therefore, it is possible that different satisfaction levels could be observed within the same RJV, with participants valuing differently the project outcomes.

In terms of project outcomes *versus* tasks, *Knowledge Developers* and *Promoters* are expected to perform all the assigned work and achieve the expected results within the project timeframe. However, *Knowledge Exploiters* are putatively more interested in those R&D outcomes that positively impact on their market-driven competitiveness (George, Zahra, and Wood 2002), and therefore result in tangible outputs outside the timeframe of the project. Since EC-funded RJVs are pre-competitive, it is assumed that there is a gap between the R&D outcomes and the impacts on business activity, as described by Pertuzé and colleagues (2010) for US-based cooperative relationships. If such a gap exists at the European level, members in the role of *Knowledge Exploiters* might express a lower satisfaction level than the partners from the remaining roles, while *Coordinators* and *Partners* are expected to express similar overall satisfaction, due to lack of discrimination. Therefore, the following hypothesis emerged:

> *H3: Knowledge Developers and Promoters report more often than Knowledge Exploiters a high overall satisfaction.*

(IV) CONSORTIUM CONTINUITY

Consortium continuity is a form of commitment, which has been defined as a belief that a relationship is important enough to maintain based on the identification of future learning perspectives (Olk and Young 1997; Greve, Mitsuhashi, and Baum 2013; Van Aken and Weggeman 2000; Morgan and Hunt 1994). When members expect their partners to remain in the consortium, cooperative behaviour and cohesiveness are reinforced (Shamdasani and Sheth 1995; Olk and Young 1997; Heide and Miner 1992), ensuring continuous access to external and valuable sources of innovation (Lunnan and Haugland 2008; Powell, Koput, and Smith-Doerr 1996; Arranz and Arroyabe 2008). However, in the particular case of firms, several authors found that remaining in an R&D consortium may not always be an option, since they may prefer to exploit the R&D outcomes without collaboration in order to preserve their competitive assets (Olk and Young 1997; Sakakibara 1997). Therefore, and in line to all stated above, this study examines whether the propensity to remain in the consortium differs per role, theorizing that *Knowledge Exploiters* (composed of SMEs and large firms) could show lower interest in continuity when compared to *Knowledge Developers*, whose principal activity depends on further opportunities for research. Moreover, the majority of FP participants, according to the work of Protogerou *et al.* (2012), are only once involved in an FP-funded RJV. This might indicate that participants as a whole might be generally less willing to participate in future R&D projects. Nevertheless, *Coordinators* apparently stand out for being more interested in capitalizing their current position for future ventures (Avedas, 2009). In this respect, the KED groups are challenged with the following hypothesis:

H4: Knowledge Exploiters report less often than Knowledge Developers and Promoters the willingness to participate in future projects with members of the present consortium.

Members' centrality within R&D projects

In the aggregated network composed of thousands of FP-funded projects, past studies found that research institutions are the most central actors in the network (Avedas 2009; Breschi and Cusmano 2004; Protogerou, Caloghirou, and Siokas 2012). Moreover, the overall pattern of connections was significantly dependent on the group of research institutions that participate in multiple new projects a year (Vonortas and Okamura 2013). Despite these advances in the study of FP-networks, there is very little knowledge about the pattern of connections within each single project. At this level, literature assumed two main network configurations: the star-network or the clique network (Vonortas and Okamura 2013; Breschi and Cusmano 2004). In the former, the project coordinator acts as a central hub of all participants overseeing the progress of the various tasks, and connections among partners do not exist (Figure 4A). On the other hand, in the clique network (Figure 4B), all members share work ties, and the network is presented at its highest complexity: every member has a tie to every other member. Without relational data collected from within R&D projects, these are the only two possible configurations. Yet, reality does not appear to be represented by either model as exemplified in Figure 4C. The present study therefore challenges these extreme models considering them unfit to describe FP-funded RJVs, especially when projects are composed of a large number of members. Since network density, i.e., existing ties divided by possible ties, decreases substantially when the number of members increases (Wasserman and Faust 1994; Scott and Carrington 2011), it is unlikely that clique networks represent the reality within the vast majority of EC-funded projects (Breschi and Cusmano 2004).

In a broad sense, it is trivial to assume that there are different types of ties (former and on going; formal and informal) between all members of a consortium, such as collaborations, exchange of ideas and samples, or co-authoring of publications among others (Pinheiro, Pinho, and Lucas 2015). However, as argued above, a single member, including the project coordinator, is unlikely to maintain close work relationships with every other partner, mostly due to the resources required to maintain each relationship active. Thus considering, the present study proposes that the number of close collaboration ties reported by each member might be fairly constant, even if projects grow in size. This way, another hypothesis is withdrawn:

H5: The amount of reported Close Work Ties should not differ significantly as the number of members in the project increases.

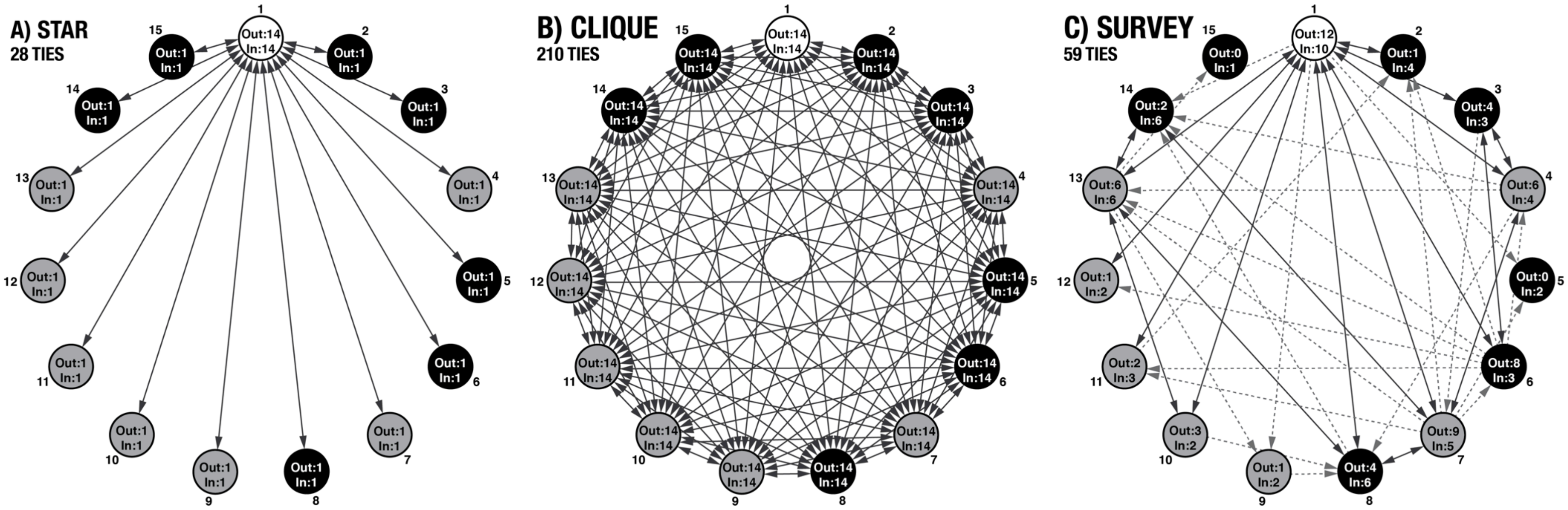

Figure 4. Network graphs of Close Work Ties among participants of an FP7-KBBE project

Coordinator = white node; *Knowledge Exploiters* = black nodes; *Knowledge Developers* = grey nodes. *Coordinator* is a *Knowledge Developer*. Ties are black if reciprocal, otherwise grey and dashed. Within each node there is a count of out-going and in-coming ties. Graph A is the star-network configuration; Graph B is the clique-network configuration; Graph C is the network based on 15 survey responses (100%). Nodes 5 and 15 responded to the survey but reported zero Close Work Ties.

On a similar note, and considering the unlikeliness of the single-focused relational involvement in a star-network (Figure 4A), this study assumes that *Coordinators* report Close Work Ties with only a fraction of their project partners, similar to what can be observed in Figure 4C (white node). Therefore:

H6: The Coordinator reports fewer ties than the number of partners in the project.

Pinheiro, Lucas, and Pinho (2015) proposed that within R&D projects, research institutions (hereby in the role of *Knowledge Developers*) report a greater number of Close Work Ties than other types of institutions. Moreover, and similarly to what was observed in the literature at the aggregate level of inter-project networks (Vonortas 2012; Avedas 2009), *Knowledge Developers* are likely to be selected more often as a close work partner, given their more substantial skills and competences in R&D activities. In sum, the present study will examine whether differences can be found among the number of inward and outward ties by institutions that perform different roles (represented by arrows directions in Figure 4) addressing the following two hypotheses:

H7: The amount of reported Close Work Ties differs across KED roles.

H8: Knowledge Developers are selected more often for Close Work Ties than the remaining two KED Roles.

Within each RJV's network, members can report collaborating with institutions with the same or a different role as themselves. If the members with a particular role tend to work with members with the same role, this is referred as a homophilic behaviour; otherwise, if they tend to work more often with members with a different role, then heterophilic behaviour is observed (Wasserman and Faust 1994). This calculation of ties within and between roles is performed based on the collaboration choices of each network member, and it is useful to understand the patterns of collaboration among different institutions. In other words, this metric helps to identify which roles prefer or avoid collaborating with others. Previous research (Pinheiro, Lucas, and Pinho 2015) analysing a single RJV, reported that universities and research centres prefer to collaborate with each other, while companies would rather collaborate with universities and not with other companies.

This study tries to verify whether this behaviour is generalizable to a broad group of consortia. For that purpose, it hypothesizes that *Knowledge Developers* report close work relationships with members of all roles, albeit a higher preference for forming ties with other *Developers* (H9) — homophilic behaviour. Additionally, *Knowledge Exploiters* are predicted to report a majority of ties towards institutions that are not *Exploiters* (H10) — heterophilic behaviour. Since *Promoters* are most often largely out-numbered in the vast majority of projects funded by the EC, accounting for only 10.6% of the total participations in the projects analysed in this study[3], it is assumed that their reported Close Work Ties are towards institutions that are not *Promoters*, thus being naturally heterophilic. Accordingly, with regard to *Developers* and *Exploiters*, the following is hypothesized:

H9: Knowledge Developers choose more frequently other Developers as their work partners.

H10: Knowledge Exploiters choose more frequently non-Exploiters as their work partners.

The star-network configuration depicted in Figure 4A assumes that the *Coordinator* (white node) is the main resource recipient and integrator, being in-between every pair of partners. This central position through which all relationships must occur is a consequence of the need to coordinate the R&D project. The total amount of work performed in the project is therefore constrained by the coordinator's ability to manage all relationships as a rate-limiting step of resources flow. Accordingly, and as argued above for H6, this configuration is considered unrealistic (Figure 4C). This research tests whether the centre of the network is occupied by *Knowledge Developers*[4]. If this proves to be so, they will be positioned more often in-between pairs of members than the other two KED roles. In other words – using SNA terminology – *Knowledge Developers* will have higher betweenness centrality. However, the remaining members can be differently positioned in the network for which reason they may or may not have some degree of betweenness centrality regardless of their role. This work will address whether betweenness centrality also recognizably differs among *Promoters* and *Exploiters, i.e.*, this study will test whether there might be a gradient of betweenness centralities involving the three KED roles. *Developers* are expected to have the highest value, based on the rationale presented above

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[3] Of the 69 projects in this research, 24 projects (35%) did not have a Promoter, while 19 projects (28%) had a single Promoter. As such, only a minority of the projects under study could allow the possibility of studying the homophilic or heterophilic behaviour in Promoters' ties, under the E-I index.

[4] In this study, 80% of Coordinators are in the Knowledge Developers role, but Coordinators represent only 7,5% of all Developers.

and, grounded on the description of the role of *Promoters* (i.e., bridging *Developers* and *Exploiters*), these institutions are expected to have a lower betweenness centrality than *Developers* but higher than *Exploiters*. The existence and significance of these differences will be tested across several projects:

H11: Knowledge Developers have higher betweenness centrality than Promoters.

H12: Promoters have higher betweenness centrality than Knowledge Exploiters.

Finally, this research will test an additional network measure, focused on each project *Coordinator,* called Beta centrality or Bonacich's Power centrality (Bonacich 1987), which measures the extent to which a *Coordinator* might be working closely with few members within the network, who hierarchically connect preferentially with a restricted number of other members in a sort of chain of command. This is expected to be the case for very large projects, in which it is more difficult for *Coordinators* to have Close Work Ties with every member of the project (see the argument justifying H6), but rather with a smaller number of members that coordinate sub-groups or clusters within the consortium. This way, the *Coordinator* will have a rather low out-degree centrality (for example, being connected to only 40% of the members of the network), but simultaneously a high Beta centrality if the few ties that exist give him/her access to information from all sub-groups in the project. In accordance with these arguments, it is hypothesized that the Beta centrality of *Coordinators* should (i) be much higher than that of *Partners*, and (ii) not decrease as projects grow in size, thus ensuring efficiency in the number of ties required to oversee the project activities despite the actual number of members (H13 and H14, respectively).

H13: Beta centrality of Coordinators is higher than the Partners'.

H14: Beta centrality of Coordinators does not decrease with increasing project size.

METHODOLOGY

Having built the conceptual framework and the surrounded literature, the proposed hypotheses were tested in a quantitative study. As previously mentioned, the study is based on a large survey involving participants of Biological Sciences funded R&D projects from the 7th Framework Programme. This section presents the criteria used for selecting the RJVs to include in the study and the process of data collection.

Criteria for R&D consortia selection

In order to select FP7 projects involving R&D cooperation, the following criteria were adopted:

1. Project contract type: "Collaborative project", "Large-scale integrating project", "Research for SMEs", or "Research for SME associations/groupings". This criterion ensured a selection of projects with greater and more immediate societal impact, in which both R&D institutions and end-users worked closely to develop technology-based products and markets.
2. Projects with begin-date between January 2008 and March 2012, thereby focusing on on-going or recently concluded projects. On-going projects were in collaborative work for at least 18 months prior to data collection (on average, 31 months), while the remaining projects had finished less than 36 months prior to data collection (on average, 11 months);
3. Projects with a research purpose related to (i) the Biological Sciences, and (ii) funded by calls from the FP7-Health, FP7-Environment, FP7-KBBE, FP7-NMP and FP7-SME programmes. These two sub-criteria were chosen because Biological Sciences comprise the research foundations of many knowledge areas, with direct implications in activities concerning environment, health, food/beverage, agriculture and pharmaceutics, as well as other less conventional bio-sectors, like plastics or fuels development.
4. Projects having at least one Portuguese member (either as project coordinator or partner);

These four criteria yielded a dataset of 69 RJVs (Database 1), which included 849 institutions from 55 countries (Database 2), 30 of which were outside the European Union. Some of the institutions in Database 2 were partners in more than one project, totalling 1,149 participations. In accordance with the European Commission's guidelines, at least three member-states were included in each project consortium, while 94% of the RJVs included at least five different nationalities, thus representing very international networks. Accordingly, and in spite of the first selection criterion above mentioned, Portuguese members accounted only for 8.5% of all institutions. For each project in Database 1, the following data were collected: the FP7 Specific Programme / Thematic Area, the amount of EC funding, the project duration, the number of partners and which member was the coordinator (see Table 4 for a summary of the research projects under study, grouped by FP7 Specific Programmes). Database 2 listed each member's affiliation, country and in which RJVs participated. In Database 2, institutions were subsequently classified using the KED Roles, which include the following categories: *Knowledge Developers*, *Promoters* and *Knowledge Exploiters*.

Table 4. Characterization of FP7 RJVs under study, according to their Specific Programme

FP7 Specific Programme	**Health**	**Environ.**	**KBBE**	**NMP**	**SME**	**Total**
Number of RJVs in study	5	12	15	10	27	69
Avg. number of members per RJV	23.8	25.8	17.5	16.5	10.7	16.6
Avg. number of countries per RJV	12.4	13.7	10.1	8.8	5.7	9.0
Avg. EC funding per RJV	11.6 M€	6.4 M€	4.8 M€	6.1 M€	1.3 M€	4.4M€
Avg. duration of RJV (months)	59.6	48.7	48.3	48.4	31.9	42.8

Data collection

For each of the 69 RJVs, the contacts of project personnel were collected from the CORDIS database (http://cordis.europa.eu), research papers and poster presentations acknowledging the project funding, as well as the project's own website when available. However, it should be noted that in the case of universities and research institutions, preference was given to senior researchers and professors, and thus contact data were not collected for non-PhD holders (i.e., administrative staff, laboratory technicians and master or PhD students). RJVs' personnel were contacted from June to December 2013, and were invited to fill in a web survey on behalf of their organization addressing the patterns of collaboration with members of their consortium as well as the outcomes and benefits associated with their membership. The survey questions used for the present study are presented in Table 5.

Table 5. Survey measures used for the present study

Measure	Survey Question	Source
Satisfaction	Overall, I am very satisfied with the outcomes of PROJECT.#	Adapted from Shamdasani and Sheth (1995)
Continuity	I would definitely participate in future R&D projects with members of this consortium.#	Adapted from Shamdasani and Sheth (1995)
New R&D ideas	This project provided new ideas for future R&D projects.#	Adapted from Perkmann and Walsh (2009)
Cooperative Learning	The cooperation within PROJECT provided a learning experience otherwise impossible to achieve.#	Adapted from Xia et al. (2011)
Close Work Ties	Within PROJECT, I worked closely with the following partners: &	Adapted from Uzzi (1997), Wuyts and Geyskens (2005)

The word PROJECT (in capitals) is a placeholder for the name of the EC-funded RJV. While responding to the survey, each participant would see the correct name, instead of the placeholder. Notes: # - Measured using a 5-point Likert Scale (1 = "Strongly Disagree" / 5 = "Strongly Agree". & - To answer this question, respondents were presented with the list of project members, plus the option "None of the partners".

The survey yielded a total of 882 valid responses. Within this set, 695 institutions provided a single response to the survey, and 82 institutions provided multiple responses, as more than one senior researcher from the same project filled the survey. In these latter cases, the multiple responses of each institution were averaged and a Mean score was obtained. In Table 5, four of the five questions were answered using a 5-point Likert Scale. The difference between the maximum and minimum values answered was equal or lower to 1 point[5] in nearly 90% of all these multiple answers, ensuring consistency between the respondents of the same institution and validating the average calculation. For the fifth question in Table 5, measuring Close Work Ties, a matrix was built, one row per respondent. For the multiple respondents from the same institution, the union of those rows was considered. Since these rows are composed of binary values, the Sokal-Michener similarity measure (Seung-Seok, Sung-Hyuk, and Tappert 2010) was calculated between each pair of multiple responses. The average value of all measures was above 70%. Therefore, the final dataset corresponded to 68% response rate and included 777 participations. Overall, 88% of respondents were affiliated with EU institutions based in 24 countries, with the remainder coming from institutions in 22 countries outside the European Union.

[5] *As example, if respondents A and B from institution X selected a 4 and a 3, respectively, in the 5-point Likert Scale of a given question, their range equals (4-3=) 1. Nearly 98% of multiple response cases had a difference in range ≤ 2 points of the same scale for each question. However, it was preferable to report the range ≤ 1 point, since that difference never changes a response from the negative to the positive side of the scale, or vice versa.*

In order to answer the study's hypotheses H1 to H4, statistical group comparison was required. Preliminary analysis of normality using Shapiro-Wilk tests revealed significantly skewed distributions in the top four variables from Table 5 (*p-value = 0.000*). Homogeneity of variance among KED groups was verified using Levene's test based on the median (Brown and Forsythe 1974), with p-values ranging from 0.077 to 0.400. When responses were grouped using the *Coordinator* and *Partner* roles, p-values in the Levene's test ranged from 0.119 to 0.758, except for Continuity, which value suggested unequal variances (*p-value =* 0.002), limiting the ability to infer whether there is a difference in Continuity between *Coordinators* and *Partners*. Without normally distributed data, non-parametric tests were used to analyse the differences in means of attitudinal variables: Kruskal-Wallis with Pairwise comparison tests for differences among three groups (e.g. the three KED Roles) and Mann-Whitney U tests for differences between two groups (e.g. the *Coordinator* vs. *Partner* roles). Calculations were performed using routines from the software IBM SPSS Statistics v.21.

Given the nature of hypotheses H5 through H14, network centrality measures based on respondents Close Work Ties were calculated using UCINET v.6. Importantly, it should be noted that these network hypotheses required a high level of response rate within each project in order to minimize errors associated with missing data (Kossinets 2006). Among the 69 projects under study, the response rates ranged from 15% to 100%. Following the recommendation of Kossinets (2006), only the projects with at least 70% of response rate were used for SNA involving centrality measures. This decision reduces the number of projects under study to 34, with a total of 540 participations (47% of the original data). Among these participations, there were 425 institutions, with 71 of those involved in more than one project (average of 2.6 participations). Within the 34 projects under study with SNA, the number of members (*Coordinator* + *Partners*) ranged from 7 to 41, with an average and standard deviation of 15.5 ± 7.3 members. These are larger projects than the average values of 9 to 11 members, previously reported in the literature and reports of FP7 research projects (European Commission 2013; Vonortas and Okamura 2013; Protogerou, Caloghirou, and Siokas 2012).

Regarding the network measures used in this study, out-degree centrality (or outward ties) represents the number of ties reported by a member, i.e., the number of institutions with which this member reports to work closely. Similarly, the in-degree centrality (or inward ties) represents the number of partners that selected a particular institution in the project, closely resembling a measure of popularity within each consortium. Accordingly, institutions with higher in-degree centrality are selected by more partners and become more prominent in the network. Betweenness centrality measures how often a particular member is positioned in between two members of the network, mediating the work relationship. Members with higher betweenness centrality can be expected to control the flow of resources within the network.

In this study, measures were normalized, transforming the value in a percentage, based on the size of the network where it was measured. For example, an in-degree centrality value can be read as “receives ties from 6 members”, while normalized in-degree centrality can be read as “receives ties from 50% of the network”. In order to allow comparisons across networks of different sizes, out-degree, in-degree and betweenness centrality have to be normalized (Wasserman and Faust 1994). To test the significance of hypotheses involving network data, 10,000 permutation tests were performed in UCINET for each hypothesis. Permutation-based significance tests when applied to non-independent data, such as within networks, calculate sampling distributions of statistics directly from the observed networks (Hanneman and Riddle 2005) and allow interpretation of results similarly to classical hypothesis testing using a t-test, ANOVA or linear regression.

The first purpose of this study is to examine the extent to which the role performed by each member within a RJV affects its perceived benefits accrued from cooperation (RQ1 / H1 through H4). In order to address this objective and relying on data collected from FP7 members, Table 6 shows the descriptive statistics of the responses to the survey, grouped by the two sets of roles defined as *Knowledge Exploiters, Knowledge Developers* and *Promoters* (KED) and the *Coordinator* / *Partner* – see Section 2. Despite several differences observed in Means for each group (Table 6), additional analysis is required to determine their significance. Further, non-parametric comparison tests for the various groups were used, as shown in Table 7.

Table 6. Survey variables grouped according to the categories of the KED and Coordinator / Partner classifications

Categories	**Cooperative Learning**		**New R&D ideas**		**Satisfaction**		**Continuity**	
(a) KED Roles	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Knowledge Developers (n = 523)	4.16	.84	4.23	.71	4.14	.80	4.50	.71
Promoters (n = 75)	4.15	.75	4.08	.69	4.12	.83	4.38	.64
Knowledge Exploiters (n = 179)	3.96	.95	3.79	.83	3.77	.91	4.06	.86
(b) Coordinator / Partner								
Coordinators (n = 58)	4.52	.65	4.48	.55	4.37	.78	4.60	.67
Partners (n = 719)	4.08	.87	4.09	.77	4.02	.85	4.37	.76

All variables were measured using a 5-point Likert Scale, from 1 (“Strongly Disagree”) to 5 (“Strongly Agree”).

The first hypothesis (H1) assumed similar perceptions of cooperative learning across KED roles. Table 7 shows that the differences are not significant across KED roles, confirming it. For their part, *Coordinators* and *Partners* are significantly different, and thus coordinators tend to report more often than partners that their learning experience would be impossible to achieve without cooperation. This difference was not expected and portrays *Coordinators* as significantly more aware of the interdependence in learning provided by R&D consortia.

Table 7. Non-Parametric tests grouped by (a) KED Roles and (b) Coordinator / Partner categories

(a) KED Roles	**Cooperative Learning**	**New R&D ideas**	**Satisfaction**	**Continuity**
Kruskal-Wallis Statistic & Sig.	5.966	43.712 ***	25.514 ***	43.544 ***
# Pairwise Comparisons	Standardized Statistic & Sig.	Standardized Statistic & Sig.	Standardized Statistic & Sig.	Standardized Statistic & Sig.
1 DEV x EXPL	-	6.576 ***	4.970 ***	6.547 ***
2 PROM x EXPL	-	2.497 *	3.125 **	2.360 §
3 PROM x DEV	-	1.836	.006	1.979
(b) Coordinator / Partner				
Mann-Whitney U Statistic & Sig.	4.289 ***	3.680 ***	3.408 ***	-

EXPL = "Knowledge Exploiters", PROM = "Promoters", DEV = "Knowledge Developers". A hyphen (-) is presented where Pairwise comparisons were not performed due to non-significant Kruskal-Wallis Test Statistic or unequal variances between groups in the Mann-Whitney Test. Adjusted p-values were considered in Pairwise Comparisons tests, in order to control type I errors. Significance levels: § for $p \leq 0.1$ / * for $p \leq 0.05$ / ** for $p \leq 0.01$ / *** for $p \leq 0.001$.

Hypothesis H2 proposes that *Knowledge Developers* report more often than the other two KED roles that new R&D ideas emerged from the project. While the difference between *Developers* and *Exploiters* is highly significant (*p-value = 0.000*), the difference between *Developers* and *Promoters* is not (*p-value = 0.199*). Therefore, results confirm that there is a difference in perceptions among the members of KED roles with regard to the new R&D ideas generated in the project, though H2 does not mirror the differences observed. *Knowledge Developers* and *Promoters* are not distinguishable by this variable, and they are both significantly different from *Exploiters*. Accordingly, H2 was partially supported. *Coordinators* reported much more often than *Partners* that new R&D ideas emerged from the current project (*p-value = 0.000*), again showing how *Coordinators* are unique members within consortia, perceiving more benefits than the average partner.

Concerning the overall satisfaction with the R&D outcomes, H3 states that *Knowledge Developers* and *Promoters* report high overall satisfaction more often than *Knowledge Exploiters*. Results indicate that this hypothesis is supported. Surprisingly, *Coordinators* and *Partners* reported different levels of satisfaction, with the former group evidencing higher levels than the latter, further strengthening the above argument.

The last hypothesis on perceived benefits addressed consortium Continuity. H4 states that *Knowledge Exploiters* report less often than *Developers* and *Promoters* willingness to participate in future projects with members of the present consortium. Results in Table 7 confirm H4 (*p-value = 0.000*). Due to unequal variances (reported in Section 4), it is not possible to infer on Continuity differences between *Coordinators* and *Partners*.

The second purpose of this study is to examine the extent to which the role performed by each member within a RJV affects its centrality within the cooperation network (H5 through H14). Table 8 presents the social network measures of the participations in the 34 projects grouped by the distinct roles described previously (KED roles and *Coordinator/Partner*). The fifth hypothesis states that the number of ties reported by each member should not increase as projects grow in size. Using a linear regression based on node-level data, the number of ties reported by each respondent (its out-degree centrality) was determined as a function of the number of members in the project. To confirm this hypothesis, the number of ties should be constant, for which the regression coefficient needs to be zero. For this calculation, only survey respondents with at least one outward tie were considered (n = 426). The linear regression was calculated in UCINET with 10,000 subsequent permutations to assess the significance of the model fit and regression coefficient. As shown in Table 9 (Model 1) and unlike hypothesized, the number of ties increases with project size, as both the model fit and the regression coefficient are significantly higher than zero (both, *p-value = 0.000*). Accordingly, it is assumed for subsequent hypotheses that project size impacts the number of ties. Therefore, normalized measures are used to index project size. While the number of reported ties grows towards larger projects, it does so at a slow pace, requiring roughly nine new members in a project to increase by one the reported ties of each member.

In order to test the H6, which postulates that coordinators report ties to fewer than the total number of partners of the project, the number of ties reported by each *Coordinator* was normalized (dividing it by the number of partners). If the normalized out-degree is lower than 100%, then the *Coordinator* is only working closely with a fraction of its network. For this calculation, only *Coordinators* who responded to the survey were considered (*n = 33*). In this particular calculation, independence of data was assumed, given that only two projects had the same institution as *Coordinator* but the teams involved in each project were completely different (e.g. Agronomy versus Fish Nutrition).

Table 8. Network measures of 34 FP7 projects with more than 70% survey response rate

Network Measures	Role	N	Mean	Std. Dev.	Range	#
Normalized Out-Degree[1]	Developers	286	33.4%	23.4%	97.5%	1
	Promoters	42	30.8%	25.4%	94.4%	2
	Exploiters	98	29.0%	27.5%	96.4%	3
	Coordinators	33	57.7%	30.8%	87.0%	4
	Partners	393	30.0%	22.8%	97.5%	5
Normalized In-Degree	Developers	356	27.6%	18.7%	100%	6
	Promoters	49	22.9%	16.6%	66.7%	7
	Exploiters	135	20.4%	17.4%	66.7%	8
	Coordinators	34	52.2%	17.1%	80.0%	9
	Partners	506	23.6%	17.0%	83.3%	10
Ego-network E-I Index[1]	Developers	286	-0.651	0.490	2.000	11
	Exploiters	98	0.610	0.481	2.000	12
Normalized Betweenness[1]	Developers	286	6.8%	9.8%	58.3%	13
	Promoters	42	4.0%	7.6%	34.0%	14
	Exploiters	98	1.9%	4.2%	25.2%	15
	Coordinators	33	20.3%	15.8%	58.3%	16
	Partners	393	4.1%	6.6%	47.5%	17
Normalized Beta Centrality[1,2]	Coordinators	33	75.7%	28.2%	77.2%	18
	Partners	393	45.1%	27.3%	97.7%	19

Adjacent rows with similar shading colour (white or grey) within the same network measure are comparable, since they represent mutually exclusive groups. Notes: 1 - only respondents with out-degree greater than zero were considered in this measure; 2 - With fixed Beta ($\beta = 0.133$)

Table 8 (Row #4) shows that coordinators have close work ties with 57.7% ± 30.8% of their partners (*median = 50%*), and that it is statistically unlikely for coordinators to report Close Work Ties with all of their partners (*p-value < 0.003 for test value > 75%*), supporting H6.

Table 9. Linear regressions based on the number of members in an FP7 R&D project

Regression	Model 1 (from H5)	Model 2 (from H14)
Dependent Variable	Project members out-degree centrality	Project coordinators' normalized beta centrality
Nr. of project members	0.107 ****	0.002
Intercept	3.012	0.718
Regression Fit		
F-value	28.28	0.147
R^2	0.063 ****	0.005
Adjusted R^2	0.058 ****	-0.057
N	426	33

Significance levels: § for p ≤ 0.1 / * for p ≤ 0.05 / ** for p ≤ 0.01 / *** for p ≤ 0.001 / **** for p ≤ 0.0001

With regard to H7, which states that the amount of reported ties differs across KED roles, a technique of group comparison adequate for network data was required. An ANOVA test was performed using the normalized out-degree centrality values of the three KED roles using UCINET with 10,000 permutations. Similarly to H5, only survey respondents with at least one outward tie were considered (*n = 426*). The results of the ANOVA test (Table 10) did not show significant difference among groups (*p-value = 0.2877 /* R^2 *= 0.006*). H7 is, therefore, not supported and KED roles do not differ in the number of reported Close Work Ties.

H8 postulates that *Developers* are selected more often for Close Work Ties than the remaining two KED roles. An ANOVA test was performed using the normalized in-degree centrality values of the three KED roles using UCINET with 10,000 permutations. For this calculation, unlike in H7 the whole population was used (*n = 540*), because even if some members did not respond to the survey, others in the network might have mentioned them in their Close Work Ties. The results of the ANOVA test (Table 10) show that there are significant differences among groups (*p-value = 0.0003 /* R^2 *= 0.029*). This led to performing three subsequent pairwise comparisons using t-tests in UCINET, also with 10,000 permutations each. These latter tests allowed determining which KED roles had statistical differences between them (Table 10). No difference was observed between *Developers* and *Promoters*, but both of these roles show difference towards *Exploiters*, although with very different levels of significance (*respectively, p-value = 0.0003 and p-value = 0.0971*). H8 is therefore partially confirmed.

Table 10. ANOVA tests and Pairwise Comparisons based on network centrality measures

		H7	H8	H11 / H12
F-Statistic and Test Significance		1.234	8,030 ***	12.537 ***
#	Pairwise Comparisons	Difference in Normalized Out-Degree & two-tailed Test Significance	Difference in Normalized In-Degree & two-tailed Test Significance	Difference in Normalized Betweenness & one-tailed Test Significance
1	DEV x EXPL	-	0.071 ***	0.049 ****
2	DEV x PROM	-	0.047 §	0.028 *
3	PROM x EXPL	-	0.025	0.021 *

Significance levels: § for p ≤ 0.1 / * for p ≤ 0.05 / ** for p ≤ 0.01 / *** for p ≤ 0.001 / **** for p ≤ 0.0001

With regard to H9 and H10, which relate to the homophilic or heterophilic behaviour of project members with regard to their Close Work Ties, the E-I index was calculated for every *Knowledge Developer* and *Knowledge Exploiter* that responded to the survey (*n=384*). This ego-network analysis results from the formula in E-I Index equation (presented below), where 'External Ties' are the number of ties from actor i towards members with a different role, and 'Internal Ties' are the number of ties from actor i towards members with the same role. The numerator corresponds to the actor's out-degree.

$$E\text{–}I\ Index_i = \frac{External\ Ties_i - Internal\ Ties_i}{External\ Ties_i + Internal\ Ties_i}$$

The E-I index ranges from -1, when all ties are inwards and the actor is classified as perfectly homophilous, and +1, when all ties are outwards and the actor is classified as perfectly heterophilous. Results show that *Developers* have an average E-I index of -0.651, indicating that most of their Close Work Ties are with other *Developers* (homophilic behaviour). On the other hand, *Exploiters* present heterophilic behaviour (E-I index of 0.610), as the majority of their Close Work Ties goes towards non-*Exploiters*. A t-test performed on UCINET assessed the difference between these groups to be highly significant (*mean difference = -1.262 / p-value = 0.0001*). Based on the above results, both H9 and H10 are confirmed.

Table 11. Distribution of perfectly homophilic and heterophilic *Developers* and *Exploiters*

	Knowledge Developers (n = 286)		Knowledge Exploiters (n = 98)	
	Perfectly Homophilic (E-I index of -1)	Perfectly Heterophilic (E-I index of +1)	Perfectly Homophilic (E-I index of -1)	Perfectly Heterophilic (E-I index of +1)
Nr. of cases (%)	150 (52%)	5 (2%)	2 (2%)	53 (54%)

It is interesting to notice that the values observed cover the whole -1 to +1 range in both cases of *Developers* and *Exploiters* (Table 8, Rows #11 and #12). This indicates that there are cases of perfect homophily and heterophily in both *Developers* and *Exploiters* groups. Table 11 shows the frequency and proportion of these extreme cases, and interestingly portrays *Developers* and *Exploiters* with nearly opposite behaviours. Table 11 allows concluding that it is rare to find a *Developer* that does not work with other *Developer*s, as well as to find an *Exploiter* that works solely with other *Exploiters*. The initial assumption that *Developers* tend to work closely with members of all groups revealed to be a less frequent scenario than predicted, further reinforcing how *Developers* tend to be a very closed group.

In order to test H11 and H12, the normalized betweenness centralities of the three KED roles required comparison. An ANOVA test was performed, similarly to what was done for H7 and H8, with results indicating significant differences in at least one group (*p-value = 0.0003* / R^2 = *0.056*), justifying subsequent Pairwise comparisons (Table 10). As expected, *Developers* have significantly higher betweenness than *Promoters* (*one-tailed p-value = 0.026*), and *Promoters* have significantly higher betweenness than *Exploiters* (*one-tailed p-value = 0.020*). H11 and H12 are therefore confirmed, and the betweenness centrality 'gradient' was observed in the expected sequence.

Finally, to test the hypotheses H13 and H14, related to how *Coordinators* monitor consortium activities through their Close Work Ties, the normalized Beta centrality values were calculated for both *Coordinators* and *Partners*. For each individual project, the algorithm in UCINET suggested a unique value of Beta, 0.5% smaller than the reciprocal of the largest eigenvalue for that network. Accordingly, each network generated a different Beta, which ranged from 0.133 up to 0.704. This will be referred as the set of project Betas. The normalized Beta centrality values were also calculated using a fixed Beta. This was determined as the smallest value in the set of project Betas, ensuring a valid Beta across all projects. The Pearson's correlation between normalized Beta centrality values with fixed and variable Beta was 95.2%. Due to the high correlation, the normalized Beta centrality values with fixed Beta were used to determine differences between *Coordinators* and *Partners*. A t-test was used as described for H9. The results in Table 8 rows #18 and #19 show that the Beta centrality of *Coordinators* is higher than the value measured for *Partners* (*mean difference = 0.306 / one-tailed p-value = 0.000*), confirming H13. The variation of the Beta centrality of *Coordinators* as a function of project size was assessed similarly to what was done for H5. For the regression, the normalized Beta centrality values with fixed Beta were used. Table 9 (Model 2) shows that both the model fit and the regression coefficient are not significantly different from zero (*p-value = 0.711 and p-value = 0.359, respectively*). These results confirm H14, and show that *Coordinators* are monitoring consortium activities through hierarchical rather than direct work ties, despite project size.

DISCUSSION

The aim of this research was to study the differences in perceived benefits and network centrality of members of FP7-funded Biological Sciences Research Joint Ventures (RJVs). To achieve this end, a survey was distributed to 849 FP7 participants involved in 1,149 participations, from which 777 responses were obtained. These participants were classified using a new system, hereby presented. This new system classifies participants according to their performing roles in the process of sharing knowledge, namely as *Knowledge Developers, Knowledge Exploiters*, and *Promoters*. These were designated along the paper as Knowledge Exploiters and Developers roles (KED roles). Additionally, the same members from each surveyed RJV were classified as *Partners* or *Coordinator*, based on public information made available by the European Commission. The two classification systems were used to create groups within consortia, allowing for a test of potential differences in members' perceived benefits and in their centrality within each collaboration network.

KED Roles, perceived benefits and network centrality

Results from this study evidenced that member's perceived benefits differ according to their KED role. Overall, *Knowledge Developers* and *Promoters* were the most satisfied with the project outcomes, as well as the most interested in a possible continuity of their consortia. Also, these members were more often receptive to promising and interesting ideas for future research. In contrast, firms in the role of *Knowledge Exploiters* perceive fewer benefits from cooperation. This discrepancy may be explained by the so-called *outcome-impact gap* (Pertuzé et al. 2010). This is commonly associated with university-industry collaborative work, and derives from projects' failure in delivering tangibles that impact directly on the firm's short/medium-term activities and objectives. The fact that more than 60% of all newcomers in FP1 through FP7 are firms, and that around 70% of the partners participated only once in EC-funded RJVs (Protogerou, Caloghirou, and Siokas 2012), supports the existence of this discrepancy, and suggests different expectations between *Exploiters* and R&D service performers. From the perspective of any participant, a positive match between expectations and outcomes can result from activities proceeding as planned, and tasks concluded as due towards the end of the project. Nevertheless, *Knowledge Exploiters* still need to invest in further R&D in order to turn the technology marketable. This results from the fact that the European Commission only funds pre-competitive R&D in Framework Programmes, and not product development (Breschi and Cusmano 2004; Mothe and Quelin 2001). This study points to the possibility that *Satisfaction with project outcomes* might be a variable that is closely related with the pre-competitive nature of FP-funded projects. Due to *Exploiters* for-profit aim, it is possible that they can only assess a successful match between expectations and outcomes when the full extent of their efforts turns into market solutions that generate tangible benefits as revenues in a manageable period of time. In contrast, the majority of *Knowledge Developers* are likely satisfied if their efforts turn into research deliverables, such as papers, patents or reports that can contribute to leveraged future R&D activities. The high scores in Cooperative Learning and the lack of differences among the three KED roles indicate that all participants in FP-funded R&D consortia acknowledge a high level of dependence on other members to obtain their expected level of learning experience. This conclusion is line with the work of Mothe and Quélin (2000), which state that members enter R&D consortia in order to access new knowledge, skills and competencies through collaboration.

Regarding the perceptions of *Continuity* and the *Generation of new R&D ideas*, results indicate that *Knowledge Developers* are very interested in engaging in future R&D activities with members of their consortia, and this is a direct consequence of their role in the project, i.e., generating new knowledge. Consequently, *Developers* are more receptive in detecting new ideas for future R&D projects because their core activities depend on it, both inside and outside their consortia. According to recent literature, their internal exploration experience allows them to recognize external opportunities for future R&D projects (Hoang and Rothaermel 2010). It is plausible that members of this role identify in their present consortium a group of partners capable of continuing to deliver interesting results and provide valuable learning opportunities. This motivation to continue the collaborative work is in line with the research of Olk and Young (1997) that studied US-based inter-firm R&D consortia. In contrast, the nature of *Exploiters* is to transform knowledge into marketable products *sensu lato* with the goal of maintaining their competitive advantage. For this reason, and according to the work of Sakakibara (1997), firms are frequently less interested in pursuing future joint R&D projects with their current partners. This is because, after acquiring new knowledge, firms expect to develop their own market solutions without the need to cooperate with potential competitors, particularly when the product or technology is rather mature.

Regarding the Close Work Ties among RJV participants, the key assumption of both the clique and the star-network (Figure 4B and Figure 4A, respectively) is that there is no discernible difference in the pattern of connections reported by each member, other than the *Coordinator* in the star-network configuration. The present study shows that project members with different KED roles vary significantly in their pattern of connections. Namely, *Knowledge Developers* and *Promoters* are selected more often than *Exploiters* for Close Work Ties. On the other hand, *Developers* and *Exploiters* have opposite behaviours when selecting their partners, with *Developers* choosing mostly *Developers,* and *Exploiters* choosing mostly non-*Exploiters*. Finally, a statistically significant descending gradient of betweenness centralities can be observed from *Developers* through *Promoters* to *Exploiters*. These observations imply that the role performed by each member affects its centrality within the cooperation network.

The fact that *Developers* are mostly working closely with other *Developers* within RJVs is worthy of deep consideration. The core of FP-networks is composed of research institutions participating in multiple projects a year, with a significant recurrence in terms of their shared partners in each new project (Vonortas and Okamura 2013; Avedas 2009; Protogerou, Caloghirou, and Siokas 2012). At the periphery of FP-networks, many one-time participants are found, mostly firms (Protogerou, Caloghirou, and Siokas 2012). According to Avedas (2009), in Framework Programmes, there is a positive relationship between the amount of funding attributed to a thematic area, and the accentuation of the core-periphery pattern with a heavy centralization around very few actors. These authors identify a challenge around this network pattern: it reduces the "likelihood that new knowledge and novel ideas enter the network, thus impeding the ability to develop new and creative ideas" (Avedas 2009, 12). Through time, these structures evolve into knowledge sets lacking diversity that preserve the *status quo* and limit new insights that can lead to breakthrough innovations.

The present study shows that the pattern observed at the macro-level, involving thousands of RJVs, is propagating from behaviours in individual projects. The results in this study place *Developers* in a more central position within each RJV, working mostly with their peers, while *Exploiters* are frequently relegated to the periphery, being selected fewer times and being less in-between partners. If the pattern of ties within the project reflects the resource-sharing and task-dependence among partners, it is not evident that *Exploiters* are frequently important in these networks. This work proposes that the observed behavioural discrepancy between roles might have one of two roots. On one hand, members in the role of *Developers* might deliberately interact more frequently with their peers due to common language, shared experiences, and previously established workflows, leaving *Exploiters* to less frequent and cohesive interactions. On the other hand, *Exploiters* might deliberately step back from the spotlight in order to lower their involvement and consequent resource deployment while still benefiting from the R&D outputs of the project. Either way, the Framework Programmes intrinsic objective of generating cohesiveness among countries and regions is threatened, since for this to happen, it demands that the participants in all KED roles originating from different regions and/or countries actually have ties to each other within their project.

The vantage point of a project Coordinator

The results of the present study portray *Coordinators* in a vantage point comparing to their partners, both regarding their centrality within the network as well as the perceived benefits. The coordinator is probably the member that is most aware of the contribution of each participant to the overall success of the project, as well as the expected outcome from each research task. Their higher satisfaction with the project outcomes when compared to *Partners* probably results from their bird's-eye view of all tasks and not just from those in which they were directly involved. Likewise, as coordinators can be expected to centralize the research contributions of all members, they are in a better position to realize that the learning experience depends on the participation of various members and cannot be achieved without cooperation. This learning vantage position and the detailed feedback naturally received from the different groups within the project likely helps *Coordinators* to be more aware of how the current project can lead to new developments in future R&D initiatives.

Present results show that the clique network generates a highly undue overestimation of *Partners* and *Coordinators* outward and inward ties. This work clearly showed that partners are usually connected to 30% of their consortium and are selected by almost a quarter of their network. Moreover, the star-network is not a common configuration from the perspective of the *Coordinator* and its assumption in previous studies is exacerbated (Breschi and Cusmano 2004; Vonortas and Okamura 2013). *Coordinators* in this study typically worked closely with around 50%-60% of their *Partners*. These data highlight a likely hierarchical and expected configuration within R&D networks which alleviate the number of institutions with whom the *Coordinator* needs to check the progress of research tasks, increasing the efficiency of their work. *Coordinators* appear to cope well with increasing project size, maintaining the efficiency of their ties despite the greater complexity of coordinating larger networks, without the need of being connected to or in-between every pair of members.

CONCLUSIONS AND IMPLICATIONS

The present study found that members with different roles within EC-funded RJVs perceive benefits differently and have diverse centralities within the cooperation network. Therefore, a new classification is proposed. This is based on the roles the participants play in a given project network, instead of their institutional background, and was designated as *Knowledge Exploiters and Developers* – KED – roles. Applying this to the data obtained in the large survey involving participants on FP7 funded RJVs on Biological Sciences, showed that the roles and tasks performed within a consortium are required to fully understand the perceptions and relationships among R&D project participants. Classifying institutions by their principal activity as proposed in the Frascati Manual was shown to be inadequate for these studies. There is no one type of role that a given type of institution plays, with the exception of Universities. Moreover, using just the *Coordinator / Partners* classification reduces the scope of study because it mostly focuses on the *Coordinator*, referring to *Partners* indistinguishably. All taken, the KED roles are an attempt of developing a more suitable classification to analyse R&D projects, and future research in this stream will possibly contribute to improve the understanding the dynamics within EC funded networks.

Recognizing the pointed differences among RJVs participants should have implications both on programmes design and management, in particular, at the level of coordination. This is an opportunity for managing relationships more effectively by taking into consideration the differences in expectation of benefits, outcomes and impacts of R&D activities according to each role. This should enable the creation of strategic value for each group within the consortia (Serra and Kunc 2014; Chih and Zwikael 2014), putatively increasing the level of satisfaction of all participants, which at first hand should impact the promotion of continuity to new projects, ensuring greater participation of members that usually are less inclined to be involved. These enhanced perceptions should also positively impact project performance in the long run (Lunnan and Haugland 2008), while reducing the time and effort in developing new teams and relationships (McFadyen and Cannela 2004), benefiting the overall results and impact of Framework Programmes. Ultimately, this differentiated treatment of participants at the individual project level can help reduce the heavy and persistent centralization around research institutions observed in past Framework Programmes networks (Avedas 2009; Vonortas and Okamura 2013).

The obvious implication for research derived from the present work is that an analysis based exclusively on *Coordinators* versus *Partners* will necessarily be biased. *Coordinators* are a special member within each RJV, and will not transmit perceptions and relational patterns that mirror all partners, e.g. possibly overestimating the network density. Moreover, *Partners* are frequently found to play all possible KED roles, contributing to different knowledge-sharing tasks, and should not be treated as a single indistinct category. Also, in order to properly measure the network connectedness and understand the associated behaviours it is necessary to assess the underlying heterogeneous data.

This work calls for attention to another important concept: the diversity in Close Work Ties that should be observed across all KED roles. Yet, *Knowledge Developers* were found not to diverge in their ties, forming a nearly closed group within each project. This generates the core-periphery structure described above with implications in reduced innovative capacity. The *Coordinator* (*Knowledge Developer* in 80% of the cases from this study) should become aware of this problem and be responsible for implementing diversity in the Close Work Ties within each RJV for the sake of success in future networks. In any case, the individual motivations to select work ties within R&D consortia need further and deeper assessment. Avedas (2009) suggested that the core-periphery network structure is the result of built trust, past ties and a shared understanding among participants, which configure the three dimensions of Social Capital (Nahapiet and Ghoshal 1998; Tsai and Ghoshal 1998). The present work created the conceptual roots that justify and validate the need for understanding the role of Social Capital within FP-funded networks at the project level.

CHAPTER 5 THE ROLE OF SOCIAL CAPITAL TOWARDS RESOURCE SHARING IN COLLABORATIVE R&D PROJECTS: EVIDENCES FROM THE 7TH FRAMEWORK PROGRAMME

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ABSTRACT

This research examines the role of Social Capital dimensions (structural, relational and cognitive) towards Resource Sharing within R&D cooperation projects funded by the 7th Framework Programme (FP7) of the European Commission. Data were collected in a survey of over 550 FP7 participants and analysed with two different social network analysis (SNA) methodologies: Logistic Regression Quadratic Assignment Procedure and Exponential Random Graph Models.

Results showed that all Social Capital dimensions helped to explain Resource Sharing among partners, although to a different extent. Prior Ties were often significant, while Shared Vision and Commitment were very frequently positive contributors to Resource Sharing. Trust was rarely significant, and occasionally detrimental, to partners' Resource Sharing. Consequently, Framework Programmes are potentially providing a collaborative but opportunistic environment for public and private actors.

The novelty of this study derives from the combination of Social Capital theory with SNA to study intra-project partner relationships, from which a set of validated measures resulted. Moreover, the impact of each Social Capital dimension towards Resource Sharing was assessed, which contributed to a better understanding on the diversity of partner relationships within R&D projects. Finally, valuable insights are provided for future research and management of FP projects.

Keywords:

Social Capital; Resource Sharing; R&D projects; Framework Programmes; LRQAP; ERGMs

INTRODUCTION

The European Commission has made substantial efforts, since 1984, to improve Europe's international competitiveness through successive Framework Programs for Research and Technological Development (FPs). These fund mostly networks in the form of Research Joint Ventures (RJVs) composed of public and private international institutions. Despite the over €40,000M of funding attributed between 2007 and 2013 (European Commission 2015), past research on RJVs mostly addressed composition and size as well as the frequency and diversity of institutional participation (see, for example, Caloghirou et al. (2001) and Pandza et al (2011)). The relationships among partners were not studied. Some works have used Social Network Analysis (SNA) to understand collaboration patterns within FP-funded RVJs, but only analysing the co-participation in RJVs, and not the patterns of *de facto* cooperation (Ortega and Aguillo 2010; Breschi and Cusmano 2004; Protogerou, Caloghirou, and Siokas 2013; Vonortas and Okamura 2013). Notwithstanding these contributions, understanding partner relationships is critical for comprehensively understanding R&D cooperation, because inter-organizational contracts and agreements represent only a fraction of the overall set of ties in R&D cooperation (Bekkers and Freitas 2008). In fact, network interactions at the individual level among scientists and university researchers have been described as a leading source of new knowledge (Liebeskind et al. 1996), thus suggesting a predominantly social process around resource sharing. Moreover, effective relational mechanisms are linked with greater resource sharing among partners (Yli-Renko, Autio, and Sapienza 2001), which signals interactive cooperation, and increases the likelihood of R&D success. This is particularly important in fast-paced high-technology sectors, such as the Biological Sciences, where institutions frequently depend on network partners to access sources of innovation (Powell, Koput, and Smith-Doerr 1996; Fontes 2005).

Based on the rationale above, Social Capital, i.e. the actual and potential resources embedded in relationships (Nahapiet and Ghoshal 1998), is likely to play a relevant role in predicting collaboration patterns within FP-funded RJVs, as previously described for networks composed only by firms (Tsai and Ghoshal 1998; Yli-Renko, Autio, and Sapienza 2001). Accordingly, the major drivers of resource sharing might not be the number and diversity of RVJ partners, but rather the commitment, trust, prior ties and shared vision embedded in the relationships among partners (Adler and Kwon 2002; Pérez-Luño et al. 2011). Instead of researching the role of Social Capital towards Resource Sharing within FP-funded project networks, past studies either focused on inter-project networks and their implications in knowledge diffusion across Europe (Avedas 2009; Kastelli, Caloghirou, and Ioannides 2004; Protogerou, Caloghirou, and Siokas 2013; Vonortas and Okamura 2013), or on Social Capital as a driver of innovation without studying the actual network of interactions (Pérez-Luño et al. 2011). Therefore, the novelty of this study results from the combination of Social Capital theory with SNA to study intra-project partner relationships and their impact on Resource Sharing. Ultimately, this study could contribute to a better understanding on what promotes effective R&D collaboration, leading to greater success of FPs. Accordingly, the following research question is addressed:

> *To what extent do Social Capital dimensions (structural, cognitive and relational) impact Resource Sharing among participants of FP-funded R&D projects?*

By using SNA, this study contributed to a better understanding on the diversity of partner relationship within R&D projects, using data collected in a survey of over 550 FP7 participants. Results showed that Social Capital dimensions increase the odds of Resource Sharing among partners. Prior Ties were often significant, while Shared Vision and Commitment were very frequently positive contributors to Resource Sharing. Trust was rarely significant, and occasionally detrimental, to partners' Resource Sharing. Consequently, Framework Programmes are potentially providing a collaborative but opportunistic environment for public and private actors. Based on the present study, future works should research partner relationships within successful FP projects in order model the pattern of ties that enabled success, thus contributing to understand how Social Capital could improve the efficacy of FPs financial support.

Social Capital for studying R&D cooperation networks

Social Capital theory has helped understanding how relationships impact resource exchange (Bourdieu 1986; Adler and Kwon 2002; Inkpen and Tsang 2005), value creation (Tsai and Ghoshal 1998; Li et al. 2013), and innovation (Tsai 2001; Pérez-Luño et al. 2011). Most definitions of Social Capital converge to the idea that actors influence and are influenced by their networks, drawing upon the notion that relationships represent a form of capital that can be leveraged to reach individual and collective goals (Nahapiet and Ghoshal 1998; Adler and Kwon 2002; Inkpen and Tsang 2005; Hartmann and Herb 2015). Over time, consensus emerged regarding the major constructs to measure Social Capital, namely: network ties, trust, norms and obligations as well as shared codes and languages (Nahapiet and Ghoshal 1998). These constructs are relational and therefore should be measured between pairs of actors. For instance, it makes little sense to ask a participant his/her overall level of trust in a 5-member network. Trust should be reported at the tie level with each member, since it is not an attribute of a single actor, such as native language, affiliation, or years of experience in FPs. In this particular case, Trust is a directed tie, meaning that A may trust B, but the opposite may not be true. So in order to properly measure Trust and all the other constructs that form Social Capital, research must focus on each tie between every pair of actors, therefore requiring a study of the whole network of actors. Additionally, and just like financial or physical resources, Social Capital is a resource of limited availability. Consequently, partners in R&D networks are likely investing selectively in relationships that allow achieving their goals in the RJV, not necessarily sharing the same relationship engagement with all members. Hence, the study of Social Capital in R&D cooperation networks should be able to measure the availability of these social resources, embedded in partner relationships, and explain the extent to which that availability affects or describes the network of close collaboration and sharing of human, physical and technical resources among partners.

Social Capital dimensions and Resource Sharing

Nahapiet and Ghoshal (1998) classified Social Capital into three dimensions: Structural, Cognitive and Relational. Tsai and Ghoshal (1998) confirmed the existence of causal relationships between Social Capital dimensions, resource exchange and value creation. This was inferred based on research in a network of subsidiaries from a multinational company, and has since then been extended to other contexts (Hartmann and Herb 2015; Atuahene-Gima and Murray 2007). The present research extends Tsai and Ghoshal (1998) work into the study of RJVs funded by the European Commission.

(I) RESOURCE SHARING

Tsai and Ghoshal (1998) dealt simultaneously with resource exchange and combination among firms, by assuming exchange as a requisite for combination (Nahapiet and Ghoshal 1998). The resulting output of those two activities would be the creation of new resources. However, resource exchange (or transfer) could theoretically imply delivery from A to B, where A loses the resource to B. Nonetheless, for some resources, such as tacit knowledge or access to infrastructures, "exchange" does not prevent its sender from accessing it; instead, "exchange" actually means "sharing", as more actors have access to the same resource and can work with it for individual and collective benefit. For that reason, the present study employs the notion of resource sharing, instead of the joint activities of exchange and combination.

(II) STRUCTURAL DIMENSION AND RESOURCE SHARING

The structural dimension is partially based on the "appropriable organization", i.e. the existence of a network, with a given density, pattern of ties and hierarchies created for one purpose, which may be used for another purpose (Coleman 1988; Nahapiet and Ghoshal 1998). These pre-existing ties can act as channels for information and resource sharing (Scott and Carrington 2011; Tsai and Ghoshal 1998; Liao and Welsch 2003) and potentially affect upfront the resources that a member is capable of accessing. Tsai and Ghoshal (1998) defined this dimension based on social interaction between firms' members outside their work environment, i.e., their history of social ties. However, many scholars studying R&D cooperation, or University-Industry (U-I) links, have found that prior ties can predict current or future collaborations (Santoro and Bierly 2006; Defazio, Lockett, and Wright 2009; Pinheiro, Pinho, and Lucas 2015), partly because there is an enhanced perception of the potential cooperation value (Petruzzelli 2011). Moreover, the strength of those prior ties might have a role on resource sharing. Strong ties, such as those resulting from institutions involved in past joint R&D projects with very frequent interactions, facilitate knowledge sharing but limit the access to novel sources of information (Hansen 1999). On the other hand, weak ties, such as those resulting from socially interacting in scientific workshops and conferences, facilitate the search of information, but impede tacit knowledge sharing (Hansen 1999). Moreover, the combination of strong and weak ties has been suggested to have a positive interaction effect (Michelfelder and Kratzer 2013).

Accordingly, based on the above rationale, the following hypotheses are presented:

H1: R&D consortium members with prior ties have greater odds of sharing resources between them when they participate in the same RJV.

H1a: R&D consortium members whom have socialized in events prior to the RJV have greater odds of sharing resources between them.

H1b: R&D consortium members whom have collaborated previously in R&D activities have greater odds of sharing resources between them.

(III) COGNITIVE DIMENSION AND RESOURCE SHARING

The cognitive dimension refers to shared representations, interpretations, and systems of meaning among parties (Nahapiet and Ghoshal 1998), which the work of Tsai and Ghoshal (1998) could only indirectly link to resource exchange and combination. These complex codes shared between different but cooperative institutions were tested and validated in the area of U-I links (Plewa and Quester 2007; Plewa, Quester, and Baaken 2005; Pérez-Luño et al. 2011). A greater compatibility and alignment in regard to the objectives of R&D projects involving academic and private partners led to greater integration and more radical innovations (Plewa and Quester 2007; Pérez-Luño et al. 2011). Notwithstanding, while the research goals and milestones are defined by all members in the project application phase, those goals are not expected to be equally important to all R&D consortium members. If that is not the case in intra-corporate networks managed by the same headquarters (Tsai and Ghoshal 1998; Inkpen and Tsang 2005), in FP-funded RJVs goals and vision diversity should be even more pronounced. All taken, when RJV partners align in their collective goals, it could be expected a greater tendency to share resources. Accordingly, the following hypotheses are presented:

H2: R&D consortium members that share collective goals have greater odds of sharing resources between them, within their RJV.

H2a: R&D consortium members that share similar interests and objectives have greater odds of sharing resources between them.

H2b: R&D consortium members that share a common vision for the project's success have greater odds of sharing resources between them.

(IV) RELATIONAL DIMENSION AND RESOURCE SHARING

The relational dimension of Social Capital comprises the relationships that partners build among each other through mechanisms of trust, friendship, relational norms, obligations and mutual identification (Nahapiet and Ghoshal 1998; Liao and Welsch 2003). Tsai and Ghoshal (1998) focused on measuring Trust and Trustworthiness (through reliability and promise keeping), but the majority of research on U-I links focuses on measuring Trust and Commitment (Plewa and Quester 2007; Frasquet, Calderón, and Cervera 2011; Pérez-Luño et al. 2011). These past studies showed a positive and significant role of Trust and Commitment on cooperation and innovation, although Trust is not always a positive predictor of cooperation (Chow and Chan 2008). In line with the stream of literature on U-I cooperation, this study expects to find that Trust and Commitment positively contribute for partners' Resource Sharing, leading to the following hypotheses:

H3: R&D consortium members have greater odds of sharing resources with partners they trust within the RJV.

H4: R&D consortium members have greater odds of sharing resources with partners to whom they feel highly committed.

Criteria for R&D consortia selection

In order to select FP7 projects involving R&D cooperation, the following criteria were adopted:

1. Project contract type: "Collaborative project", "Large-scale integrating project'", "Research for SMEs", or "Research for SME associations/groupings". This criterion ensured a selection of projects with greater and more immediate societal impact, in which both R&D institutions and end-users worked closely to develop technology-based products and markets;
2. Projects with begin-date between January 2008 and March 2012, thereby focusing on on-going or recently concluded projects. On-going projects were in collaborative work for at least 18 months prior to data collection (on average, 31 months), while the remaining projects had finished less than 36 months prior to data collection (on average, 11 months);
3. Projects with a research purpose related to (i) the Biological Sciences, and (ii) funded by calls from the FP7-Health, FP7-Environment, FP7-KBBE, FP7-NMP and FP7-SME programmes. These two sub-criteria were chosen because Biological Sciences comprise the research foundations of many knowledge areas, with direct implications in activities concerning environment, health, food/beverage, agriculture and pharmaceutics, as well as other less conventional bio-sectors, like plastics or fuels development;
4. Projects having at least one Portuguese partner.

The first three criteria returned over 1,000 projects. The need for the last criterion is exclusively quantitative, i.e. it reduces the size of the sample into a manageable one. The final dataset was composed of 69 RJVs, which included 849 institutions from 55 countries, 30 of which were outside the European Union. The geographical constraint in the fourth criterion does not implicate a meaningful change in diversity of the countries and institutions involved in the projects selected for the present study, when compared to the whole Programme[6] (European

[6] With the exception of Portugal, on average, the relative frequency of participation of each EU-28 country varied by 1% when compared to the whole 7th Framework Programme.

Commission 2015). Moreover, Portuguese members accounted for 8.5% of the analysed networks. Therefore, it is not predictable that results are consequently biased towards a subset of initiatives within the Programme and conclusions should be applicable to the ensemble of the FP7-funded networks. Some of the 849 institutions were partners in more than one project, totalling 1,149 participations. In accordance with the European Commission's guidelines, at least three member-states were included in each consortium, while 94% of the RJVs included at least five different nationalities, thus representing very international networks.

Data collection

For each of the 69 RJVs, the contacts of project personnel were collected from the CORDIS database, research papers and posters acknowledging the project funding, as well as the project's website when available. However, in the case of universities and research institutions, preference was given to senior researchers and professors.

RJVs personnel were contacted from June to December 2013, and were invited to fill in a web survey on behalf of their organization addressing the patterns of collaboration with members of their consortium. Survey data were collected from individuals who were more likely to represent decision makers acting on behalf of their institution. On the majority of cases, the project website identified these key researchers. For most of the questions in the survey, respondents were presented with the list of their consortium members from which they could pick the members with whom they had a specific relationship. To reduce potential bias caused by social desirability, respondents were informed that their responses were completely confidential, and that the analysis would not allow for individual identification.

The survey yielded a total of 882 valid responses across all RJVs, with project response rates ranging from 15% to 100%. However, network hypotheses require a high level of response rate in order to minimize errors associated with missing data (Kossinets 2006). Accordingly, only projects with at least 60% response rate on all survey questions were used for subsequent analysis. On large projects, with 20 or more participants [twice the average size of cooperative RJVs (European Commission 2015)], projects were included if they had at least 50% response rate on all survey questions. This decision reduced the number of projects under study to 43, with a total of 708 participations. Within this set, 487 institutions provided a single response to the survey, and 66 institutions provided multiple responses, as more than one senior researcher from the same project filled the survey. For these cases, the union of their responses was used in order to obtain a single response. The match between each pair of responses from the same institution was calculated using the Sokal-Michener similarity measure (Seung-Seok, Sung-Hyuk, and Tappert 2010), revealing a degree of 77% ± 10% of similarity among respondents. Therefore, the final dataset included responses from 553 participations.

Measures

(I) RESOURCE SHARING (EXCHANGE AND COMBINATION)

Resource sharing is an expected intrinsic activity of R&D projects. For this study, the focus was on both tangible and intangible assets that consortium members accessed while in collaboration, using the following four questions: (1) ”Within [acronym of the RJV], I shared human resources (students, post-docs, etc.) with the following partners”, (2) “Within [acronym], I shared samples and materials (strains, cell lines, collections, chemicals, drugs, etc.) with the following partners”, and (3) “Within [acronym], I had access to facilities / technologies from the following partners”. In order to capture collaboration ties involving information and advice sharing, as well as other resources not mentioned in the previous questions, the following was asked: (4) “Within [acronym] consortium, I worked closely with the following partners”. Similarly to Tsai and Ghoshal (1998), the present work deals simultaneously with resource exchange and combination, assuming that partners share resources with each other in order to combine them in their own activities. The four matrices were combined into a single measure of Resource Sharing following a minimum rule. Accordingly, if one institution reports at least one tie in any of the four matrices, then the tie exists in the combined matrix. The Sokal-Michener similarity between the four resource matrices was assessed prior to the combination and averaged at 78% (67% of the correlations with a p-value ≤ 0.05), calculated in UCINET (Borgatti, Everett, and Freeman 2002) using the QAP correlation procedure with 100,000 permutations of each pair.

(II) STRUCTURAL DIMENSION: PRIOR TIES

Plewa et al. (2013) and Pinheiro, Pinho, and Lucas (2015) suggested that relationships among R&D partners evolve over time and encompass increasing dependencies in terms of shared resources. These collaborative relationships tend to grow from simple service provisions, where the outcomes interest mostly one of the partners, towards more complex externally funded projects with mutual goals. Moreover, prior ties in University-Industry (U-I) collaborations have been shown to lead to the achievement of higher innovative outcomes (Petruzzelli 2011), simultaneously requiring resource sharing among partners. Similarly, at the level FP-funded projects, DeFazio et al. (2009) found that the structure of prior relationships among consortium participants positively impacts current collaboration patterns, as measured by a greater output of publications.

Based on these contributions, the measures proposed by Tsai and Ghoshal (1998) were adapted to account for prior ties, and adjacency matrices were constructed for each project based on the following two questions: (1) "Prior to [acronym] consortium, I spent time (at conferences, workshops, courses, business fairs or alike) with people from the following institutions", and (2) "Prior to [acronym] consortium, I worked in R&D with the following institutions". For both questions, the matrices were symmetrized based on the maximum rule, since "spending time with" and "working with" can be considered undirected relationships. The similarity between these matrices across all projects averaged at 80% (in 95% of projects, p-value ≤ 0.05).

(III) COGNITIVE DIMENSION: SHARED COLLECTIVE GOALS

The cognitive dimension in the work of Tsai and Ghoshal (1998) used non-relational measures that required conversion in order to be analysed using social network methodologies. Those authors realized that better conceptualizations of that dimension were appropriate. Accordingly, two adjacency matrices were constructed for each project based on the following two questions: (1) "I share similar interests and objectives with the following partners", and (2) "I shared a common vision on the key success factors for [acronym] with the following partners". These questions were based on the works of Plewa et al. (2007) and Pérez-Luño et al. (2011), which have found that a shared vision on the cooperation success factors, as well as similar objectives, lead to U-I cooperation. For both questions, the matrices were not symmetrized, since each response represents a perception that is not necessarily common. The similarity between these matrices across all projects averages at 76% (in 93% of projects, p-value ≤ 0.05).

(IV) RELATIONAL DIMENSION: TRUST AND COMMITMENT

The relational dimension tested by Tsai and Ghoshal (1998) focused on measuring Trust and Trustworthiness (through reliability and promise keeping). The first is a relational measure based on ties between partners, while the second is a perceived attribute of each partner. However, much of the research on U-I links focuses on Trust and Commitment between partners (Plewa and Quester 2007; Frasquet, Calderón, and Cervera 2011; Pérez-Luño et al. 2011), which are both relational measures and have shown to be essential for organizational cooperation (Morgan and Hunt 1994). Accordingly, two adjacency matrices were constructed for each project based on the following two questions: (1) "I believe the following partners will never take advantage of me, even if given the opportunity", and (2) "Within [acronym] consortium, I had a high level of commitment with the following partners". The measure of reliability was adapted from Tsai and Ghoshal (1998), while the measure of commitment was adapted from Pérez-Luño et al. (2011). For both cases, the matrices were not symmetrized, since Trust and Commitment are directed relationships. The similarity between these matrices across all projects, which averaged at 64%, was very often non-significant (only in 19% of projects, p-value ≤ 0.05).

Research Models

In order to test the proposed hypotheses, three models were devised using the measures defined in the previous section. Models 1 and 2 used a single measure for each Social Capital dimension to estimate the probability of Resource Sharing, while Model 3 used both measures of each dimension to estimate the same dependent matrix. Accordingly, for Models 1 and 2, only the "Time Spent" variable from the Structural dimension and the "Shared Vision" variable from the Cognitive dimension were used, given their resemblance to the original measures and model tested by Tsai and Ghoshal (1998). For the Relational Dimension, Model 1 used the "Trust" variable, while Model 2 used the "Commitment" variable.

Data imputation procedure and network reduction

A multiple imputation algorithm was used in this study based on the concept of preferential attachment (Barabási and Albert 1999). As proposed by Huisman and Steglich (2008), this procedure states that the probability of an edge between missing actor i and actor j will be proportional to the in-degree of actor j, therefore preserving the degree distribution of the network. In short, for each actor with missing links, the algorithm randomly draws an out-degree d_i from the observed out-degree distribution. After determining the observed out-degree d_i^{obs} for each actor i with missing links, it draws, without replacement, $j = (d_i - d_i^{obs})$ actors from the set J_i, which comprises all actors j whose tie from i is missing, using preferential attachment probabilities $\pi\ (k_j)$, that are proportional to the out-degree of each actor $j\ \in\ J_i$. In a last step, the algorithm imputes the missing X_{ij} to be equal to 1 for the sampled actors, and 0 for all others.

A robustness check for the multiple imputation procedure is provided by running a complete case analysis, which was based on smaller networks for each project by looking solely at the institutions that gave valid responses for all questions used in the analysis. We arrived at these smaller matrices by performing list wise deletion of actors that failed to answer any single question. The results of the robustness tests can be found in the appendix.

Logistic Regression Quadratic Assignment Procedure

LRQAP, short for Logistic Regression Quadratic Assignment Procedure, is a nonparametric regression technique developed for modelling network data with a binary dependent variable. LRQAP is part of the QAP routines, which have been described as robust in their ability to control for varying and unknown amounts of row and column autocorrelation (i.e., lack of independence among observations), a characteristic of network data (Krackhardt 1988; Kilduff and Krackhardt 1994). These procedures are based on row and column-wise permutations that keep the data structure intact, except for the order of the objects which is randomly permuted (Dekker, Krackhardt, and Snijders 2007). The model fit and regression coefficients of the non-permuted data (or observed data) are compared to the same indexes obtained with thousands of permutations, allowing to determine how frequently the indexes of the observed data models are larger or equal (in absolute value) to the indexes obtained with all random permutations. In the present study, QAP routines were performed with 100,000 permutations.

The network data in all variables of the present study are binary, so LRQAP is an adequate technique for analysis. However, LRQAP does not control for collinearity, i.e. dependence among independent variables. Since all models in the present study include at least three variables, collinearity might bias the results, especially in Model 3, which has six independent variables. In order to control for collinearity, the same models were analysed using MRQAP (Multiple Regression QAP), which is capable of handling collinearity without increasing Type I errors (Dekker, Krackhardt, and Snijders 2007). According to Borgatti et al. (2013), MRQAP routines are aimed at valued data, but they can be cautiously used with binary data. In such cases, the model fit (R^2) and significances of the regression coefficients (p-values) are valid for interpretation (and comparable to those obtained with LRQAP), while regression coefficients are not interpretable. Accordingly, results from MRQAP and LRQAP were compared to assess (i) if the model fits were similar, and (ii) if both routines signalled the same independent variables as significant or non-significant to Resource Sharing. This comparison resulted in a robustness test for LRQAP regarding the models in this study and the detailed findings are presented in the appendix. A short version with the main results is presented in the following section.

Results from LRQAP analysis

In the 43 R&D projects analysed, all independent variables except Trust were very frequently correlated with Resource Sharing (the dependent variable) – correlation data available in the appendix. Based on this information, the logistic regression fits of the three research models (M1, M2 and M3) were compared in order to understand if the change or addition of independent variables between models was improving the data fit. Since the model fits were normally distributed ($p\text{-value} \geq 0.084$ in Kolmogorov-Smirnov test), an ANOVA test was performed to asses their differences ($F\text{-value} = 21.282$; $p\text{-value} = 0.000$) and a post-hoc Tukey-B test showed that each model was statistically different from each other at $\alpha = 0.05$ (mean of each group: M1 = 0.191; M2 = 0.302; M3 = 0.365).

A robustness test to LRQAP modelling was performed by comparing its results to the same models ran in MRQAP (detailed in the appendix). The test found (i) no statistical differences in the research model fits at α = 0.05, and (ii) match levels of 96% (M1), 98% (M2) and 79% (M3) achieved in selecting the same variables as significant or non-significant. These results mean that, for Models 1 and 2, MRQAP and LRQAP analysis provided very similar information. However, Model 3 is likely introducing Type I errors due to collinearity among independent variables, given the substantially reduced match level. As a consequence, those results will not be further presented nor discussed, limiting the study's ability to answer H1b and H2a.

Taking into account the 43 projects under study, Figure 5 represents how often each independent variable had a significant and positive (in green), significant and negative (in red) or non-significant regression coefficient (in black) towards Resource Sharing. The median change in Odds Ratio (O.R.) towards Resource Sharing (when that binary variable was one) can be found adjacent to each significant graph slice. The median value is reported because Ratios do not follow normal distributions.

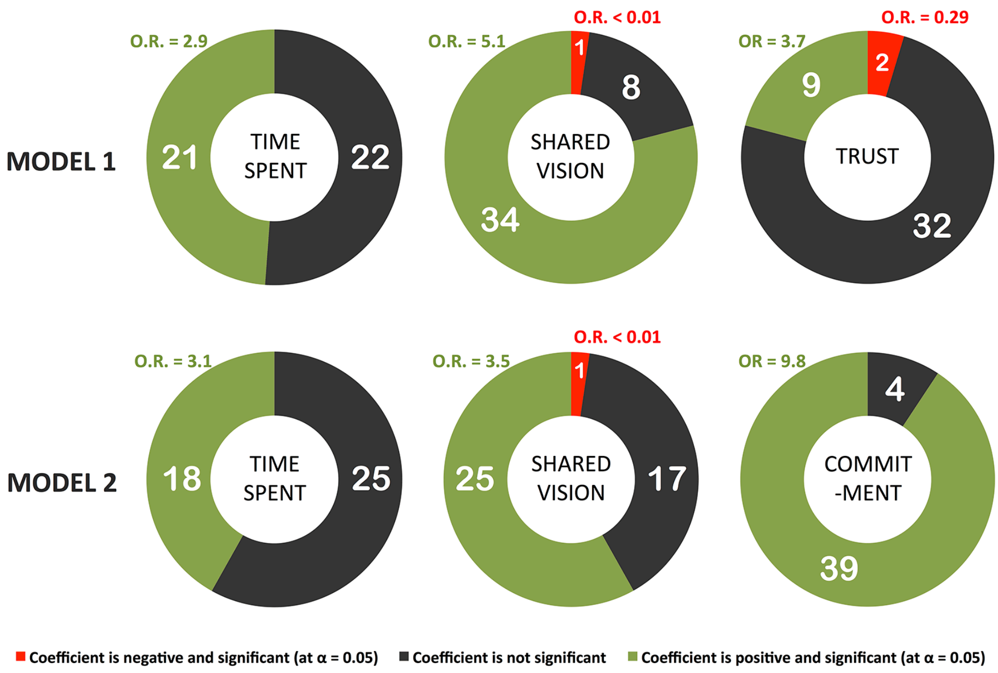


Figure 5. Summary results of the LRQAP models for all 43 projects

Each graph slice represents the number of projects were it was observed a significant and positive (in green), significant and negative (in red) or non-significant regression coefficient (in black) towards Resource Sharing. The median change in Odds Ratio (O.R.) towards Resource Sharing can be found adjacent to each significant graph slice.

Figure 6 shows the distribution of all 100,000 permutations for each network variable in Model 1 for project ENV-06, along with the estimated regression coefficients (represented by the dashed lines). It should be noted that Figure 6 represents a single but illustrative instance of the results summarized in Figure 5.

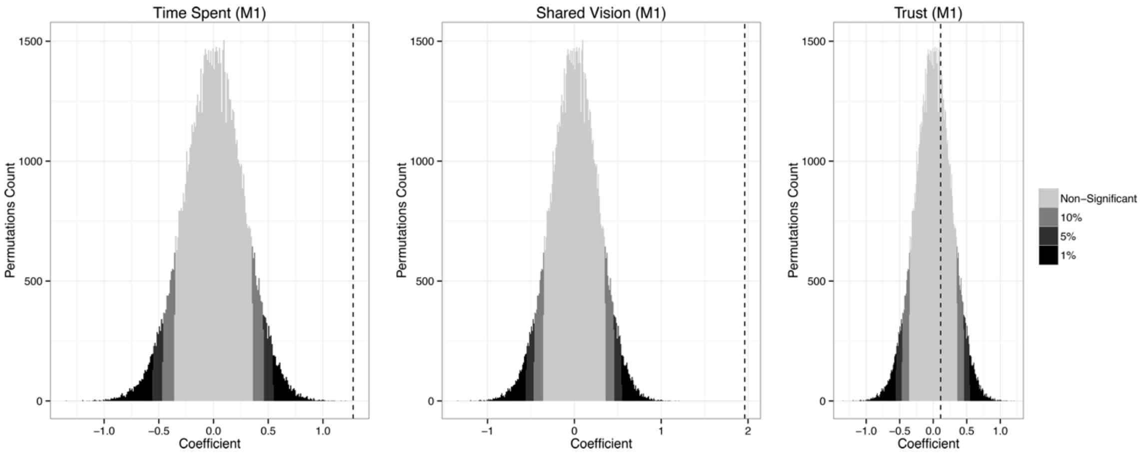


Figure 6. Distribution of the 100.000 LRQAP permutations for three network variables in Model 1, for project ENV-06

The dashed line indicates the observed logistic regression coefficient for each of the variables.

Based on Figure 5, it is observable that the Structural Dimension of Social Capital (variable “Time Spent” in Models 1 and 2) contributed positively to Resource Sharing in 40-50% of projects (green slice). In that respect, the odds of members sharing resources were roughly 3 times larger when partners had spent time in social events prior to their consortium. The variable being significant in about half of the projects moderately supports H1a.

The Cognitive Dimension of Social Capital, measured through Shared Project Vision, contributed positively to sharing resources between members in the vast majority of projects and it contributed negatively to one project. In this single latter case, sharing a common vision with a partner was very detrimental to Resource Sharing. Overall, the odds of members sharing resources were 3 to 5 times larger among partners whom shared a common vision for the project's key success factors, when compared to partners whom did not have similar understandings of collective goals. These results support H2b.

The Relational Dimension of Social Capital was measured through partners' Trust and Commitment. In 21% of projects, Trust was a positive predictor of Resource Sharing, as hypothesized. Therefore, there were higher changes for that outcome tie to occur when partners shared a Trust tie. However, in two projects, Trust was found to be a negative predictor of Resource Sharing. In such cases, partners had much lower odds for sharing resources if they trusted each other, contradicting H3. Moreover, in the remaining 32 projects, Trust did not help describing the dependent variable. Therefore, the results from 79% of projects do not support H3. This means that Trust was not significant for partners' Resource Sharing choices. Regarding the study's last hypothesis (H4), Commitment was found to be a predictor of Resource Sharing in nearly every project (91%). R&D consortium members had nearly 10 times greater odds of being involved in Resource Sharing with whom they reported being highly committed. As a result, H4 was supported.

Exponential Random Graph Models

Take graph Y as a simple representation of a social network, comprising a set of vertices V (commonly referred to as nodes or actors) and a set of edges E (commonly referred to as links or connections), such that $Y = (V, E)$. Let Y be understood as a random variable and y as a single realisation of Y. Then, if y denotes the adjacency matrix of the network, $y_{ij} = 1$ when there is an edge between vertices i and j, and $y_{ij} = 0$ otherwise. In the networks analysed in this study, when the ties between institutions are undirected (symmetric), $y_{ij} = y_{ji}$.

By defining Y as a random variable, it is known comprise the set of all possible networks with the same number of vertices as the observed realisation y. In the case where ties are directed (asymmetric), the set of all possible networks reflects both the direction and the number of nodes of the observed network y. Therefore, Y contains all possible networks ranging from an empty network, where there are no edges E between vertices V, to a full network, where all vertices V are tied by an edge E (Desmarais and Cranmer 2012b). Note that for an undirected graph, the total number of possible realisations of the network is equal to $2^{\binom{V}{2}}$.

Let $g(y)$ be a scalar-valued network statistic in the observed network y, and θ the exponential random graph (ERG) parameter estimated for this statistic (equivalent to β in the context of standard regression analysis). The number of θ parameters to be estimated is a function of the network statistics $g(y)$ that are chosen to capture the network tie-formation processes. These network configurations (or statistics) chosen to specify the model should be motivated by theory, as they reflect the local regularities and processes that give rise to the patterns that compose the observed network (Lusher and Robins 2013). The underlying theoretical proposition of the ERG modelling approach is the idea that global patterns observed in the network emerge from decisions made at the individual level, which are themselves influenced by *endogenous* and *exogenous* factors. If we can capture what factors are driving the decision of institutions to connect with others, on different levels, we can produce an empirical distribution of networks that will exhibit the same global patterns that are present in the observed network.

The exogenous factors capture the propensity actors unveil to select their connections based on personal attributes, i.e. their propensity to match their attributes with other nodes in the network. This tendency is commonly referred to as *homophily*. For example, institutions from the same country may tend to collaborate more often due to physical proximity and language similarity. The network configurations that emerge from this selection process are dyadic independent, as they only consider factors that are exogenous to the network structure, and could very well be captured in a traditional regression framework. The endogenous factors capture dyadic dependent processes in the network, and are crucial for the occurrence of particular patterns of ties at the global network level. For example, a tendency for transitivity will generate clique-like clusters in particular areas of the network, where the density of ties is higher. We could not observe the global affect of transitivity (emergence of clusters or cliques) if the actors did not themselves have a tendency for closure (transitivity). For an overview of all the network configurations that can be modelled, see Handcock et al. (2010) and Snijders et al (2006).

After selecting the endogenous and exogenous configurations, the vector of p-sufficient statistics $g(y)$ is calculated globally in the network. However, it simply reflects individual tie formation choices at the local level that, when aggregated, give rise to the observed macro structure (Stadtfeld 2012). In the Resource Sharing networks, the number of ties observed for all projects, as a share of the total possible number of ties, is quite high (around 0.5, which means half of all possible ties do exist). This is a measure of density, a global feature of the network, but that can be nonetheless explained by the choices of individual institutions: if we assume there are diminishing marginal returns to collaborations, due to time and resource constraints, institutions will select an optimal number of partners to collaborate with. This statistic will control for the propensity for the occurrence of ties, similar to the intercept in standard linear regression models, and it takes the following form:

$$g_1(y) = \sum_{i,j} y_{ij}$$

Based on the chosen network statistics and respective parameters, the ERGM yields the probability of occurrence of graph y conditional on the subgraph counts of the local network processes that constitute the network statistics, relative to the rest of the possible networks in the sample space Y. This probability is proportional to $\exp\left(\sum_{k=1}^{p} \theta_k g_k(y)\right)$, which means that the direction of the network statistics g_k will be determined by the sign of the parameter θ_k: if a triangle parameter is large and positive, than the graphs in the sample space with more triads become more likely under the model, *ceteris paribus*. If we also take into account the configuration of a 2-path, where in a set of three vertices, two vertices have a common neighbour but no tie between them, then by including both the triangle and the 2-path configurations in the model we are able to assess the partial effect of a tendency for transitivity (triangle) given the propensity for actors to share a partner (2-path). We can then draw inference on whether there is an unusual tendency for transitivity at the local level in the network. Thus, the probability of observing y in the sample space, given the network statistics specified, is given by:

$$P(Y = y) = \frac{exp\left(\sum_{j=1}^{p} \theta_k g_k(y)\right)}{\sum_{y* \in Y} exp\left(\sum_{j=1}^{p} \theta_k g_k(y)\right)}$$

The normalisation requires evaluating the probability at every possible realisation of graph y in the sample space Y. Essentially, the ERGM will produce a distribution of graphs in which the configurations of the observed network are central. From here we can simulate a graph from the model and compare it to the observed network, to assess the goodness of fit. The estimation of these models directly from Maximum Likelihood is computationally demanding given the size of Y even for small networks[7]. To approximate the maximum likelihood estimates θ, we use MCMC-MLE, a Markov-Chain Monte Carlo simulation method. To understand the inner workings of the algorithm, see Desmarais and Cranmer (2012a).

MODEL SELECTION

The ERGM modelling offers two main advantages in the context of this study: (1) it allows for estimation of binary networks; (2) it estimates the effect of exogenous attributes on the presence or absence of ties whilst controlling for processes that are endogenous to the tie formation mechanism. The main disadvantage is that it assumes that the proposed model captures the true tie formation process, which makes model selection a crucial step in estimating ERGMs. The

[7] For example, the sample space of a graph (undirected) with 20 nodes is composed of 68,719,476,736 possible realisations of the observed graph.

theoretical framework presented above (see from page 105 onwards) established the causal relationship between the three dimensions of Social Capital and the phenomenon of resource sharing between R&D institutions, therefore, each of the dimensions will be introduced in the models as edge/dyad covariate configurations. This term requires an exogenous whole network from which it calculates the sum of the covariate values for each edge that appears in the network (for directed networks) or for each dyad in the network (undirected networks). In terms of the network covariates, the models estimated via exponential random graph modelling are identical to those estimated via LRQAP.

Other exogenous effects included were homophily and assortative mixing. Collaborative ties require ease of communication between the actors, so we deemed it necessary to control for all factors that would facilitate resource sharing between certain institutions and make it harder for others. The uniform homophily measures included counts the number of ties between two nodes that share the same attribute. In the two models run, we included "country", and "role" as attributes, in order to control for homophily and selection processes based on similarities of these attributes.[8] The statistic is given by the following expression:

$$U_q(y): \sum_{i<j} y_{ij}.I\{x_{qi} = x_{qj}\},$$

Where x_{qi} is the attribute value for actor i for attribute q.

The assortative mixing configuration captures the tendency for certain attributes to share more ties in common than others. Due to the predominance of particular countries in the FP projects under study, we included parameters for each combination of institutions from France, UK, Italy and Germany, as they were more likely to collaborate between themselves (European Commission 2015).

The statistic that captures this effect is given by:

$$M_{q,a,b}(y): \sum_{i \in X_{qa}, j \in X_{qb}, i<j} y_{ij},$$

Where X_{qa} is the set of all actors who have value a for attribute q, and X_{qb} is the set of all actors who have value b for attribute q. This resembles a set of dummy variables, each representing an exact pairing of countries.

The endogenous process of tie formation is a function of the type of interaction under study and has important implications to the overall network structure. Processes like transitivity (the

[8] The "role" attribute corresponds to a segmentation of members based on the tasks performed within each RJV, namely a group that performs R&D tasks, a group aiming to embed the new knowledge into market solutions and a group of mediators between the other two roles. This classification is explained in detail in Chapter 4.

tendency for a dyad to form a tie if they both share ties to common partners), if unaccounted for, can give rise to erroneous inference on the causal effect of a tie in network X on a tie in network Y, when the presence or absence of the latter is driven by (in)transitive tendencies in network Y. In order to control for endogenous tie formation in the Resource Sharing network, we include in both models six configurations: a count of mutual ties; a count of intransitive triads; a geometrically weighted in-degree distribution; a geometrically weighted out-degree distribution, a geometrically weighted distribution of edgewise shared partners (triangle, $v(y)$), and a geometrically weighted distribution of dyadwise shared partners (2-path, $w(y)$). The degree statistics are important to unveil popularity effects within the network (who shares resources with most partners, or who receives the most resources). The remaining statistics capture the tendency for closure in the network: is shared collaborative tie leading to new ties within a project? Can certain institutions bridge potential collaborations between their partners? And does it trump the effect of the dimensions of social capital? In essence, it sheds some light on whether redundant connections or sparse networks accurately reflect resource sharing between institutions. The edge and dyad-wise statistics are calculated by the expressions below:

$$v(y, \alpha_1):\ e^{\alpha_1} \cdot \sum_{n=1}^{V-1} \{1 - (1 - e^{\alpha_1})^n\} \cdot \sum_{i,j} y_{ij} I \left\{ \sum_n y_{in} y_{nj} = n \right\}$$

Where n is the number of shared partners for the edge i, j and parameter α_1 controls the geometric rate of decline in the effect of triad closure on the tie probability for an increasing number of shared partners.

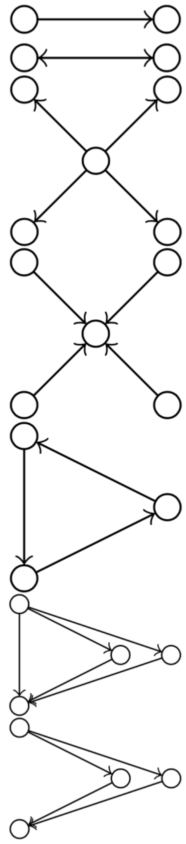
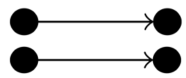
The dyad-wise statistic is given by:

$$w(y, \alpha_2):\ e^{\alpha_2} \cdot \sum_{n=1}^{V-1} \{1 - (1 - e^{\alpha_2})^n\} \cdot \sum_{i,j} I \left\{ \sum_n y_{in} y_{nj} = n \right\}$$

Where n is the number of shared partners between the dyad i, j and α_2 controls the geometric rate of decline in the effect of 2-paths on the tie probability for an increasing number of shared partners between the dyad

The iterative process taken in the exponential random graph algorithm evaluates the observed network statistics by deleting and adding ties to the network until it is evaluated at all possible realisations that constitute the sample space. Adding and deleting ties between nodes means the ERGM can only handle binary edges, such that the weight carried by an existent tie is equal to 1. This is a problem when the adjacency matrix of the observed network (dependent variable) has valued edges, where a higher value indicates a stronger link between the vertices. Therefore, in order to estimate the ERGMs we dichotomise the shared resources network by coercing all edges $> k$ to be equal to 1, where $k = 1, \dots, m$. The two models estimated are composed of endogenous, exogenous and network covariate configurations listed in Table 12.

Table 12. Network configurations (covariates, endogenous and exogenous effects) included in both ERGM models, estimated for all 43 FP-7 projects

Covariate Networks	Model 1	Model 2
Time Spent	Yes	Yes
Shared Vision	Yes	Yes
Trust	Yes	No
Commitment	No	Yes
Endogenous Effects	All models	
Arc		
Reciprocity		
Out-degree (gw)		
In-degree (gw)		
Intransitive triads		
ESP: Edgewise Shared Partners (gw)		
DSP: Dyadwise Shared Partners (gw)		
Exogenous Effects	All models	
Homophily (country)		
Homophily (role)		
Assortative Mixing (country)	DE, UK, FR, IT	

Note: "gw" stands for geometrically weighted

Results from ERGMs analysis

The heterogeneity of the projects in terms of their size is one of the main obstacles to a direct comparison of the results across RJVs. The larger the network, the more opportunities for collaboration arise, but the more difficult it becomes to form close-knit groups where all institutions share resources with every other. As the network density decreases, the average geodesic increases and the information flow in the network slows down. At the same time, the emergence of particular network structures, such as cliques and other closure-type formats, are also less likely to emerge by chance than in smaller networks, which gives us some leeway in the interpretation of these network effects.

The joint distribution of network density for all projects follows a normal distribution, with both median and average network density around 0.5, and consequently decreasing with network size (see Figure 7). Theoretically, this should not affect how well the endogenous effects capture the tie-formation process at the individual level. However, the networks size will affect the number of parameters we are able to estimate, and models are adjusted appropriately to account for that.

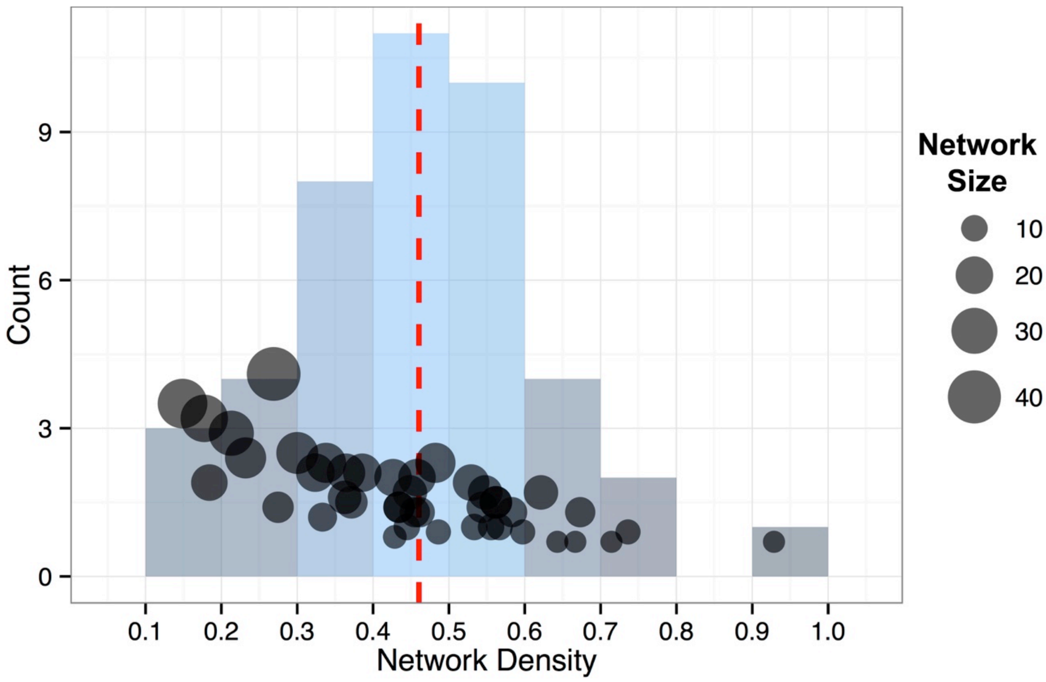


Figure 7. Histogram of network density, where bars represent counts of FP projects (N=43) and circles represent the size of Resource Sharing networks

The dashed line indicates the average network density for the 43 FP projects.

An aggregate perspective on the performance of each configuration is present in Table 13. Overall, the results from the ERGMs confirm the results obtained using the LRQAP permutation tests in both proportion of significant coefficients and direction of the effect. Therefore, the effect of structural, cognitive and relational dimensions of Social Capital on Resource Sharing in R&D networks is robust to the inclusion of endogenous network effects, such as homophily, popularity and transitivity. The results for each of the dimensions are broke down by project in Figure 8, for both models.

Table 13. Summary of ERGM results in terms of significance and direction of the estimated coefficients for Models 1 and 2

For each model, the columns indicate the number of projects for which the models ran (N), the percentage of projects for which the coefficient was significant, and for this subset, what percentage was positive and negative, respectively. AIC values of model fit display the median value for all projects.

Configuration	**Model 1**				**Model 2**			
	N	**Signif.**	**Posit.**	**Neg.**	**N**	**Signif.**	**Posit.**	**Neg.**
DSP (gw)	40	35.0	92.9	7.1	40	32.5	84.6	15.4
ESP (gw)	33	21.2	100	0.0	33	24.2	87.5	12.5
In-degree (gw)	40	10.0	25.0	75.0	39	7.7	33.3	66.7
Out-degree (gw)	35	8.6	0.0	100	35	11.4	0.0	100
Intransitive Triads	39	69.2	3.7	96.3	38	65.8	0.0	100
DE-IT	11	0	–	–	11	9.1	0.0	100
DE-UK	10	0	–	–	10	20.0	50.0	50.0
IT-UK	14	7.1	0.0	100	14	7.1	0	100
Mutuality	41	29.3	100	0.0	41	26.9	100	0
Homophily (country)	27	7.4	50.0	50.0	26	3.8	100	0
Homophily (role)	39	7.7	33.3	66.7	39	2.6	0	100
Time Spent	41	61.0	100	0	41	41.5	100	0
Shared Vision	41	70.7	100	0	41	51.2	100	0
Trust	40	15.0	83.3	16.7	–	–	–	–
Commitment	–	–	–	–	40	87.5	100	0
		$\boldsymbol{AIC_{\bar{\mu}}}$	229			$\boldsymbol{AIC_{\bar{\mu}}}$	215	

The ERGM coefficients reported are the log odds of a tie, which means that spending time together prior to the RJV in NMP-04 (Model 1) will increase the odds of sharing resources by a factor of $exp(1.25) = 3.49$, given no change in the values of the other statistics. The effect of this structural component of Social Capital receives moderate support in Model 1, and little support in Model 2, when "Commitment" was included as a covariate network. The cognitive dimension hypothesis receives strong support in Model 1, but also loses relevance in Model 2. In terms of the relational dimension of Social Capital, it shows a strong positive effect on the probability of Resource Sharing through reported "Commitment" within the project, rather than through "Trust", which was only significant in 15% of the projects.

The endogenous effects did not fare well in terms of significance, which can be attributed to the sheer number of parameters that needed estimation and the low number of nodes in certain networks. Nonetheless, the results suggest that Resource Sharing dynamics in R&D projects is not driven by popularity or activity (degree statistics), by a tendency towards role or country homophily, or by particular patterns of assortative mixing (particular country-dyads being more likely than others), but rather by closure and mutuality. The intransitive triads parameter was negative in almost all instances where it achieved statistical significance, which suggests intransitivity is not a local configuration that will produce the global patterns of ties at the network level. In other words, if institution A collaborates with B, and B collaborates with C, than A is likely to collaborate with C as well.

The closure effect is reinforced by the positive and statistically significant coefficients of the geometrically-weighted edge-wise shared partners' statistic. For those projects where closure was not a significant predictor of tie formation, the dyad-wise shared partner statistic was significant and in part driven by the low tendency to reciprocate ties in most networks (notice that the coefficient for the mutuality statistic was only a significant predictor of tie formation in less than $1/3$ of the networks). In some networks there is a significant tendency to reciprocate ties, which will close several triadic structures and form close-knit groups, but in others, reciprocation does not happen and intransitive structures are more likely to emerge.

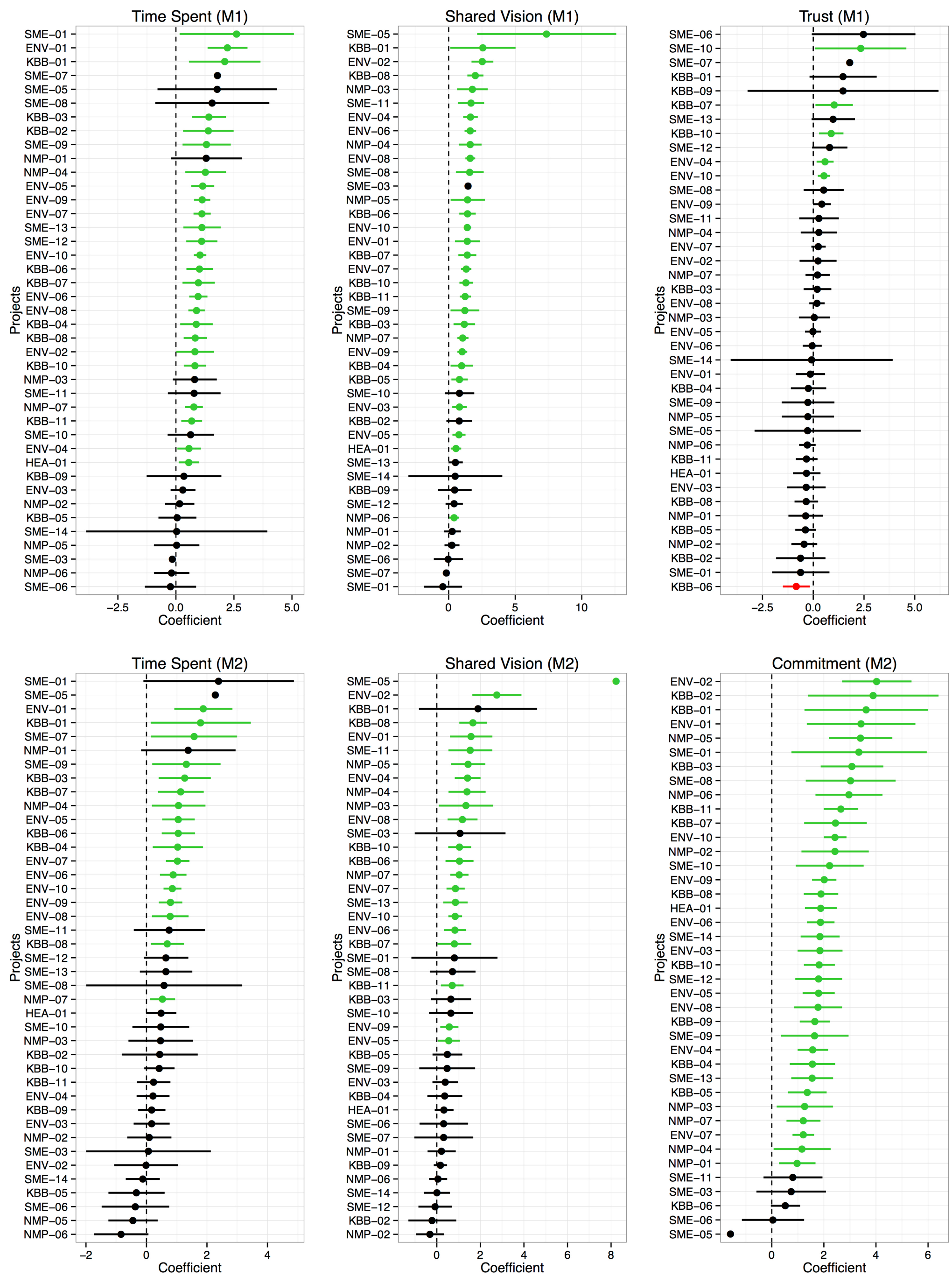


Figure 8. ERGM coefficients and standard error bars of the three edge covariate networks for 41 projects (Models 1 and 2)

Bars and dots are coloured if significantly different from zero (green for positive, significant and red for negative, significant), otherwise black. For some projects, the standard errors were so large that the confidence bar was excluded from the plot. Projects are named according to their funding programme: HEA = FP7-HEALTH; ENV = FP7-ENVIRONMENT; KBB = FP7-KBBE; NMP = FP7-NMP and SME = FP7-SME. Within each programme, projects are numbered sequentially as an ascending function of the number of members. Projects SME-02 and SME-04 were excluded from the results due to non-convergence of ERGM models.

DISCUSSION

The present study aimed at examining the role of Social Capital dimensions (structural, relational and cognitive) towards Resource Sharing within R&D cooperation networks (defined as RJVs) funded by the European Commission. The novelty of this study results from the combination of Social Capital theory with Social Network Analysis (SNA) to study intra-project partner relationships. Results showed that all Social Capital dimensions helped to explain Resource Sharing among partners, although to a different extent. Firstly, the structural dimension was measured using Prior Ties as suggested by the literature on University-Industry (U-I) links (Santoro and Bierly 2006; Defazio, Lockett, and Wright 2009; Pinheiro, Pinho, and Lucas 2015). In about half of the 43 projects studied, Prior Ties significantly increased the odds of partners being involved in resource sharing. Secondly, the cognitive dimension was measured through a Shared Vision of the project success, and in 50-75% of the projects it increased the involvement of the partners in Resource Sharing. These results are consistent with other works (Chiu, Hsu, and Wang 2006; Partanen et al. 2008), despite that those did not use SNA. Thirdly, the relational dimension was measured using two variables originating from Relationship Marketing but broadly used in the literature of U-I links: Trust and Commitment (Morgan and Hunt 1994). The present research found that, unlike previously suggested (Plewa and Quester 2007; Pérez-Luño et al. 2011; Hurmelinna-Laukkanen and Blomqvist 2007; Partanen et al. 2008), Trust does not contribute positively to Resource Sharing. On the other hand, Commitment was the strongest and most prevalent predictor of Resource Sharing among all variables measured in Social Capital. These results regarding Commitment and Trust align significantly with the work of Espinosa and Soriano (2014) on International Joint Ventures.

The findings here reported were simultaneously and independently verified by two different methodologies within SNA: ‘Logistic Regression Quadratic Assignment Procedure’ (LRQAP) and ‘Exponential Random Graph Models’ (ERGM). Both arrived at the same conclusions, which reinforces the validity of our results. The first conclusion is that the European Commission Framework Programmes provide a unique collaborative environment that very often is not based on inter-partner Trust, even though Trust has been deemed as a critical condition for R&D cooperation (Plewa and Quester 2007; Pérez-Luño et al. 2011; Hurmelinna-Laukkanen and Blomqvist 2007; Partanen et al. 2008). In some networks, Trust was even detrimental to the choices underlying partners' Resource Sharing. Overall this indicates that resources were mostly shared among partners that did not rely on each other. Accordingly, it can be assumed that relational governance mechanisms are not standard among different types of cooperation projects. In particular, Framework Programmes are potentially providing a collaborative but opportunistic environment for public and private actors. The second conclusion is that the high Commitment and Shared Vision observed in these projects could derive from high-stakes outcomes (high-risk & high-gain), which force partners to carefully invest their resources (technical, physical, time, money, among others) to avoid inefficiencies that could negatively impact on their organizations. Further identification of the motivations of each individual partner for getting involved should help defining what drives their commitment and their vision for the project success.

There are two important shortcomings in the present research design. One the one hand, considering the overall size of the FP7 only a small number of projects were analysed, even though the participation of the majority of EU-28 countries in this study closely resembles the distribution observed in the whole Programme (European Commission 2015). On the other hand, by using binary variables, important variation was lost regarding the degree of interaction between members. That information might have allowed a deeper insight into the conclusions hereby presented. For that purpose, each respondent should have reported the level of their interaction with N-1 consortium members for each dimension included in the analysis, which would have become cumbersome, eventually jeopardising the utilization of all the data.

CONCLUSIONS

This research advanced knowledge by proposing a set of relation-oriented measures for analysing Social Capital in R&D cooperation projects through SNA. Past studies have consistently approached these relational constructs through non-relational measures, thus disregarding the network effects that ultimately impact the collaboration choices within each RJV (Plewa and Quester 2007; Pérez-Luño et al. 2011). Collaborative ties are necessarily autocorrelated when conceptualized in a traditional regression framework: if we were able to look at the temporal evolution of the Resource Sharing network, it would become clear how the emergence of some ties is endogenous to the pre-existing structure in the network. In other words, particular types of relations have a tendency for clustering and closure. Therefore, institutions choose to share resources with other institutions with which they share a common partner, and not according to physical proximity, perceived trust or language similarities (Plewa et al. 2013; Gallié 2009; Petruzzelli 2011). Nonetheless, even when controlling for endogenous and attribute-based tie formation, the Social Capital dimensions were clearly the strongest predictors of Resource Sharing within R&D cooperation networks.

Based on the conclusions of the present study, managers of FP-funded projects, as well as the European Commission, should be aware of the importance of Commitment and a Shared Vision towards close collaboration among project partners. This study shows that these two variables frequently and positively affect Resource Sharing. This in turn should impact the effectiveness of R&D collaboration in each project, which, in turn, necessarily contributes the success of FPs in the long run. Importantly, this study provides further support to the notion that for any project network, the distribution of ties should be shaped in a manner that *a priori* provides a structure enabling success. The absence of this pattern of relations may not be enough to completely jeopardize the predicted outcomes of a project, but will limit them to the minimum that can be achieved by that particular group of collaborating partners. These types of consequences were previously analysed and reported for inter-firm networks (Cross, Borgatti, and Parker 2002). Accordingly, modelling the network ties of FP projects that were recognizably very successful should unveil ideal patterns of ties that lead to success, putatively allowing future improvement of the Programmes' financial support efficacy.

CHAPTER 6 GENERAL CONCLUSIONS

The present thesis aimed at providing guidelines for managing R&D cooperation networks in order to maximize value creation, by taking into account partners' relationships, shared resources and perceived benefits. The underlying research described the patterns of relationships and resource sharing among partners within R&D networks, highlighting opportunities for value creation and for enhanced perception of benefits obtained from cooperation. The main contributions of the study are presented below, followed by its limitations and the implication for theory and practice.

Main research contributions

Based on the thesis' first research question, chapter 2 proposed Social Network Analysis (SNA) as a relevant tool to examine and understand U-I R&D cooperation at both personal and organizational levels. SNA results revealed preferential relationships between different types of institutions, and exposed relational asymmetries within the U-I R&D network. The main conclusion deriving from those results was that within R&D cooperation networks it is important not to assume that relationships among U-I actors are all alike, as if membership in a project included a known level of *a priori* interaction or closeness. Instead, as members of an R&D consortium strengthen or weaken their ties, different structural configurations may arise, potentially impacting on the scientific output of the project. This is relevant because U-I links are not be valuable *per se*, and outcomes will vary with partner involvement. Because of this association between the structure of ties and the network's possibilities of value creation, SNA was proposed as the adequate methodological tool to understand the establishment and maintenance of U-I relationships within R&D cooperation, instead of measuring just tangible R&D outcomes at the end of a project like most literature to date.

Chapter 3 contributed with a deep understanding of the ARA-model and Social Capital theory, which were further used to assess U-I relationships within R&D cooperation projects. Both research streams acknowledged the importance of studying the activities and resources exchanged among actors in order to understand cooperation dynamics. The focus on both activities and resources was relevant, because the availability of resources *per se* does not guarantee successful cooperation. Actors involved in the process must be able to exchange and combine the different resources to achieve novelty beyond results obtained individually; otherwise there is little incentive for cooperation. Alongside, as resources are limited, institutions can only invest in selected links, forcing the study of U-I relationships to consider the network effects and the structural dependence of actors. Moreover, for any given institution, each link has the capacity to positively or negatively influence other existing or potential links, embodying the opportunities and constraints promoted by network interactions. The crucial topic in these theories, when compared to other organizational theories, is the acknowledgment of the capital embedded in relationships as a unique non-transferable resource that actors can leverage for individual and collective goals. In accordance with the rational above, and answering to the thesis' second research question, Chapter 3 showed that R&D cooperation should be approached as a continuous process, involving various common activities and resources invested throughout time. Four propositions based on this ‘developing relationship’ were studied against data collected in interviews with U-I actors. The results and conclusions of Chapter 3 can be summarized in four parts. Firstly, U-I relationships are simultaneously important at the organizational and individual level, from the outset onwards, requiring different levels of research and analysis, for which both organizational theories contributed. Focusing on just one of the levels would reduce the ability to understand how U-I links form. Secondly, low-investment low-risk activities, characteristic of the outset of U-I links, may last and occur simultaneously with other more mature types of cooperation, suggesting greater interdependence arising from more shared activities. To better understand this relational evolution, SNA is useful because it is capable of capturing the diversity of ties between partners, while controlling for data autocorrelation. Thirdly, shared interests were identified at the outset of successful U-I cooperation, and frequently grew as a result of partners sharing more complex tasks, implying an increased level of resource exchange. Finally, trust and commitment were deemed as mandatory for partners’ growing interdependence and project success, but not for the outset of their relationships. Academics and company researchers very clearly distinguished the level of trust inherent in R&D cooperation activities (often referred as partners’ reliability) from the level inherent in mere service provision (often referred as distrust). A measure of reliability was later incorporated in the survey of FP7 participants (Chapter 5). Interestingly, however, trust was not found to be a predictor of close collaboration and resource sharing within FP7 projects, which seemingly contradicts the results from the interviews in Chapter 3. However, the main premise from the cooperation continuum (explained in Chapter 3) was that U-I actors develop a relationship based on prior interactions that lead to trust between them. The correlation between Trust and Prior Ties in the data from FP7 participants is among the lowest of all correlations (Appendix A4), which means that, in the context of FP7 projects, there is very little association between prior partners and reliable partners. This link between the structural and the relational dimension of Social Capital was not tested, unlike the work of Tsai and Ghoshal (1998), but it does not seem likely that, in the context of FPs, Prior Ties are an important driver of Trust among partners, which further reinforces the claim that FP-funded projects are opportunistic environments for short-term, well-financed, and committed collaboration. It is possible that the *cooperation continuum* proposed in Chapter 2 has discontinuities but only in what concerns relational resources, which was not foreseen initially but was revealed by the data from FP7 project participants.

Chapter 3 highlighted two important issues. Firstly, understanding and influencing partners' initial interactions seems key to promote functional and successful cooperating networks, as there are relational disparities between early and established ties. Secondly, and reinforcing the above stated, relational resources described in Social Capital theory (such as personal ties, shared interests, trust and commitment) seem to drive the outset and the establishment of U-I ties, thus requiring further study along the whole *cooperation continuum*.

Based on the relational asymmetries between R&D project partners (Chapter 2), Chapter 4 focused on describing and explaining the patterns of collaboration and perceived benefits within R&D projects. To this end, a new way of classifying the consortium members was proposed, based on the knowledge-sharing roles they perform. This encloses the following categories: *Knowledge Exploiters*, *Knowledge Developers* and *Promoters* – KED roles. This new classification was needed because of the inadequacy of current institutional arrangements based on the type of institution or the roles of *Coordinator/Partner*. These classifications do not adequately match the type of project member with the role performed within the project as well as the obtained outcomes. Answering the thesis third research question, chapter 4 showed that members with different roles within EC-funded RJVs perceive benefits differently and have diverse centralities within the cooperation network. In particular, it was found that (1) *Knowledge Developers* (public or private research organizations) perceive higher benefits than firms in the role of *Knowledge Exploiters*; (2) *Developers* are more central to the network, reporting fewer Close Work Ties with other roles, and (3) *Exploiters* avoid collaborating with other *Exploiters*. If the pattern of ties within the project reflects the resource-sharing and task-dependence among partners, it is not evident that Exploiters are frequently important in these networks, as they are commonly relegated to the network's periphery, being selected fewer times and being less in-between partners. This location was already identified for Business partners at macro-level FP-networks involving thousands of RJVs (Avedas 2009; Vonortas and Okamura 2013). Nevertheless, this did not provide a distinction between business partners behaving as Exploiters or as Developers. According to the present work, Exploiters are expected to locate preferentially at the network periphery, which has direct implications at the level of innovative capacity (Avedas 2009).

Members perceived benefits are valuable concepts in the long run to evaluate the success of a funding programme, and these results point to disparities in perceptions among roles, which could indicate different realizations of the valuable opportunities generated by FPs. These disparities require managing relationships more effectively by taking into consideration the differences in expectation of benefits, outcomes and impacts of R&D activities according to each role. This should enable the identification of what each group within the consortium recognizes as strategic value and work towards providing it, consequently leading to more generalized satisfaction, and long-lasting interaction between members in all KED roles. The efficacy of the EU investment could expectably improve on a cohesive network compared to the present heavily centralized Framework Programmes networks. The goal is to achieve more with the same economical effort.

The contributions of these three chapters justified the need for understanding the role of Social Capital within FP-funded networks at the project level. Chapter 5 examined the role of Social Capital dimensions (structural, relational and cognitive) towards Resource Sharing within R&D cooperation networks funded by the European Commission. In response to the fourth research question from this thesis, results in chapter 5 showed that all Social Capital dimensions were important to explain Resource Sharing among partners, although to a different extent. Prior Ties impacted resource sharing in about half of the 43 projects studied, while a Shared Vision of the project success contributed positively in 50-75% of the projects. As referred above, Trust did not contribute positively to Resource Sharing, while Commitment was the strongest and most prevalent predictor of Resource Sharing. Social Capital dimensions were more significant predictors of Resource Sharing among partners than attribute-based variables and modelled network effects. This highlights how the structure of partners' relationships within R&D consortia is crucial for effective collaboration, maximizing the use of tangible and intangible available resources for generating mutual value.

Finally, in response to the research problem presented in the Introduction, R&D cooperation networks should be managed with the assumption that ties among partners are asymmetrically distributed with inevitable implications to the scientific outputs. If collaborative ties within an R&D consortium were randomly distributed, it should be obvious that there was a very small chance of obtaining a pattern of ties that would lead to optimal performance and maximum value creation. The corollary of this obvious inference is that maximizing the output of R&D networks requires partners to manage collaborative ties as a function of their commitment to mutually desired outputs, not by inertia or established past routines. However, in a simplistic scenario, if a network is formed to depend mostly of one or two members, the output productivity will be limited to their efficiency and capacity. R&D managers and partners should foster synergies by deciding 'who works with whom' so that the results obtained from shared resources and activities are greater than the sum of parts that would be obtained individually. R&D network managers should struggle against the network centralization that has been forming across many FPs, forcing R&D institutions to collaborate more diversely (and potentially more innovatively), while actively identifying the range of benefits that could interest each of the groups. This exercise should foster more opportunities for value creation that benefits the whole consortium, promoting solely (or mostly) the ties that achieve maximum performance and thus use the funding resources more effectively. Bearing in mind that the exact realization of the ideal structure of ties within each research project still needs further and deeper assessment, the results of this thesis justify the need for that research.

Research Limitations

The findings of this study should be considered in light of its limitations. Although the sample analysed is rather significant in relation to the universe of the Biological Sciences in Portugal, the amount of projects that ultimately integrated the study is limited considering not only the ample U-I R&D cooperation context in Portugal, or the Portuguese participation in Framework Programmes, but also the whole 7th Framework Programme. Data collection was performed in 69 projects, and 43 or fewer were used for SNA (Chapters 4 and 5). This number is consistent with previous works on U-I relationships (Plewa and Quester 2007; Plewa 2005), which usually require response from both ends of the dyad or from a large fraction of each network (Kossinets 2006). Importantly, the lack of respondent anonymity when collecting relational ties likely added to the difficulty of data collection. However, studies on U-I cooperation frequently measure their sample reach by the number of dyadic relationships analysed (Plewa 2005). According to that metric, this survey analysed over 4500 ties only in the Resource Sharing matrix, i.e. the dependent variable in the models analysed in Chapter 5.

Another limitation relates to the fact that the survey measures were binary, and therefore did not account for variations in respondents' perceptions, even though the interviews highlighted growing relationships with increasing resources shared and greater interdependencies. As explained in Chapter 5, the option of simplifying the survey and increasing response rate was preferred to increasing the detail of each response, while making the survey much harder on respondents to fill.

Finally, the interview data were collected within the same cultural environment and all interviewees were therefore restricted by the same social, political and economical constraints. Quite the opposite, the sample used for the survey was very heterogeneous, measuring relationships across borders and in some cases across continents. The cultural factors that might have affected the use and sharing of resources were therefore not accounted for and their potential impact on collaboration choices is unknown.

Implications and future research

The implications of the present thesis extend beyond the dyads and triads directly involved in R&D tasks. In particular, Universities, through their technology transfer (TTOs) offices should start their involvement with U-I links from the outset, in order to identify and promote strategic links of mutual interest. Hence, TTOs should be actively engaged in promoting networking activities and informal meetings that could spark the cooperation, even if this only goes as far as mutual service provision. Additionally, universities have to develop the capacity to communicate their researchers' skills in a language that companies value and understand, acting as facilitators of these links (Lundberg and Andresen 2012), while ensure maximum benefits for all parties in cooperation.

At the R&D project level, coordinators/managers should be aware of the collaboration patterns among partners, in order to identify existing constraints and potential opportunities towards more cohesive and less centralized collaboration. The networks' structural properties have implications in knowledge diffusion among partners (Protogerou, Caloghirou, and Siokas 2012; Avedas 2009; Vonortas 2012). Accordingly, this study strengthens the view that the distribution of ties within R&D projects should be shaped in a manner that *a priori* ensures successful cooperation.

At the European level, the European Commission should encourage or benefit project applications that are coordinated/managed by institutions in the role of Promoters, not Knowledge Exploiters or Knowledge Developers (for an overview of the roles, see Chapter 4). The reasoning behind this recommendation is that Promoters should be in the best position to avoid many of the network constraints identified in this thesis, namely (i) the heavy centralization around research institutions, (ii) the lower level of collaboration between research institutions and companies and (iii) the low level of collaboration between companies. Moreover, due to their mediating role, Promoters should be capable of identifying value propositions and research benefits for all roles involved in R&D cooperation, thus ensuring both maximum performance and value creation.

Regarding implications for theory, this thesis contributed to a better understanding on how to research relationships between university and industry partners in collaborative R&D projects. Moreover, the results of this thesis present SNA as a methodological approach that adequately captures the diversity of ties within R&D networks. Future studies on U-I relationships should take this technique into consideration due to its capacity to model relational data, as it is seems more in line with the reality to be measured. Likewise, future studies on inter-organizational links could benefit from the combined approach of the ARA model, Social Capital and Relationship Marketing described in Chapter 3, as more areas in the field of Marketing and Strategy are likely dealing simultaneously with individual and organizational interactions among actors.

Concerning the study of U-I R&D cooperation, this thesis also supports the creation of a research stream on U-I relationships, as suggested by Plewa and Quester (2007). In that regards, the *cooperation continuum* could be challenged and improved to account for more diverse activities and resources shared among R&D partners as well as to identify the motives that lead partners to break the link. Understanding what leads these relationships to failure at each stage is the first step to managing them for success from the outset, and future research should focus on the lower but indispensable levels of the *cooperation continuum.* Longitudinal studies should be able to deepen the results here presented and fill the gaps regarding the possible relational discontinuities towards higher levels, especially in what concerns inter-partner trust.

The present work presented new binary measures of Social Capital adapted for SNA, which can be extended to other contexts, and potentially improved to account for relational levels. Future research could try to link the cooperation dynamics observed within R&D networks with the outcome measures of each project to understand the structure of ties that fosters greater performance and higher levels of innovation.

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APPENDICES

A1. PUBLICATIONS SINCE ENROLMENT IN THE DOCTORAL PROGRAMME

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2012. "**Interações Universidades-Indústria: uma abordagem baseada nas redes sociais**". Abstract book from 3° Encontro de Analistas de Redes Sociais. Lisbon, Portugal.

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2012. "**Examining University-Industry interactions from the perspective of relationship marketing and business networks**", in: Proceedings of the 28th IMP Group Conference. IMP Group, Rome, Italy, p. 11. Full paper available at: http://www.impgroup.org/paper_view.php?viewPaper=7841

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2013. "**The role of social network analysis in University-Industry cooperation: In search of a new methodological approach**". Poster presented at the SUNBELT 2013 Conference. INSNA, Hamburg, Germany.

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2013. "**SNA as a new methodological tool to understand University-Industry cooperation**". Full paper accepted at INBAM 2013. Lisbon, Portugal

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2014. "**Social Network Analysis as a new methodological tool to understand University-Industry cooperation**". Abstract book from KITAB 2014 - Knowledge, Innovation and Technology Across Borders: An Emerging Research Agenda. Lisbon, Portugal.

Pinheiro, M.L., Lucas, C., Pinho, J.C., 2014. "**The role of R&D project outcomes in partner satisfaction and relationship continuity: the case of FP7 cooperation projects**". Abstract book from KITAB 2014 - Knowledge, Innovation and Technology Across Borders: An Emerging Research Agenda. Lisbon, Portugal.

Pinheiro, M.L., Lucas, C. and Pinho, J.C., 2015. "**Social Network Analysis as a new methodological tool to understand University–Industry cooperation**", *International Journal of Innovation Management*, Vol. 19 No. 1, 1550013 p. 22. doi: 10.1142/S1363919615500139

Pinheiro, M.L., Pinho, J.C. and Lucas, C., 2015. "**The outset of U-I R&D relationships: the specific case of biological sciences**", *European Journal of Innovation Management*, Vol. 18 No. 3, pp. 282–306. doi: 10.1108/EJIM-08-2014-0085

Pinho, J.C., Pinheiro, M.L., 2015. "**Social network analysis and internationalization of small and medium sized firms: Towards a different methodological approach**". *European Business Review (accepted for publication)*

I: Identification of respondent, institution e general data

II: R&D Activities and Collaboration Networks

- What lead you to (not) collaborate in R&D activities? What are the major advantages / disadvantages in R&D collaboration? What are the main objectives and difficulties?
- Have cooperated in R&D projects? What type of institutions were partners?
- Within your network of contacts, how many institutions can provide you with important resources (information, knowledge, consulting, technology, etc.)? How important could those resources be for the development of the R&D project?

III: R&D funds and type of R&D activities — discussed mostly with RCDs.

- Annual R&D budget, main source of funds, evolution of funding opportunities, main types of R&D activities

IV: R&D Activities in cooperation with other institutions

- Identify fruitful R&D cooperation, over the last 5 years. Is it still active? Why and how did the cooperation start?
- How did the relationships that lead to the cooperation came about? Formal / informal contacts? What was crucial for the decision to start cooperating (funds, technological resources, previous relation, expectations, common interests)?
- Based on your experience, how do you describe a successful R&D cooperation relationship? Describe your most positive and negative experiences.
- What do you value from R&D cooperation? Was it the same as your partner?
- Did you and your partner have the same objectives for the cooperation? Same priorities? What are the major differences between you and your partner?
- If patents and new knowledge are achieved, the performance is always positive?
- How frequently did you communicate with your partner? Mutual feedback?
- Would you say you trust your partner? What leads to trust? What is needed to maintain it? How did it evolve over time with the cooperation?
- Would you say you are committed to your partner? How do you show that commitment? What leads to it? How did it evolve over time with the cooperation?
- What did you receive from the cooperation? Resources? Ideas? Learning? Problem-solving for future issues?
- What resources did you provide? What resources did you receive?

A3. SURVEY TEMPLATE

1. Within PROJECT consortium I was affiliated with: (Consortium Roster presented)
2. Prior to PROJECT consortium, I spent time (at conferences, workshops, courses, business fairs or alike) with people from the following institutions
3. Prior to PROJECT consortium, I worked in R&D with the following institutions
4. I am CURRENTLY working in R&D with the following institutions
5. Within PROJECT consortium, I worked closely with the following partners
6. I share similar interests and objectives with the following partners
7. I shared a common vision on the key success factors for PROJECT with the following partners
8. I believe the following partners will never take advantage of me, even if given the opportunity
9. Within PROJECT consortium, I had a high level of commitment with the following partners
10. Within PROJECT, I shared human resources (students, post-docs, etc.) with the following partners
11. Within PROJECT, I shared samples and materials (strains, cell lines, collections, chemicals, drugs, etc.) with the following partners
12. Within PROJECT, I had access to facilities/technologies from the following partners
13. Please, rate the following sentences using the scale below.
    - Overall, I am very satisfied with the outcomes of PROJECT.
    - I would definitely participate in future R&D projects with members of this consortium.
    - The deliverables, papers and/or patents produced by the consortium were the MOST IMPORTANT assets obtained from this project.
    - The EU funding was the MOST IMPORTANT asset obtained from the project.
    - This project provided new ideas for future R&D projects.
    - The cooperation within PROJECT provided a learning experience otherwise impossible to achieve.
    - I greatly value the networking and experience gained by participating in PROJECT.

The word PROJECT (in capitals) is a placeholder for the name of the EC-funded RJV. While responding to the survey, each participant would see the correct name, instead of the placeholder. In Questions 2 through 12, respondents were presented with the PROJECT roster plus the option “None of the respondents”. In Question 13, a 5-point Likert Scale from “Strongly Disagree” to “Strongly Agree” was used.

Given the binary nature of the survey variables, the correlations were calculated using the QAP simple matching routine available in UCINET (Borgatti et al., 2002), along with 100,000 permutations. Table 14 shows the average matching score across the 43 projects for each pair of variables as well as how often the observed correlation was significant at α=0.05. It should be noted that all independent variables except Trust were frequently correlated with the dependent variable (Resource Sharing).

Table 14. Average Sokal-Michener similarities among model variables

Sokal-Michener Correlations (N = 43)	**1**	**2**	**3**	**4**	**5**	**6**
1.Prior Ties: Time Spent						
2.Prior Ties: Work in R&D	0.73 (84%)					
3.Trust	0.52 (9%)	0.59 (12%)				
4.Commitment	0.59 (65%)	0.67 (60%)	0.64 (28%)			
5.Shared Vision	0.62 (60%)	0.61 (58%)	0.60 (21%)	0.70 (81%)		
6.Shared Objectives	0.63 (65%)	0.68 (67%)	0.61 (21%)	0.74 (93%)	0.72 (91%)	
7.Resource Sharing	0.63 (60%)	0.63 (67%)	0.57 (21%)	0.72 (88%)	0.68 (77%)	0.68 (81%)

Values in parentheses indicate the percentage of projects with significant correlation at $\alpha = 0.05$

As explained in Chapter 5, QAP routines are robust to unknown and varying amounts of row and column autocorrelation. However, unlike the Semi-Partialling MRQAP proposed by Dekker *et al.* (2007), LRQAP does not control for collinearity, increasing the likelihood of Type I errors when models are multivariate. In order to test whether collinearity was affecting the analysis, LRQAP models were compared to the results obtained in MRQAP. This test focused on assessing:

1. How similar are MRQAP and LRQAP regression model fits?
2. How often do MRQAP and LRQAP models signal the same independent variable as significant or non-significant?

To answer the first question, the model fits ran through group comparison techniques. Since LRQAP and MRQAP model fits were normally distributed (p-value ≥ 0.084 in Kolmogorov-Smirnov test, except for one case of p-value = 0.039), an ANOVA test was performed to assess their differences along with a post-hoc Tukey-B test (Table 15). Results showed that, pairwise, each respective model is not significantly different in MRQAP and LRQAP, thus suggesting that both techniques provide similar information. The similar pairs are highlighted in Table 15.

Table 15. ANOVA test and Pairwise group comparisons (Tukey-B test) of MRQAP and LRQAP regression fits for Models 1, 2 and 3 with imputed data

ANOVA Model Fit (R^2)	**Tukey's B test**	**N**	**Subsets for $\alpha = 0.05$**		
			1	2	3
F-value = 16.705 P-value = 0.000	Model 1 (MRQAP)	43	0.1884		
	Model 1 (LRQAP)	43	0.1907		
	Model 2 (MRQAP)	43		0.2931	
	Model 2 (LRQAP)	43		0.3021	0.3021
	Model 3 (MRQAP)	43		0.3490	0.3490
	Model 3 (LRQAP)	43			0.3652

To answer the second but even more critical question, the significances of the model coefficients (i.e., the p-values) from MRQAP were compared to those obtained in LRQAP. The objective was to determine how often these techniques would be in agreement regarding the significance of an independent variable. For this purpose, an agreement is achieved when either of these two scenarios occurs, given a significance value of 95%:

- Both MRQAP and LRQAP signal the same variable as significant;
- Both MRQAP and LRQAP signal the same variable as non-significant.

Table 16 presents the level of agreement across 43 research projects regarding MRQAP and LRQAP match towards signalling the same independent variable as significant or as non-significant. Accordingly, as example, for Model 1 (M1), MRQAP and LRQAP agreed, in 93% of the projects, whether Trust was either significant or non-significant to Resource Sharing. This does not mean that Trust had a significant impact toward Resource Sharing in 93% of the projects, but rather a higher level of agreement between routines, therefore offering similar findings for the role of Trust.

Considering the levels of agreement displayed in Table 16, especially for M1 and M2 (average of 96% and 98%, respectively), both LRQAP and MRQAP analyses provide highly comparable results. Since MRQAP routines were controlling for collinearity, only a very small amount of bias can be assumed in LRQAP's M1 and M2 modelling. However, it should be noted that M3 showed a much lower agreement level (average of 79%), especially in variables with directed ties (last 4 columns). These results indicate that LRQAP was not capable of avoiding significance errors likely due to a high level of collinearity. Therefore, it was decided that the study, and consequent discussion, should only focus on Model 1 and Model 2, to avoid conclusions based on potential Type I errors from LRQAP analysis in Model 3.

Table 16. Level of agreement between MRQAP and LRQAP towards signalling the same independent variables as significant or as non-significant ($\alpha = 0.05$ / imputed data models)

Model	Spent Time in Events	Prior Work in R&D	Shared Objectives	Shared Vision	Trust	Commitment
M1	98%	–	–	98%	93%	–
M2	98%	–	–	95%	–	100%
M3	93%	91%	95%	63%	67%	67%

A6. ASSESSMENT OF THE LEVEL OF AGREEMENT IN LRQAP'S IMPUTED AND NON-IMPUTED DATA MODELS

The multiple imputation procedure, described in Chapter 5, aimed at creating a dataset without missing values, a requirement to analyse networks using ERGMs and some QAP routines. However, a test was required to assess the level of agreement between model analyses with imputed and non-imputed data, as to verify if similar findings are returned in those analyses. Consequently, this test focused on answering two questions:

1. How similar are LRQAP model fits using imputed and non-imputed data?
2. How often are LRQAP analyses with imputed and non-imputed data presenting the coefficients of the same independent variables:
   - As significant or non-significant (level of agreement)?
   - With the equal direction (positive / negative), for each significant coefficient?

Answering the first question required comparing the two groups of LRQAP model fits: imputed and non-imputed. A paired samples t-test was used, since the imputation procedure was assumed as a "treatment" and LRQAP model fits were normally distributed (Kolmogorov-Smirnov test: p-value = 0.074 for imputed and p-value ≥ 0.200 for non-imputed data). The test indicates a mean difference of 0.131 in R^2, with imputed models having significantly smaller fits (p-value = 0.000). This was caused by the data imputation procedure, which was based on conserving tie distribution probability among non-respondents and not on increasing fit towards imputed models.

To address the second question, the level of agreement between LRQAP routines with imputed and non-imputed data was analysed, as performed previously in Appendix A5. Table 17 presents how often LRQAP routines agree on whether a coefficient is significant or non-significant (columns from "Prior Ties: Time Spent" to "Commitment") and how often does the direction of the coefficient change when both routines agree that a coefficient is significant (last column).

Table 17. Level of agreement between LRQAP routines with imputed data and non-imputed data towards signalling the same independent variables as significant or as non-significant

Model	Spent Time in Events	Prior Work in R&D	Shared Objectives	Shared Vision	Trust	Commitment	Change in signal direction*
M1	84%	–	–	91%	88%	–	0% (n = 58)
M2	91%	–	–	84%	–	98%	0% (n = 77)
M3	71%	76%	79%	60%	52%	67%	3% (n = 69)

* 'Change in signal direction' refers to how often two significant coefficients have opposed signals (+ and –). The value in parentheses is the total number of significant coefficients in both routines at $\alpha = 0.05$.

As per Table 17, the average level of agreement for each model was 88%, 91% and 67%, respectively. Similarly to the results in the previous appendix, M1 and M2 provide very similar information, without a single change in the direction of the significant coefficients. The level of agreement in M3 is very reduced, at it was caused by the larger amount of missing values in Model 3, which limited LRQAP's ability to avoid Type I errors in non-imputed data modelling.

This assessment reinforced the decision of focusing solely on results from M1 and M2 (similarly to the previous appendix) and showed that, despite the significant differences found in model fit, the imputation procedure did not change severely the results obtained from LRQAP analyses.

A7. ERGMS GOODNESS-OF-FIT

Two similar approaches were used to test the goodness-of-fit of the estimated ERG models. Here are visually illustrated some of the results from model 2 using project ENV-06.

The two procedures stem from the same principle: using the coefficients estimated in the ERG model, we simulate 100 networks and compare the distribution of particular properties in these networks with the distribution of the observed properties in our network. Figure 9 plots the distribution of the minimum geodesic distance (the shortest geodesic path between two nodes) of the observed network of resource sharing for ENV-06 over a box plot distribution for the 100 simulated networks. Overall, the model does a good job in identifying the proportion of nodes that can be reached by each value of the minimum geodesic distance, encapsulating the observed distribution within its range.

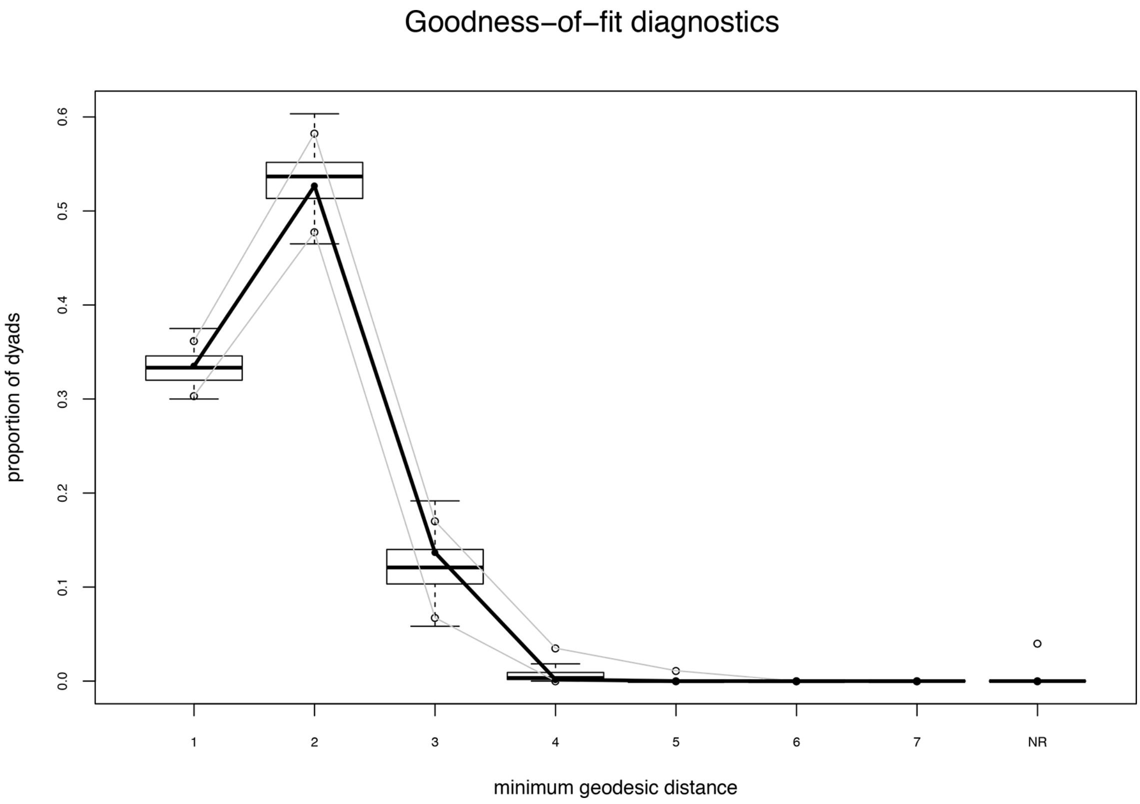

Figure 9. Goodness-of-fit diagnostics of the coefficients estimated in the ERG model

The plot compares the observed data to 100 simulated networks (generated from the ERG for model 2 and its estimated coefficients) for the minimum geodesic distance, for project ENV-06.

We were also interested to see how well the model would capture node-level properties of betweenness and eigenvector centrality or transitivity. Figure 10 plots the values for each of these measures found in the 100 simulated networks against the values in the observed network of resource sharing for ENV-06. Again, the model does a good job in predicting structural properties of the network. Not surprisingly, transitivity values bounce very closely around the observed value in the ENV-06 network of resource sharing since we included a count of intransitive ties as a configuration in model 2. We ran the same tests for all projects included in our analysis. Although model 2 seems to be a better fit in some case than others, it performed well for all projects.

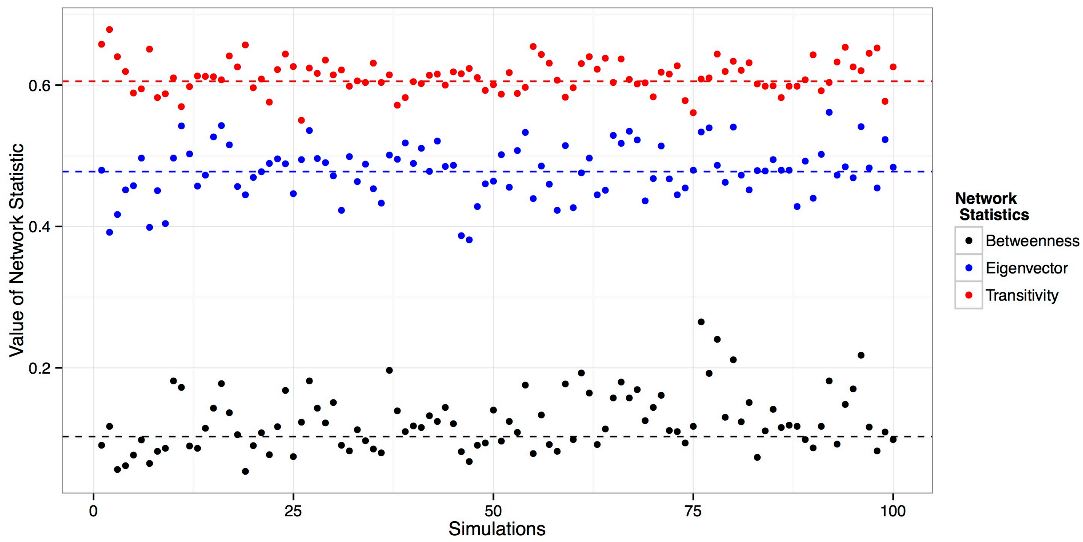

Figure 10. Statistics of 100 simulated networks produced by the ERGM Model 2 estimated for the ENV-06 project, plotted against the observed values for said statistics in the original network of Resource Sharing

A8. ROBUSTNESS CHECK: MULTIPLE IMPUTATION VERSUS ROW/COLUMN-WISE DELETION

On the main concerns of using multiple imputation of network data is the possibility of generating different local and aggregate patterns of tie formation that did not occur in reality, which we sought to avoid by using a preferential attachment algorithm in order to preserve the degree distribution of the network. In addition to this, we re-ran all the models using only complete cases to assess the robustness of the results obtained with imputed data. Therefore, we performed row and column-wise deletion of any institution that, within a project, had missing values across the rows and the columns. The summary of the ERGM results for non-imputed networks is shown in Table 18, which can be compared directly with Table 13.

The variation in network size (smaller networks) affected not only the estimation of configurations related to homophily (smaller probability of homophilous pairs), but also the statistical significance of some effects. However, we are able to compare the direction of the effect the significant configurations with those in the ERGM ran on imputed models.

Overall, the comparison suggests that the imputed networks do mimic the local patterns of tie formation that exist in the networks of complete cases. The direction of the effects is identical in both imputed and non-imputed networks for edge-covariate configurations (such as our matrices of Trust, Commitment, Shared Vision and Time Spent), only differing slightly in one project for Trust and in two endogenous configurations, but maintaining the overall tendency in the direction of the effect for both models, which lends support to the multiple imputation method and the results from the ERGM estimation.

Table 18. Summary of ERGM results for non-imputed networks (row/column-wise deletion) in terms of significance and direction of the estimated coefficients for Models 1 and 2

For each model, the columns indicate the number of projects for which the models ran (N), the percentage of projects for which the coefficient was significant, and for this subset, what percentage was positive and negative, respectively. AIC values of model fit display the median value for all projects.

Configuration	**Model 1**				**Model 2**			
	N	**Signif.**	**Posit.**	**Neg.**	**N**	**Signif.**	**Posit.**	**Neg.**
DSP (gw)	38	18.4	71.4	28.6	37	21.6	37.5	62.5
ESP (gw)	34	14.7	100	0.0	34	11.8	100	0.0
In-degree (gw)	38	2.6	0.0	100	37	0.0	—	—
Out-degree (gw)	13	7.7	0.0	100	13	7.7	0.0	100
Intransitive Triads	13	38.5	0.0	100	13	15.4	0.0	100
DE-IT	3	0.0	—	—	3	0.0	—	—
DE-UK	3	0.0	—	—	3	0.0	—	—
IT-UK	3	0.0	—	—	2	0.0	—	—
Mutuality	38	28.9	100	0.0	38	18.4	100	0.0
Homophily (country)	1	0.0	—	—	1	0.0	—	—
Homophily (role)	6	0.0	—	—	6	0.0	—	—
Time Spent	37	51.4	100	0.0	37	29.7	100	0.0
Shared Vision	38	81.6	100	0.0	37	51.4	100	0.0
Trust	35	17.1	100	0.0	—	—	—	—
Commitment	—	—	—	—	33	87.9	100	0.0
		$AIC_{\bar{\mu}}$	105			$AIC_{\bar{\mu}}$	86	