EUROPEAN UNION INNOVATIVENESS FROM THE PERSPECTIVE OF SYSTEMS OF INNOVATION AND COMPLEX SYSTEMS

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ABSTRACT

EUROPEAN UNION INNOVATIVENESS FROM THE PERSPECTIVE OF SYSTEMS OF INNOVATION AND COMPLEX SYSTEMS

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This study analyzes the innovativeness of European Union. Literature related with complex systems, Systems of Innovation, network studies, Framework Programmes and European Research Area will be used to establish a theoretical framework for a policy analysis to increase the innovativeness of European Union. First of all, this Thesis analyzes system dimension of Systems of Innovation in terms of complex systems. Secondly, it forms a database from Community Research and Development Information Service (CORDIS), Innovation Union Scoreboard, and Regional Innovation Scoreboard data to establish a European Research and Innovation Network, appearing as a result of policy and programme implementations at the European level; investigates this network in terms of the metric developed in the Thesis in order to analyze whether it is a complex system or not. Finally, the innovativeness of European Union is discussed for developing policy recommendations, benefiting from the analytical studies, derived from network analysis and notion of entropy, and theoretical discussions on complex systems,

Systems of Innovation, and network studies. Consequently, it is found that implementation of a relatively simple rule by European Commission, in addition to policies focusing on development of diversity and absorptive capacity of countries and/or regions may make important contribution to improve the cohesion and competitiveness of European Research Area, as well as the innovativeness of European Union.

Keywords: Complex Systems, Systems of Innovation, Network Analysis, European Research Area, Framework Programmes

ÖZ

YENİLİK SİTEMLERİ VE KOMPLEKS SİSTEMLER AÇISINDAN AVRUPA BİRLİĞİ'NİN YENİLİKÇİLİĞİ

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Bu çalışma, Avrupa Birliğinin yenilikçiliğini incelemektedir. Kompleks sistemler, yenilik sistemleri, ağ yapı çalışmaları, Çerçeve Programları ve Avrupa Araştırma Alanı ile ilgili yazından faydalanılarak oluşturulan kuramsal çerçeve; Avrupa Birliğinin yenilikçiliğini arttırmaya yönelik bir politika analizi yapmak amacıyla kullanılacaktır. İlk olarak bu Tez, Yenilik Sistemlerindeki sistem kavramını kompleks sistemler açısından ele almaktadır. İkinci olarak, Topluluk Araştırma ve Geliştirme Bilgi Hizmeti, Yenilik Birliği Skor Tahtası ve Bölgesel Yenilik Skor Tahtası verileri kullanılarak, Avrupa seviyesindeki politika ve program uygulamalarının bir sonucu olarak Avrupa Yenilik ve Araştırma Ağ Yapıyı meydana getirmek üzere bir veritabanı oluşturulmuş ve bu ağın kompleks olup olmadığı, Tezde geliştirilen ölçütlerden faydalanılarak incelenmiştir. Son olarak Avrupa Birliğinin yenilikçiliğinin arttırılması için uygulanması tavsiye edilen politika önerileri; ağ yapı ve Termodinamiğin İkici Kanunu hesaplamalarına dayalı analitik çalışmalar ile kompleks sistemler, Yenilik Sistemleri ve ağ yapı çalışmaları ile ilgili kuramsal tartışmalardan faydalanarak geliştirilmiştir. Sonuç olarak, Avrupa

Komisyonu tarafından ülke ve/veya bölgelerin farklılığını ve soğurma kapasitesini arttıracak politikaların yanı sıra uygulanacak görece basit bir kuralın, Avrupa Araştırma Alanında uyumun ve rekabetçiliğin geliştirilmesine ve Avrupa Birliğinin yenilikçiliğinin arttırılmasına önemli katkıda bulunacağı saptanmıştır.

Anahtar Kelimeler: Kompleks Sistemler, Yenilik Sistemleri, Ağ Yapı Analizi, Avrupa Araştırma Alanı, Çerçeve Programları

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CHAPTER 1

INTRODUCTION

With regard to innovativeness, Europe’s falling behind compared to its important rivals, or at least its lacking the desired level, is a topic that has been extensively discussed and studied in the related body of literature. In general, targets set to increase the innovativeness of Europe, or improve its competitiveness are expressed more often than not in the programmes implemented, such as FPs. In this context, the aspiration is to increase the capabilities and the capacities of the members deemed innovative and competitive, as well as to advance swiftly those levels of comparatively lesser innovative and competitive members. Many academic studies were made on the measures to be taken to realize this demand, and it seems that there are many more to come. Accordingly, rather than repetitive researches, peculiar studies with an interdisciplinary approach in the area would evidently make important contributions to increasing the innovativeness of Europe.

In this sense, this Thesis focuses on the innovativeness of European Union (EU). In order to evaluate and provide policy recommendations for increasing the innovativeness of the Union, different mainstream academic arguments and practical implementations of EU are overviewed. Basic academic framework of this study is based on Systems of Innovation (SIs) approach, which is considered complex in the related body of literature. The intricacies contained within the Systems of Innovation approach bring us to the discussions on complex systems (CSs). According to the literature, network analysis, which is also an important concept in SIs studies, is one of the principal methods to study complex systems. Not only innovativeness values, but also the network, labeled as European Research and Innovation Network in this Thesis, is obtained from the practical implementations of European Commission (EC), as the database for innovativeness and network analysis is constructed using the data from Innovation Union

Scoreboard (IUS), Regional Innovation Scoreboard (RIS), and CORDIS. Investigation of innovation and network relations is also supported by European Research Area (ERA); another practical implementation by EC. Results of this analysis become inputs for policy recommendations, based on academic discussion on systems of innovation and complex systems, for increasing the innovativeness of European Union. In accordance with framework profiled above, the Chapters of this Thesis are outlined as follows.

Chapter 2 is aimed to establish the theoretical infrastructure of the Thesis. In the first Section of Chapter 2, answers to the following questions, "what is complex system" and "what are the characteristics of complex systems" shall be investigated within the framework of this thesis without making a comprehensive review of all literature related with CSs, ranging from biology to computer science. Second Section launches a simple theoretical discussion, including basic types of networks such as random, small world, scale free, concept of robustness, etc. on network studies. Section 3 presents the basics of SIs approach. In this Section, some basic points and touchstones of SIs approach are summarized without delving into details; much effort has been spent to show relationships between SIs, CSs, and network studies. In the fourth Section, past and future of European Research Area (ERA) and Framework Programs (FPs) will be discussed. Final Section of this Chapter presents a general overview of the discussions made in Chapter 2.

European Research and Innovation Network will be established and analyzed via benefiting from data explained in **Chapter 3**. In other words, data and methodology infrastructure of the Thesis will be established in this Chapter. In this sense, three types of database, those of Innovation Union Scoreboard, Regional Innovation Scoreboard, and CORDIS, are selected as inputs for analytical analysis. How these databases are obtained, cleaned, and prepared for the analytical analysis will be described in this Chapter. Consecutively, basic concepts and methodologies to be benefited from Chapter 4 will also be explained in Chapter 3.

Analytical studies will be presented in **Chapter 4**, consisting of six Sections. In the first Section, an investigation will be made into whether European Research and Innovation Network is complex or not, in accordance with the metric developed in

Chapter 2. In the second Section, the network, where nodes are formed by countries and regions (NUTS-2), will be analyzed. In the third Section, relationship between innovativeness of countries and regions with network structure will be discussed. Fourth Section shall focus on ERA and discuss whether ERA has been on the right track or not. Network analysis and entropy calculations are used in order to analyze the innovativeness of EU in Section 5. Final Section presents and discusses a brief overview of the findings in this Chapter.

Final Chapter, consisting of two Sections, starts with the summary of discussions to be made throughout the Thesis. Subsequently, policy recommendations in order to increase innovativeness of European Union as well as further research areas shall be presented. According to discussions to be made throughout the Thesis and the results, it is found that current approach and implementations of European Commission related with innovativeness of EU and ERA are showing the tendency towards the centralization, in order to make effective and efficient planning, to prevent duplication in research activities, govern the major shares of public budget, which are criticized in this Thesis. Within the scope of the Thesis, mainly based on systems of innovation, complex systems, and network studies, two recommendations are suggested as policies to increase innovativeness and competitiveness of European Union.

CHAPTER 2

THEORETICAL BACKGROUND

To obtain theoretical base for developing policy recommendations in Chapter 5, this part of the Thesis will benefit from discussions on complex systems, systems of innovation, network studies, Framework Programmes and European Research Area. Topics mentioned, shall not only be used for developing policy recommendations in Chapter 5 but also for making analytical studies and investigating practical implementations of European Commission. Put differently, among those, studies on complex systems and network studies will be also used for making analytical studies in Chapter 4. Studies on Framework Programmes and European Research Area will also be utilized for understanding the current situation of Europe in terms of research, technology and innovation. Therefore, five topics shall be integrated and discussed to acquire a base for providing theoretical and analytical inputs to make policy recommendations in Chapter 5.

The first Section (2.1.1) of this Chapter, answers to the questions; “what is complex system” and “what are the characteristics of complex systems”. The discussion will start with a short introduction to linear systems, since non-linearity is widely argued to be a key characteristic of complex systems by the researchers of the field. In fact, a discussion on the linear approach, thanks to Newton, will serve as a springboard for diving into the complex system soup to provide some answers to the essential questions stated above. In this way, it is indented to introduce the reader the fascinating, interesting and exhausting world of complex systems, followed by a short trip into the related literature. For the purposes of this study, the aim of this sub-section is not to make a comprehensive review of all literature related with complex systems, which encompasses an extensive range of fields from biology and physics to political science and computer science; but rather, to summarize the key studies in the field in order to derive some basic characteristics of complex systems to be presented in the conclusion part of Section 2.1. This discussion shall also provide us with some sort of a metric, which, along with the related discussions, shall bring in the basic input for Chapter 3 (Data and Methodology) and Chapter 4 (Analysis).

It is possible to speak of a general divide between holism and individualism in social sciences, and both can be accepted as reasonable depending on the point of view. From the individualistic perspective, it can be stated that individuals, acting to achieve their "goals", make a choice between the availability of options and their interests, whereas the structure is "constructed" with accumulation of those individuals' interests. On the other hand, holistic view argues that structure mainly determines the individual behaviors. In the discussion on the place of complex systems in Section 1 (2.1), it will be stated that complex systems are placed as a 'midpoint between order and chaos'. In analogy with the place of complex systems, studies on networks can be considered in the midst of holism (order) and individualism (chaos), whereas network analysis itself is "often employed in complex systems analysis". In other words, structure cannot be reduced to the sum of individual behaviors and individuals can behave freely; however, this does not mean that structure has no limiting effect on the behaviors of the individuals (Granovetter, 1983). Therefore, second part of this Chapter launches a simple theoretical discussion on network studies. Instead of focusing pure mathematical explanations, this Section focuses on main types of network structures (random networks, small-worlds, and scale free networks) within the scope of Thesis. The existence of these networks is also shown by studies done with real data. After that notion of robustness concept in networks shall be discussed shortly. As a result, discussion related with networks shall be used to establish a theoretical base for Chapter 3 *Data and Methodology* and base for analysis to be done in Chapter 4.

Although concept of SI was introduced by Lundvall in 1985 (Lundvall, 2004), it is believed that roots of concept can be traced back at least to the Friedrich List´s (1841) conception of "The National System of Political Economy"(List, 1966). At the beginning, researchers focused on idea of National System of Innovation and then SIs have been categorized into different levels, which are national innovation systems, regional innovation systems, local innovation systems, technological innovation systems and sectoral innovation systems. Until now, a myriad of relevant articles and books have been published; accompanied by not a lesser amount of web pages, showing up through an internet search with the keyword 'systems of innovation'. Furthermore, today, SIs' approach is popular and most countries and institutions such as Word Bank, European Union, UN, etc. benefit from and/or acknowledge these systems as tools for policy development and implementation. In this framework, Section 3 (2.3) shall not review all types of SIs and their implementations[1], but provide in its stead, a brief overview on SIs, to have a basic understanding of the historical roots of SIs, and prepare the reader to subsequent discussion on complex systems and network analysis. Afterwards, the relationship between systems of innovation and complex systems shall be demonstrated, benefiting also from discussions made in first Section (2.1). A similar approach shall also be followed when the relationships between systems of innovation and network approach is discussed. In this way, not only the relationships among SIs, CS and network analysis shall be depicted; but also, the substantial theoretical components to be used in Chapter 4 and Chapter 5 shall be yielded.

Actually, for more than two decades, policymakers and institutions working at European level, have been developing and implementing policies and programs; providing technical and financial support in order to increase the innovativeness of EU. In fact, the current system in place that aims to increase innovativeness and competitiveness of Europe, has been analyzed specifically from the perspective of SIs and ERA, by only some authors such as Edquist (1997), Borrás (2000), and Fernández-Ribas (2009). Therefore, the rhythm of fourth Section (2.4) is a bit different from the previous ones. Here, the past and future of European Research Area and Framework Programmes shall be discussed, implying that the main feed will be from the implementation of "real politics" of EU. First, the development of the ERA and FPs shall be presented at the beginning of Section. This will be followed with an overview of the current situation of Europe vis-à-vis its

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[1] Following examples are given to demonstrate historical sources of SIs: Dosi et al., 1988; Lundvall, 1992; Nelson, 1993; Edquist, 1997; Cooke and Morgan, 1998; de la Mothe and Paquet, 1998, etc.

competitors. The discussion shall focus on the European Union with regards to Horizon 2020 and ERA in the final part of fourth Section. The need to include this Section that differs from the more theoretically inclined parts above, stemmed from the reasons stated as follows:

- The flows of information in a system and relationships between flows and structure, besides being attractive points to ponder, are also still open questions. Any study investigating into, this type of phenomena should not only focus on the constituent elements of a system, but also on the relationships among those constituents. In this sense, FPs, where information flow and structure affect each other simultaneously and continuously, present a useful example.

- Thousands of networks are formed with the contribution of Framework Programmes. In addition to their contributions to European innovativeness and competitiveness, those networks also provide the data that allows us to make network analyses.

- This data is critical for not only integrating complex system and system of innovation approaches and network analysis techniques; but also to benefit from network analysis for developing policy recommendations.

In accordance with previous studies, the discussions to be made in Section 4 (2.4) shall enable us to understand EU’s aims and anticipations from the ERA and FPs. In this way, analytical studies, including analysis of network characteristics formed by the support of FPs, can be covered with real policies within the framework of complex system and system of innovation approaches in Chapter 5.

Currently, the increasing number of actors and links among the actors; clashing regional, sectoral, national and international interests and pressures; changing societal expectations (e.g. decreasing unemployment, high income, environmental sustainability, etc.), the roles of actors, and similar factors create additional pressures on policymakers. From the perspective of the European innovation policymakers, the situation is getting ever more complex, in which, not only linkages among the nodes of SIs and active participants on these nodes are increasing, but also the expectations concerning the development of inclusive and not top-down policies are heightened. In fact, efforts of policymakers at the regional, national, and European levels can be considered as important ingredients for the emergence of an EU research and innovation infrastructure. These efforts assist both to the implementation of European level programs, like FPs, and in escalating the performance of policy coordination efforts at all levels (Caracostas and Muldur, 1998). In this light, conclusion Section of this Chapter will not only present an overview of the discussions made in this Chapter; but also discuss the use of network concept in policy analysis, in the framework of previous Sections, in order to complete the theoretical groundwork to be used in Chapter 5.

2.1 Complex Systems

Probably, a good strategy to initiate a discussion on complex systems is to approach the subject matter from the opposite way; that is, to start with a discussion on linear systems. In this sense, an argument on Newtonian (linear) view will be presented in this sub-section to draw a framework; at the very least, in order to have an understanding of what complex system is *not*. Generally, when one mentions of Newtonian science or view, s/he refers specifically to the scientific developments that took place in the 17th century. However, in view of the studies of complex system, the importance of developments realized in this period and its aftermath is mainly related with the outcome of the developments in terms of doing science per se, or the perception regarding how science should be done. In this sense, Laplace (1952), who can be considered among the most vocal supporters of the Newtonian view, states that:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

Fortunately, until now, science has not fulfilled the Laplace's dreams. Otherwise, if we would live in the world imagined by Laplace, we would find no room for chance, freedom, uncertainty, free will, etc., as everything would be predetermined. Based on Kellert's (1993) study, some basic characteristics of Newtonian view (Laplace's dream) can be summarized as follows:

First (Generality): Newtonian view believes in the existence of universal laws, which are independent from both time and space.

Second (Objectivity): Newtonian view assumes that reality exists and is independent from the observer, as a result of which objective knowledge can be obtained. Therefore, facts, as empirically testable inputs are separated from others that cannot be subjected to empirical test.

Third (Reductionism and Additivity): Universe is made of separate entities. It can be broken down into its constituents to analyze each of them in isolated conditions for understanding the characteristics and relationships with other constituents and then they can be brought back.

Fourth (Cause-Effect and Linearity): Not only entities but also relations are linear, meaning there is one-to-one interaction among causes and effects.

Fifth (Predictability): Linearity also brings predictability; if all information pertaining to the examined phenomenon were known, prediction of its future would not be a problem.

Sixth (*Determinism*): A system follows a clear path, which means that the beginning and the end are known and there is no room for surprise.

Therefore, one can mostly decompose a system into its constituents; work on each element separately with the assumption of the existence of linear, predetermined and fixed links among those; and then can gather those parts together in order to understand the behavior of the system at global level. This assumption is criticized by Casti (2002) besides others, who argued following characteristics to be the indicators of simple systems: *"predictable behavior", when* initial inputs and conditions are known, the future of the system can be deduced; "*few interactions and feedback loops"* as they consist of a few number of actors interacting infrequently, and of loops that maintain general characteristics of a system; *"centralized decision* *making"*, where power or authority is accumulated in one or a few hands; and finally, *decomposability*, denoting that the links among parts are weak and a system can be reconfigured even if it is disjointed.

On the whole, although Newtonian view has made important contribution to the progress of modern science and initiated the development of basic logical and mathematical tools (Eve et al., 1997), discomfort with this approach started to show itself, as early as the well-known three-body problem. Poincare, a French mathematician and theoretical physicist, realized that some of differential equations, though they describe the simple mechanical motions, could not be integrated in the classical sense. He argued, "It may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter, and "[p]rediction becomes impossible" (Hand and Finch, 1998). In other words, he introduced us with the *chaotic systems*, a discovery which played a critical role in the development of the modern *chaos theory*.

In addition to the three-body problem, a number of other cases also indicate the inability of Newtonian views to explain such phenomena. Among those, Heisenberg's uncertainty principle, demonstrating the impossibility of knowing both momentum and position of sub-atomic particles; or discussions on the dualistic nature of light (a particle or a wave); or the case of different vortexes created by the same water molecules, can be situated as examples demonstrating the inability of the Newtonian view. Therefore, it is safe to say that the assumptions of classical Newtonian view cannot be taken for granted as universal laws, since not all phenomena conform to these assumptions. Fortunately, as it was understood that an approach based on reducibility concept can only partly help us to deal with those systems, a door was opened to the previously ignored phenomena, to be included in modern science. For instance, life cannot be fully understood by means of chemistry, no matter how much information we obtain.

The problems faced due to the limits of the Newtonian paradigm or classical science based on reductionist approach have initiated new forms of scientific investigation, which may be considered as a conceptual transformation in science (Prigogine and

Stengers, 1984). The basic reason for this transformation can be found in the notion of non-linearity, which states that outcomes generated by actions are non-proportional to inputs. Since, these non-linear relations have the potential to produce a new emergent form of order, which can be different from the past and not be understood via investigating the residuals of the past. Conceptualization of this transformation can also be traced in the discussions on the notion of time. From the classical science perspective, based on reductionism, it can be said that the world is simple, not complex, and is governed by the time reversible universal laws, which means that a system can move backward and forward without making any differences (Prigogine and Stengers, 1984). However, from the perspective of complex systems, this is not possible, due to the notion "arrow of time" (Eddington, 1929), which, simply put, states that the future is essentially different from the past and there is no possibility to reconstruct the past from the present. The reason for this impossibility is interrelated with the notion of entropy that shall be further explained and used in this and other Chapters. Another reflection of this transformation can be seen in the approaches of Newtonian and complex system views to the investigation of phenomena. While, even in the simplistic systems, such terms as error or noise are added into models to avoid problems of predictability in Newtonian approach; from the complex systems perspective, it is this randomness or whatever that is accepted as the reason for order. In other words, inconsistencies, ignored or seen as outliers in classical views, are taken into consideration in studies of complex system approach as a potential for new order. All in all, both Bak (1997) and Cilliers (1998) argue that due to concentration on constituents such as *homo-economicus*, cells, quarks, etc. of the investigated system, we are lost in the details, which means that we ignore the interactions of constituents and their relations within the system as well as with the system's environment. Hence, this shall be the focus of the next section in order to bring us the excluded worlds.

2.1.1 An Excursion into the Literature

First and foremost, a clear statement should be made at the very start of this part that there is no consensus on the definition of what complex system is in scientific literature; in this sense, the discussions complex systems made in this thesis, as well as interpretations from literature, are subject to author's deductions. For instance, Horgan (1998) gives a list of 30 definitions of complexity collected by Seth Lloyd, which have minor differences and drawbacks. Besides the problems emerging from the nature of complex systems themselves; different nomenclatures preferred by authors for their studies (among others, science of complexity, complexity theory, self-organized critically, complex adaptive systems and complex evolutionary systems), the key characteristics underlined, and the ranging level of emphasis put on similar concepts can be considered as main sources for the indeterminacy realized in the literature regarding the studies on complex systems. This situation is especially problematic when there is a need to draw a global picture.

One of the arguments articulated by those who study complex system is the confusion in the usage of the word 'complicated', instead of 'complex'. This confusion between complexity and complicated can be traced in many dictionaries in their old prints, for instance, 'complex' simply meant "made of many interrelated parts" not more than three decades ago (Koch and Laurent, 1999). On the other hand, Shannon and Warren (1949) sophisticated the notion of 'complicated' and argued that a thing is complicated if the concepts of cause and effect can be used for explaining it. Cilliers (1998), and Martin and Sunley (2007) furthered the argument by putting that, if a system is complicated, it can be depicted by its parts, no matter how many parts the system has. Furthermore, Shannon and Warren (1949) sophisticated the notion and argued that a thing is complicated if the one-cause and one-effect relationship can be used for explaining it.

There is a growing interest towards complex systems, as can be observed in the parallel increase in the related literature with journals such as *Complex Systems, Advances in Complex Systems, Emergence: Complexity and Organization* to name a few, in addition to other references cited and listed in this thesis[2]. Along with this diversity, the author approaches to complex systems studies display a wide variance. From the positive side of the spectrum, it can be said that some authors

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[2] For a comprehensive reading list, please see; LSE Complexity Group. 'LSE Complexity Group - Units - Research and Expertise - Home'. Accessed 4 January 2012. http://www.lse.ac.uk/researchAndExpertise/units/complexity/home.aspx.

think complexity is a theory (e.g. Cachon et al., 1999); while others accept it as a science (e.g. Dent, 1999); or believe that it is a collection constituted by results, models and methods (e.g. Cohen, 1999). From the negative side of the spectrum, some authors argue that it is an over-hyped fad (e.g. Sardar and Ravetz, 1994); while others believe that it is a bunch of unsuitable transfers from physical science notions into social realm (Presti, 1996). As an epilogue to his study, Strogatz (2003) makes the statement that "[e]very decade or so, a grandiose theory comes along, bearing similar aspirations and often brandishing an ominous-sounding C-name. In the 1960 it was cybernetics. In the '70s it was catastrophe theory. Then came chaos theory in the '80s and complexity theory in the '90s."

In a similar fashion, the origin of studies on complex systems are not clear, with different references provided by various authors: some think they were started with the cybernetics and dynamical system modeling (Capra, 1997); while some believe the research that took place in Santa Fe Institute to be the instigator; others initiated it with mathematics of deterministic chaos; and some others argue that they originate with Nobel laureate Ilya Prigogine's studies on open systems (Prigogine, 1961). Obviously, this uncertainty mainly resulted from different streams of thought developed by various studies/approaches in the analysis of complex systems; which establish the basis for an understanding of the concept. A number of theories and names illustrate this situation: *General Systems* Theory (Bertalanffy, 1950), *Cybernetics* (Wiener, 1948, 1968), *System Dynamics* (Forrester, 1980), *Computational Genetic Algorithms* (Von Neumann, 1966), *Dissipative Structures* (Prigogine and Stengers, 1984), *Complex Adaptive Systems* (Holland, 1995), *Deterministic Chaos Theory* (May, 1976), *Catastrophe Theory* (Zeeman, 1977), *Synergetics* (Haken, 1983), *Autopoiesis* (Maturana and Varela, 1980), and *fractals* (Mandelbrot, 1983); to name just a few. As an inevitable result, definitions by authors of complex systems, which are already very limited, differ from one to another; however, they stay on a similar basin of attractors, as can be discerned from the following quotes:

> Complexity theory—or to be more precise, the science of complexity – is the study of emergent order in what are otherwise very disorderly systems. (McElroy, 2000)

Complex system theory is a collection of ideas that have in common the notion that within dynamic patterns there may be underlying simplicity that can, in part, be discovered through the use of large quantities of computer power and through analytic, logical and conceptual developments (Lissack, 1999)

Complex systems contain many relatively independent parts which are highly interconnected and interactive and that a large number of such parts are required to reproduce the functions of truly complex, self-organizing, replicating, learning, and adaptive systems (Cowan et al., 1994).

A complex system is an evolution generated by simple mathematical rules or physical principles that exhibits complicated, unpredictable behaviour. (Griffeath, 1992)

Complexity is the study of the behavior of macroscopic collections of such units that they are endowed with the potential to evolve in time. (Highfield, 1996)

A Complex Adaptive System (CAS) is a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. (Holland, 1992)

Complex System [is] one not describable by a single rule. Structure exists on many scales whose characteristics are not reducible to only one level of description. Systems that exhibit unexpected features not contained within their specification..3

Complex Adaptive Systems [is] macroscopic collections of simple (and typically nonlinearly) interacting units that are endowed with the ability to evolve and adapt to a changing environment.4

Complex Systems is a new field of science studying how parts of a system give rise to the collective behaviors of the system, and how the system interacts with its environment. (NECSI, 2014)

A complex system is a system for which it is difficult, if not impossible to restrict its description to a limited number of parameters or

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[3] 'Complexity, Artificial Life and Self-Organising Systems Glossary'. Accessed 2 January 2010. http://www.calresco.org/glossary.htm#c.

[4] CNA Corporation. 'Nonlinear Dynamics and Complex Systems Theory (Glossary)'. Accessed 11 April 2008. http://www.cna.org/isaac/Glossb.htm#CAS.

> characterizing variables without losing its essential global functional properties. (Pavard and Dugdale, 2002)

There indeed is a vast number of definitions in the literature that can be linked with complex systems in one way or another. However, it is not possible to put all those definitions ranging from the origin of life, i.e. genetics, to artificial life, i.e. computer sciences, in this text. In this sense, well-known authors in the area of complex system prefer to discuss the characteristics of complex systems in accord with their interests/disciplines, rather than trying to provide a full definition, which has a high potential to be incomplete as very well depicted by (Nicolis and Prigogine, 1989): "complexity is one of those ideas whose definition is an integral part of the problems that it raises". A similar approach shall be followed in this thesis by avoiding this well-known trap of making incomplete definitions. As such, before passing to the discussion on the characteristics of complex systems, some topics should be presented for a more comprehensive discussion. In this regard, the philosophical question—is CSs created or discovered—will be discussed and this discussion will be ended by relating to the concept of complex systems as perceived in this thesis, with a comparison to the previously discussed linear systems.

The basic philosophical question regarding complex systems is, whether we *create* or *discover* complexity; in other words, whether the notion complexity is *epistemological* or *ontological*. Looking for a concrete answer to this question is beyond the aim and scope of this thesis and the author is also aware of the prominence thereof in terms of its weight in the philosophy of science. Taking note of these points for the clarity of the framework of this study, it is thought that a short discussion on this topic help better understand problems around the definition and characteristics of complexity.

If the meaning of complexity changes from one author to another, where there is no separation between the observer and subject, an argument may be put on the impossibility to outline the general characteristics of complex systems. That is, "we first have to realize that complexity is an inherently subjective concept; what's complex depends upon how you look" (Casti, 2002), or "the complexity of an object is in the eyes of the observer" (Klir, 1991). With reference to this interpretation of the notion, it can be said that it is much dependent on the subjective capacities, say, if one has the sufficient intellectual capacities, s/he may have chance to realize what complexity is; and as such, there is a possibility that one day complexity of a system will decline because of increasing knowledge. Alternatively, if complexity is inherited from the characteristics of a system, implying a clear separation between observer and the subject, and it is beyond our perception, in this case, it may be argued that there is a supernatural force(s) behind the complex systems (McIntyre, 1997); or if complexity is inherited, then, as per Laplacian view (deterministic view), it may be argued that complexity may result from our ignorance, since the world is deterministic and we are not able to know that system due to our inability to provide a properly explanation of the system. Nevertheless, improving our knowledge and tools to deal with complex systems, we may grasp the mechanisms that drive complex systems.

Therefore, it may be argued that if complexity is inherited from the system itself, we should think it must be independent from the observer and/ or observation. Yet, due to lack of consensus on what complexity really is, it is difficult to find two people discussing the same system on the same terms with each other. That is to say, complex systems studies have not yet reached a sufficient level of maturity, leaving many questions to be answered. A discussion on the same system, by two people, with access to same information, still has a high potential to be inconsistent with each other. On the other hand, a number of authors known to be resorting tow a more post-modernist tendency, *e.g.* (Casti, 1995), argur the impossibility of separation of object and subject. Since, they convey that subject and object are mutually constituted, and as such, it is impossible to obtain objective knowledge.

In this sense, it may be assessed that complexity is related with how one frames the problem. Overall, it is reasonable to make the following assumption: a complexity of one part of a system cannot be more complex than whole system. For instance, if an orange and its cells are compared, one can easily say a cell is more complex than an orange; however, this statement challenges to the assumption made above. Therefore, it may be deduced that the definition of problem (or phenomenon) plays a critical role in understanding complexity. Selected model and its level of detail of it also play a role for deciding the complexity of a system. For instance, explanation of the motion of cars in traffic will be increasingly more difficult when one wants to increase precision of the motion due to problems generated by calculation errors. On the other hand, it is easy draw it on the paper, if one wants to require general explanation of their motion. Thus, preferred model and its level of detail have potential to determine what complexity is. All in all, defining the boundaries of complex system is not an easy task and it is usually determined by the purpose of the analysis and/or position of the observer (Byrne, 1998). Scale also plays a critical role for determining whether a system is complex or not. Some systems may look utterly simplistic from afar, but may get increasingly complex on closer inspection, e.g. a flower. Some systems show opposite characteristics that seem extremely complex, but come out as complicated rather than complex when decomposed, e.g. a car. Due to lack of an agreed scale to determine complexity, there is always a possibility for complex and simple systems to camouflage each other.

What can be inferred from the discussions above to understand where complexity is standing? Due to lack of a consensus on the definition and methods on complex systems, we realize different approaches regarding the interpretation of studies on complex systems. For instance, there are authors who agree on some of the basic characteristics of complex systems such as non-linearity, non-reductionism, etc.; however, what they perceive from the studies on complex systems show differences. Owing to a more postmodern orientation, Cilliers (1998) argues that complex systems have the power to increase our knowledge; however, this does not mean that they help us to obtain pure knowledge, or what they bring should not be interpreted as a kind of progress. Contrarily, coming from modernist view, Byrne (1998) argues that studies on complex systems represent a kind of progress. Anyone can select the one s/he supports from his/her understanding from the complex systems' studies. From Cilliers' perspective, it can be argued that each complex system holds numerous differences from others; in this sense, generalization of basics of complex systems is beyond any study; while from Byrne's point of view, studies on complex systems may appear as strong tools to improve our understanding on micro-macro relations.

Therefore, in a similar fashion to the style of the discussion on the characteristics of linear systems made in previous part, this thesis shall perceive complex systems as follows: **First**, it is believed that there are some characteristics shared by complex systems, and as such, there are universal characteristics. However, it does not mean that all features controlling the complex systems are the same; on the contrary, features of complex system are not independent from time and space. **Second**, in contrast to the linear view, both quantitative and qualitative methods shall be utilized in this thesis. **Third**, it is not possible to investigate complex systems via breaking it down to its constituents. However, this does not mean that there is no room for using some classical methods. Thus, it is possible to benefit from Newtonian view to study complex systems but such a kind of method could only be used as a complementary to whole study based on holistic approach (Fontana and Ballati, 1999). This situation is well depicted by Fromm (2004) as follows:

> Reductionism and emergentism are complementary and supplementary to one another, emergentism needs a grounding and a base, reductionism needs connection and coherence: emergentism without reductionism is vague and unclear, reductionism without emergentism is unconnected and non-coherent.

In this sense, both approaches can be seen two sides of the investigated phenomenon (Cohen and Stewart, 1994). **Fourth**, majority of the relationships among the constituents of the complex systems are non-linear. **Fifth**, as opposed to the Newtonian view, we cannot talk about long-term predictability. Put differently, studies on complex systems contradicts to Laplacian deterministic view, thanks to Gödel and Turing, who demonstrated the impossibility of formalizing everything occurred in the universe. Rather than expecting concrete long-term predictions, it may be much more meaningful to expect increased understanding and assumptions from science.

On the other hand, attention should be given when a social complex system is investigated with the help of developments in the positive sciences. It is obvious that there are differences between aspects of positive and social sciences: **Firstly**, the history or context of the investigated object plays critical role to determine its behavior, whereas we can easily observe repeated same behaviors in physical objects. **Secondly**, social systems are not product of only physical objects, but also of symbols such as words, ideas, etc. **Thirdly**, observer itself usually can be separated from the system in positive science, whereas the same processes are open to discussion in social science. **Fourthly**, the interpretation of interaction between cause and effect in physical objects is different from that in social systems; since there is room for individuals for self-determination. **Finally**, there is one critical point, which is that it is not enough to obtain sufficient and reliable data as well as mathematical methods to achieve a solution to a given problem/issue/phenomenon in social sciences (Eve et al., 1997). In this sense, complexity studies, in one way or another should behave like a bridge to integrate those aspects into research/analysis in social systems. Put differently, "the theory serves as a basis for the organization of the model but the data itself is also used to generate ideas in an exploratory way" (Byrne, 1998). In accord with Byrne, a number of authors in the literature, such as Capra (1997), Fontana and Ballati (1999), Prigogine and Stengers (1984) to name a few, argue that we need to change our approach to provide fresh insights about the nature and functioning of the system. One reflection of this situation, as mentioned previously, is very well articulated by Anderson (1972),

> The ability to reduce everything to simple fundamental laws does not imply the ability to start from these laws and reconstruct the universe. In fact, the more the elementary particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science, much less society.

Moreover, even if science could have established a theory of everything, would it mean that we could predict everything? According to Kauffman (1995), this cannot happen due to the necessary dependence on minor details. For him, science may explain generic properties but not every detail.

Such a discussion is also related to the way in which complex systems should be investigated. There are two important major schools, the approaches of which are usually preferred to study complex systems. One is Brussels school, based on the studies of Prigogine and his colleagues, which underlines the inability of scientific methods to study complex systems. For instance, even as a Nobel laureate, Prigogine (1997) gives nuclear physics as an example to demonstrate the inability of classical scientific methods. He argues that traditional scientific method, as pointed out earlier, emphasizes the importance of separation of object and subject for the sake of purity of experiment. However, when subatomic particles are investigated, we put a means to investigate particles, but this inevitably affects the object. In this sense, he underlines the necessity of a qualitative analysis. The second main school is Santa Fe Institute, a popular one in this field, which supports a more conventional scientific approach. Their approach is mainly based on merging computers and sophisticated mathematics to study complex adaptive systems. In fact, reflection of such a division can also be found in the social realm, as presented above in the interpretations of Cilliers (1998) and Byrne (1998).

A final word of this Section is related to the changing conditions for studying complex systems. It can be speculated that studies on complex systems have been postponed for a long time due to randomness and unpredictability associated with those systems. Avoidance from these characteristics in a study of complex systems though does not change the fact that they still exist, can be criticized but is understandable as well. Holland (1998) states that "[p]arts of the universe that we can understand in a scientific sense…are small fragments of the whole" and in parallel with this statement, Prigogine and Stengers (1984) argue that science constrains itself in small events and ignores the realms of complexity. Therefore, although complex systems have already been with us for a long time, we have just started to examine those "in a controlled, repeatable, scientific fashion" with the help of advanced technology, especially computers that are used by some researchers to "build complete silicon surrogates of these systems, and use these "would-be worlds" as laboratories within which to look at the workings—and behaviors—of the complex systems of everyday life" (Casti, 2002). According to Érdi (2007), with the development personal desktops in the mid-1980s, which enabled the virtualization of equations, many models of social and natural phenomena, based on notion of non-linearity, have started to be investigated more easily. For instance, the increase in the number of studies on fractals has been closely related with developments in computers. Fractal geometry is closely related with iteration; a mathematical tool defining the repetition of a specific process. Notion of infinity for a fractal is established with millions of iterations, a process that can be realized by computer within a few seconds but not as such by humans. Moreover, regarding the developments realized in computer science and related fields, it is possible to understand why researches and research institutions for complex systems are very young. With the development of small, powerful and affordable computers, many researchers can start studying complex systems. Yet, the current availability of computers or other tools for investigating complex systems have not cleared the mysteries on complex systems. However, there are a number of important studies that can be seen as a kind of defogger, which will be presented in the following sub-section.

2.1.1.1 *Cornerstones of Complex Systems*

Despite indecisiveness and ambiguity on CSs discussed above, there are well-known studies which played a critical role in shaping our understanding of CSs. In this sense, basic approaches and concepts will be presented in this Section. At first glance, studies articulated below may seem unrelated; however, they are in fact developed to understand this long-neglected phenomenon. The reason for this probably stems from studies developed by different researchers, including Nobel laureates, in different domains, spread over almost all disciplines including economics, computer science, biology, chemistry, sociology, political science and public administration, sociology, etc. However, this academic interest is not without its costs, in the sense that it is difficult for fresh researchers newly entering into the worlds of complex systems to select basic readings and get into grips with the vast literature. Moreover, topics discussed in this Section do not aim to make an all-encompassing summary of the related literature. Rather, they are put to present essentials of basic studies and lead the way to the bases for the imminent discussion to be made about the characteristics of complex systems.

Furthermore, according to some authors, including Horgan (1998), Cilliers (1998) to name a few, there is no theory for measuring complexity completely. In this sense, studies on complexity systems, in one way or another, should behave like a bridge between quantitative and qualitative studies; in other words, “the theory serves as a basis for the organization of the model but the data itself is also used to generate ideas in an exploratory way” (Byrne, 1998). In order to establish one of abutments, many approaches developed by different authors to understand the complexity of the system is presented in this sub-section, where general information regarding touchstone techniques and/or methods will be presented without delving too much into technical details. The rhythm of this part not only complements the arguments on complex systems, but also sets up a base for further discussions to be made in different parts of the thesis.

General System Theory (GST)

General System Theory is one of the important concepts to be benefited to develop arguments of the Thesis. According to the founder of General System Theory, Bertalanffy (1973):

> In the past centuries, science tried to explain phenomena by reducing them to an interplay of elementary units which could be investigated independently of each other. In contemporary modern science, we find in all fields conceptions of what is rather vaguely termed 'wholeness'.

To prove his argument, Bertalanffy did not only investigate several branches such as physics, biology, medicine, psychology, economics, philosophy, etc.; but also argued similar concepts and laws appeared in different branches regardless of types and properties of investigated systems[5]. His studies stimulated him to state that:

> Such considerations lead us to postulate a new basic scientific discipline which we call General System Theory... [it] is a logico-mathematical discipline, which is in itself purely formal, but is applicable to all sciences concerned with systems. Its position is similar to that, for example, of probability theory, which is in itself a formal mathematical doctrine but which can be applied to very different fields[6]…the general system conception raises new and well-defined problems which do not appear in physics, because they are not met with in its usual problems, but which are of basic importance in non-physical fields. Just because the phenomena concerned are not dealt with in ordinary physics, these problems have often appeared as metaphysical or vitalistic.

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[5] In fact, we see similar arguments in engineering studies. For instance, Theory of Inventive Problem Solving (TRIZ), developed by Genrich Altshuller, is "a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature" (Hua et al., 2006).

[6] Similar argument can also be made for the network studies as they are used to explain several issues encompassing social, information, mass, etc. exchanges.

Therefore, the originality of GST or its difference from the classical scientific approach may be found its requirements for holistic view, which requires both bottom-up and top-down approaches. In this sense, it may be argued that his study did not aim to find a general theory of everything but integrate different perspectives. This situation led some authors to discuss that both system theory and CSs overlap and complex systems may be seen as a derivative of system studies, as an 'updated' version of the system theory (Zwick, 1997). In fact, there are some notions, which are not articulated by studies on complex systems for the first time, including the notion of 'whole is greater than the sum of its parts', adaptive systems, self-organization, holistic approach, and anti-reductionism, etc. On the other hand, there are important differences between system theory and complex system studies. Basically, studies on complex systems focus on systems, which are path (time) dependent, at far from equilibrium conditions and dynamic; whereas system theory concentrates on systems which are time independent, have stable states as well as on structure and as such, the role of negative feedback is discussed much more than the positive feedbacks in system theory. Even if system theory works on systems which are open, in the sense of energy transfers, it does not take system as embedded in its changing environment as it is taken in the studies of complex system. System theory mainly focuses on isomorphism and similarities rather than differences in various systems (Érdi, 2007). CS studies not only concern quantities of flows but also qualitative change in the system. CS studies also zoom on how complex behavior emerges from the constituents' interactions and evolve over time, on the other hand, system theory usually accepts a system as given and in equilibrium, which means that changing relationships among the constituents of the system are usually ignored (Manson, 2001). While system theory considers complexity as arising from a high number of paths and their interactions (Yates, 1978); the CS view regards complexity emerging from relatively simple, localized and non-linear activities (Phelan, 1999). The most commonly cited example to demonstrate these differences is developed by Reynolds (1987) as a simulation for flocking behavior of birds, which also serves as an example for the concept of emergence and self-organization. In this simulation, birds follow three rules (Reynolds, 1987):

- Collision Avoidance: avoid collisions with nearby flockmates
- Velocity Matching: attempt to match velocity with nearby flockmates
- Flock Centering: attempt to stay close to nearby flockmates

Figure 1 Flocking Behavior of Birds
Source: Reynolds (1987)

The importance of this simulation is that the flocks of birds, following over simple rules, are able to overcome changing environmental conditions that pose obstacles, without being managed by a smart bird, and to display self-organization.

Following such a simple but attractive example, there is a need to make a definition of 'system' to be used in this thesis. A system is established by any combination of tangible and intangible constituents and their interactions. In addition to this working definition for system, another necessity arises from this effort, that is, the issue of 'boundary', which has always been a hot topic discussed in the related literature[7]. Basically, subjectivity of boundary to the observer and its potential to change over time are accepted as givens in this thesis. In other words, a boundary is determined by the observer in accord with his/her aims; specifications such as constituents, relations and structure of a system can evolve due to changes in those, if it is a dynamic system. Although these two notions, subjectivity and dependence

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[7] For instance, Cooke and Memedovic (2003) discusses the boundaries of regional innovation system as follows "[t]he boundaries of regions are not fixed once for all; regions can change, new regions can emerge and old ones can perish. Therefore to analyze a region, criteria must be found that define a functioning unit within a specific time."

on time, open the thesis to criticism of objectivity/subjectivity dichotomy, no alternative way, unfortunately, has been found by the author of this thesis to avoid this well-known trap.

Cybernetics

Another important historical root for the establishment of studies on complex systems is cybernetics, which was mainly developed by the studies of Wiener (1948), McCulloch (1965), and Ashby (1956). Aim and definition of first Cybernetics can be found in the title of Wiener's book (1948), which is "Cybernetics; or, Control and Communication in the Animal and the Machine". It mainly concentrates on how an entity, either living or non-living, reacts to and processes information (Kelly, 1994); as such, despite being a cross-cutting topic used in many fields, the essence of cybernetics is to analyze process and functions of system that has goals. Although cybernetics aimed to investigate systems, including social ones, to make them more efficient and effective, inevitably, it was dissolved, due to attributed overambitious goals. Especially in the mid-70s, another movement, dubbed as the *second cybernetics*, started to gain traction with the help of researches in different fields, especially in biology, thanks to Maturana and Varela's (1980) studies on *autopoiesis*, a notion that will be mentioned later. The second period differs from the first, on the grounds of the construction of information, which was now considered to be based on the interaction of individual and its environment, opening up an epistemological discussion due to the perception of information as observer-dependent; on the micro-macro relations; and on the communications among different systems, all of which were new contributions to the existing cybernetics theory (Bailey, 1994). All in all, the notion of "circular causal" relationships can be seen as the most important outcome of both initiatives. It considers the action of a system to cause some changes in the environment; then, the change in the environment is perceived by the system via the feedback mechanism, and the system adapts to the new conditions. In this process, within the framework of cybernetics, a critical role is played by the negative feedbacks, which is the stabilizer force and enables the system to stay in equilibrium against perturbations. This process is discussed by Ashby (1956) who calls it the "principle of self-organization". He argued that a system, no matter what type and/or composition it has, always inclines to evolve through a state of equilibrium, which we call today an attractor and where the entropy of the system decreases (which means self-organization). Another cybernetician, Foerster (2003), puts forth the argument of "order from noise", an argument which found parallels in the scientific literature by Prigogine's principle of "order through fluctuations". Foerster argues that with the increase in random noise (perturbations), a possibility of the system to rapidly achieve order (self-organization) increases.

Until now, two studies are briefly presented, both of which underline the role of feedbacks. Before moving forward in the trip to the CS-related studies, it makes sense to mention negative and positive feedbacks, which would also help understand better the studies to be presented further in this Section. In this regard, the role of negative feedback is underlined by Bertalanffy (1973):

> "[f]eed-back means that from the output of a machine a certain amount is monitored back, as 'information,' to the input so as to regulate the latter and thus to stabilise or direct the action of the machine. Mechanisms of this kind are well known in technology, as, for instance, the governor of the steam-engine, self-steering missiles and other 'servomechanisms.' Feed-back mechanisms appear to be responsible for a large part of the organic regulations and phenomena of homeostasis, as recently emphasised by Cybernetics."

The differences between positive and negative feedbacks can be succinctly put forth as follows: if reaction(s), resulted from action(s), surpasses or counteracts the action, we talk about the existence of negative feedback(s). On the other hand, if reaction(s), resulted from action(s), amplifies the action(s) or goes on the "same" direction, we speak of the existence of positive feedback(s). The importance of feedbacks for us can be illustrated with the following case: in unchanging environments, provided that the system consists of negative feedbacks, it is possible to expect from the system to stay more stable, as the negative feedback(s) brings back system to the original state (condition); however, in changing environments, a system with positive feedback(s) may have a better chance to survive/improve itself, since positive feedback(s) bring drastically different conditions/configurations.

Catastrophe Theory and Synergetics

Another important historical foothold of complex system is Catastrophe theory, developed by René Thom (1975) and especially popularized by Christopher Zeeman (1968 and 1977). Catastrophe theory stemmed from quantitative theory of differential equations and was established for non-linear systems, the behaviors of which are determined by the driving parameters. It focuses on the sudden jumps between different equilibria, or fixed point attractors, called *catastrophes*, resulted from the small changes in the conditions (environment) in the state of a certain system. The basic objection raised by the critics of catastrophe theory was made on methodological grounds. For instance, Zahler and Susmann (1977) argued that modeling techniques used in this approach may be valuable for some kinds of engineering and positive science problems but not to biology and social sciences.

Abrupt jumps from one state to another makes a topic for Synergetics as well. Synergetics, named by Haken (1983), was inspired from laser theory, where interactions of competing excited atoms led to the emergence of ordered coherent light waves. This approach focuses on synergy, interactions and interoperations among the parts of the system as well as overall structure, and behavior of the system. One of the basic aims is to find out general principles of governing rules for self-organization in open systems far from equilibrium, without being bounded by the type of nature of elements constituting the system. This approach finds many applications in different areas ranging from physics (lasers, fluids, etc.), to biology (brain, motor coordination) and computer science (synergetic computer). The basic notion behind this approach is to focus on qualitative changes at the macroscopic states.

Basic principles of synergetics can be depicted in the example of Bernard convection. Imagine a liquid is heated from below. A macroscopic behavior of liquid is determined by a specially ordered pattern due to temperature differences between bottom and top surfaces. With the increase in temperature, which is a process expanding the liquid and decrease in the weight of single molecules, the rolling movement observed in the water becomes unidentifiable. However, until a certain point in temperature, the expected upward movement cannot be realized due to internal fraction. The behavior, observed in the liquid changes, is explained by Haken (1996) as "the amplitudes of the growing configurations [which] are called order parameters. They describe... the macroscopic structure of the system". Those order parameters, which become dominant, enslave many parts of the system and this is the basic theorem of synergetics called slaving principles. In other words, while "order parameters" are describing the macroscopic pattern, at the same time, they manage the microscopic parts by the "slaving principles". In this way, bidirectional relationship between microscopic and macroscopic states can be established. Moreover, similar to the liquid example mentioned above, in some cases, constituents of the system governed by a specific order parameter and pattern to be followed is determined by initial conditions. These patterns are produced dynamically, which is a characteristic called *multi-stability*. In the end, the order parameter that wins the competition, among others, is recognized and followed by the system. Therefore, synergetics, originated from physics, focuses on finding common characteristics of systems, which attain ordered states from the disordered states via self-organization, meaning a reduction of entropy of the systems resulting with an increase in order at the global level. In short, it focuses on qualitative, macroscopic changes, whereby new structures or new functions appear.

Autopoiesis

It may be said that the most inspirational source for discussion on self-organizing came from the study of Maturana and Varela (1980). They argued that a living system has an internal process, which internally connect and produce the system, to be seen as self-organizing and self-defining. They called these characteristics *autopoietic* and the most characteristic example used to explain autopoietic system is the biological cell. In other words, "[t]he key characteristic of a living network is that it continually produces itself. Thus, "being and doing of [living systems] are inseparable, and this is their specific mode of organization" (Capra, 1997). Autopoiesis is a network of processes, in which each part participates in the production of other parts. Hence a system works like a self-production machine and boundaries of a system is determined by the system itself. Therefore, a system can be seen as autonomous or "organizationally closed". These characteristics, which are sometimes associated with the notion of homeostasis, are seen as important concepts for robustness of the system. Since, it is argued that a complex system maintains its existence with the help of both negative and positive feedbacks. However, one major criticism, regarding the autopoietic system, results from the characteristics attributed to such systems. It is argued that studies on autopoietic systems should be developed for the elimination of such deficits as extreme self-referentiality, and the insufficient explanation of the relationship between the interior and exterior of the system. Moreover, Maturana argued that he would "never use the notion of self-organization, because it cannot be the case...it is impossible. That is, if the organization of a thing changes, the thing changes" (Maturana, 1987). However, many authors do not regard this note and continue to use autopoiesis synonymously with self-organization.

Self-Organized Critically

The notion of self-organization can be used as a way to pass on to another study on complex systems, called self-organized critically, which is developed by Bak (1997), and accepted as "so far the only known general mechanism to generate complexity" (Bak, 1997). A simple example will be used to illustrate this notion. For instance, when a substance (atoms) is heated up, it starts to jiggle around more frantically. If it is heated up enough, jiggling can overcome the attractive forces, holding particles together and that is why we see a substance changes from solid to gas. However, the critical question is why this change happens suddenly; i.e. ice stays hard until it melts to water. This sudden change observed in transitions between gas, liquid, and solid phases of matter is called *phase transition*, thanks to Van der Waals. This change is critical for social sciences. Although small changes have potential to trigger small effects on the society, if the system closes to a phase transition, they have a potential to trigger huge changes in the behavior of a system due to nonlinearity. Furthermore, phase transitions are not always seen in the manner of big jumps as seen in the case of freezing or others. For example, the magnet loses its magnetization above 770 °C and keeps it under 770 °C, which is an abrupt change despite the lack of a big jump. This situation is called *critical phase transition* and the point, in this case 770 °C, is called *critical point*. "Physicists tended to regard critical states as special but unstable" (Ball, 2003); however, discussions on critical state in 1980s gained importance especially when Bak initiated the study of self-organized criticality (SOC), where a system continues its position at a critical state, which is robust. The well-known example is *pile of sand*, when grains are poured onto sand; it triggers an avalanche that occurs on all sizes in a scale free manner, which is denoted in a mathematical relation called *power law*. Bak (1997) makes a discussion on sand piles as an example to explain SOC: Consider a flat table, where sand is added one grain at a time. With the increase of a pile of sand, it becomes steeper with developing small avalanches. At one point, the slope reaches a critical point, which means it cannot rise in size any more. A stationary state is observed in this condition, where the balance of average amount of input (sand) and average slope remains constant. Moreover, the addition of a sand-grain may trigger a small or large avalanche, in an unpredictable manner. As stated by Bak (1997):

> Studying the individual grain under the microscope doesn't give a clue as to what is going on in the whole sand pile. Nothing in the individual grain of sand suggests the emergent properties of the pile… In the critical state, the sand-pile is the functional unit, not the single grains of sand.

Moreover, several modifications of the model are presented by Bak (1997), and the conclusion achieved from those, despite minor differences, was that the criticality of the systems is robust, though physical appearance of the pile changes. As a result, Bak (1997) describes complexity to be due to pervasive contingency, as a consequence of criticality, where complexity is a result of the adaptation of the elements to a changing environment; that is, individual adaptation events drive the system to a global critical state. The difference of sand pile from magnet is that while magnet escapes from the critical state, sand pile seeks to return to it. Finally, Bak argues that economic markets (like an attractor) work in a state of self-organized critically due to scale-free fluctuations seen in market. Moreover, role of critical state is also echoed in the studies of Kauffman (1995), which is called the edge of chaos (EOC) or midpoint between order and chaos is often proposed as a definition of complexity. Kauffman (1995) defines complexity as being in this EOC state of maximal complexity. Complexity is then measured as the position a system takes on the order to chaos continuum, where we measure the system's divergence or convergence from different initial conditions defining the system's potential for chaos or order respectively.

Therefore, for self-organization process, a system must contain enough differences (if there is no differences, there is no tendency to change) and active feedbacks (if there is no feedbacks, there is no need to exchange information and knowledge) among the boundaries in the system. Moreover, self-organization can be associated with history or notion of path-dependency; otherwise a system cannot react to a new situation in order to keep and/or improve its conditions. With self-organization, a system moves from a larger state space to a smaller one (an attractor), which process is accompanied with the change in entropy. During the process, many existing links, among the constituents, change and/or establish new links among constituents. Moreover, if a system is forced away from its attractor, which means if the force exceeds the threshold, "self-sustaining network of reactions will suddenly appear" (Kauffman, 1995) to decrease entropy (Kay et al., 2000).

Entropy

There are many versions of entropy and some of them, used for studying complex systems shall briefly be presented without entering into technical details, as they will be provided in Chapter 3. Afterwards, by making use of the relationship between entropy and information established by Shannon, several techniques that were developed to measure the complexity of the system based on information shall be elaborated.

This brief discussion opens with Clausius's views, who is dubbed as the grandfather of entropy (Carnot, 1960). Classical thermodynamics focuses on isolated systems that are not being influenced by the flow of energy, information and/or matter. Two basic laws, among others, are important for the aim of the thesis. The first is the conversation of energy, and the second states entropy of closed thermodynamic systems never decreases. Over time, its entropy increases until entropy becomes constant, which is observed when the system reaches equilibrium. It means that the system cannot put its own affairs in order, unless it takes "help" from outside of the system. If this process goes on, at the end, the system reaches the state of maximum entropy, in other words, it dies (Allen, 2001). Formulated by Clausius based on studies of Sadi Carnot, this law, *known as the second law of thermodynamics*, can be defined as a measure of irreversibility or of disorder in thermodynamics system or of non-convertibility, or of the amount of energy in a physical system that cannot be used to do work.

Boltzmann aimed to reconcile the time-dependent second law, with time-independent Newtonian mechanics (Planck, 1959). His study ended with the introduction of statistical explanation of the second law of thermodynamics, establishing a relationship between macro and micro states of the system. Basically, this approach says that there is low entropy, if the arrangements of particles are unique on the one hand; while the entropy is high if the arrangements of particles are not unique. Accordingly, Eddington (1929) introduced the relationship between time and entropy, with the phrase "time's arrow". He argued that entropy can be used as a measure of past and future, due to the second law. That is, entropy increases over time and it can be a means to differentiate between past and future.

Before passing the Shannon's entropy, there is another study to be mentioned, based on information, which is known as Kolmogorov's entropy (Baker, 1996). Imagine two systems, which share similar phase spaces, except for minor details. The trajectories of those systems will change through time due to dependence on initial conditions. In other words, long term prediction becomes impossible due to loss of information or increase of entropy for those systems. Kolmogorov's entropy examines the deviation between trajectories, measuring the divergence between them. If there is exponential divergence, we face with chaotic conditions according to this approach.

Discussion on randomness is Boltzmann's entropy, can be associated with uncertainty, providing a bridge to pass to Shannon's entropy (Shannon and Weaver, 1949). Developed by Claude Shannon, Shannon's entropy, also known as *information theory*, studies the capacity of a communication channel in terms of its ability to transfer information under the impact of noise. This approach is mainly based on studies by Clausius and Boltzmann. One of the basic assumptions of this approach is that information can be treated like a measurable quantity and from the perspective of Shannon's study; it is a measure of the uncertainty associated with a random variable. In other words, Shannon's entropy increases with the randomness in the system.

Shannon's study was further developed independently by A. N. Kolmogorov (1965), Chaitin (1969) and Solomonoff (1964) in the framework of dynamic systems, later called as *Algorithmic Information Theory* (AIC). It denotes "the length of the shortest program that will cause a standard universal computer to print out the string of bits and then halt" (Gell-Mann, 1995). According to Cilliers (1998), the meaning of Gell-Mann's statement in terms of measuring complexity is "the complexity of a series being equal to the size of the minimal program necessary to produce that series". The basic problem of this type approach is well-articulated by Gell-Mann (1995); "[t]he works of Shakespeare have a lower AIC than random gibberish of the same length that would typically be typed by the proverbial roomful of monkeys". In other words, following such ways to measure complexity, we can measure randomness rather than complexity, since complexity is associated with randomness in those ways. For instance, Klinger and Salingaros (*2000*) discuss that fractal structures, due to self-similarity, can be described as simple due to their requirement for computational resources or a short length of algorithm. Taking into account Haken's (2000) remarks on Gödel[8] and Turing's theorem, another problem surfaces due to the difficulty of finding a minimum algorithm, which cannot be solved in a universal fashion; it means that we cannot decide whether an algorithm or program is the shortest. Therefore, the general concern with implementing those methods on the complex systems observed in social phenomena is that the data used in those solutions cannot substitute knowledge but information only.

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[8] Gödel proved that there are problems, which cannot be solved by means of a set of rules or procedures, as they require a higher set of rules.

Furthermore, Bennet's notion of *logical depth*, based on computation-based measures of complexity for numbers, can be accepted as a first measure for statistical complexity (Bennett, 1986). Logical depth is the computational resources (time and memory) taken to calculate the shortest program that can recreate a given piece of information. For instance, model of well-defined sequence such as {XXX} can be short and simple as one instruction will be sufficient: 'type {X} 3 times'. On the other hand, if letters are arranged randomly e.g. {UYC}, several instructions are required. This approach is criticized as due to differences between the logical rules followed by computers and complex systems. This situation is well-depicted by Lloyd and Pagels (1988), who question its usefulness for physical systems, which are not encoded as numbers like in computers. As a result, basically, from the perspective of these types of approaches, random expressions are accepted as complex *(*which we don't think complex*)* and highly ordered expressions are accepted as simple.

Moreover, Lloyd and Pagels (1988) proposed the notion of *thermodynamic depth* deriving from the studies of logical depth. He argues that it is a universal measure of the macroscopic states of physical systems, or in short, "equal to the amount of information required to specify the trajectory that the system has followed to its present state". In this sense, this measurement may operate well in the wholly ordered or random systems that do not have thermodynamic depth, but can be problematic in terms of measuring and defining the evolution of the system, especially if those in question are not closed systems. Gell-Mann and Lloyd (2003) proposed effective complexity, which can only be high at the region, which is between complete order and disorder (Gell-Mann, 1995). Although this proposal seems attractive, it is not problem-free, as it "depends on the cognitive and practical interests of investigators" (McAllister, 2003); that is to say, based on a subjective interpretation of the observer. Another suggestion, came from Adami (2002 a and b), who proposed to use information for measuring complexity and utilizing *physical complexity* for this purpose, which, based on automata theory, measures "the amount of information that is stored in that sequence about a particular environment". The notion behind this approach is that the amount of knowledge stored in genome about its environment increases with evolution. In this approach, although zero complexity is associated with the lack of information of genome about its environment, there is no meaningful discussion regarding completely ordered systems.

Dissipative Structures

Like synergetics, another study, focusing on self-organization and abrupt jumps, is called dissipative structures. To explain dissipative structures, a brief discussion on types and characteristics of systems from the perspective of thermodynamics is required. As mentioned above, classical science is established around the notion of closed systems, which are in equilibrium. In general, three types of conditions are used for characterizing any system, which are:

Equilibrium Level: When a system is at equilibrium, which means the dominance of negative feedbacks, a system cannot respond/adopt/change its environment. In other words, they are closed systems.

Near Equilibrium Level: When negative feedbacks are able to keep the system at the current condition despite the attempts of positive feedbacks to change the system, we say a system is at near equilibrium.

Far from Equilibrium: In far from equilibrium conditions, we see dominance of positive feedbacks and the system can cope with internal and/or external challenges.

The most important difference between near and far from equilibriums is that while flows are linear functions of the forces in near-equilibrium regimes, flows are non-linear functions of forces in far from equilibrium conditions. In other words, the difference between those conditions can be exemplified based on Prigogine's (2005) explanation. For instance, if there are two centers, linked two paths to go from one to the other, when there is near-equilibrium, we observe both paths are crowded nearly equally, while when there is far-from equilibrium, we observe that one path may be nearly full and the other one nearly empty.

Dissipative structures, a notion developed by Prigogine (1976) and other members of "Brussels school" are open systems. When open systems are included in the discussion of complex systems, we need to focus much more on the production of entropy. Prigogine explained that sum of entropy is constituted by imported and produced entropy in open systems. In “dissipative structures”, entropy is dissipated out of the system, which process increases the organization of the system at the expense of increased disorder in its environment. The existence of dissipative structure is dependent on its openness to flux and self-organization capability for renewing itself. As such, open systems that can show the ability for self-organizing by means of exporting entropy with the help of fluctuations and work under the far from equilibrium are called *dissipative structures* (Prigogine and Stengers, 1984). In other words, a dissipative structure denotes a system which is highly organized but always in process and the existence of which depends on the flux of inputs.

Prigogine and Brussels school argue that order emerges out of chaos under far-from equilibrium conditions, characterized by a minimum of entropy production, via phase transitions at bifurcation points (Prigogine and Stengers, 1984). In other words, Prigogine and Stengers (1984) clearly state that “nonequilibrium is the source of order. Nonequilibrium brings order out of chaos”. Again, the solution before the bifurcation point does not work and new solutions appear after bifurcation point as bifurcations are seen sort of indicator for qualitative changes in the system. They argue for the existence of bifurcation point in social and economic systems, if there is autocatalytic process in those systems. Therefore his findings show that open systems, in a sense, borrow some of their “order” from outside. As stated by Lung (1988):

> Prigogine has specified conditions necessary both for the maintenance of a system away from thermodynamic equilibrium (homogeneity) and for the production of new local forms of order, counter to the second law of thermodynamics (increase in entropy).

Another important point for the discussion on complex systems is that open systems develop greater heterogeneity and complexity in contrast to closed systems, which decrease the differences and attain maximum disorder. This contradiction is well stated by Bertalanffy (1973): “[a]namorphosis conflicts with classical thermodynamics, but is in accordance with thermodynamics of open systems”. In fact, it is assumed that “organisms get better as they evolve. They get more advanced, more modern, and less primitive. And everybody knows that organisms get more complex as they evolve. The only trouble with what everyone knows is that there is no evidence it's true" (McShea, 1991). From the perspective of thermodynamics, it can be said that the decrease of entropy in open systems does not challenge the increase of entropy in the universe. It decreases in open systems and is compensated with the increase in somewhere in the rest of the universe.

Variety observed within the system is seen as another candidate for definition of complexity. It may be measured by the simple counting of types or presence of sudden changes. For instance, self-dissimilarity is accepted as a measure of complexity in Wolpert and Macready (1997). The basic notion behind this measurement is that a system shows temporal and spatial self-dissimilarity at different scales and that notion is seen as "crucial reflection of the system's complexity". They also argue that wholly different types of systems at the same time or different scales can be compared via using self-dissimilarity scales. In this sense, they find low complexity associated with low self-dissimilarity signature, and high complexity with large self-dissimilarity signature. Yer, a major challenge to this approach is made on the grounds of 'emergence', as this approach basically assumes that structure of larger scale or space can be inferred from the smaller scale or space. However, this assumption challenges to the notion of emergence.

Closed systems, behaviors of which are explainable from within, are maintained by internal forces and those are not to be influenced by external forces. On the other hand, as mentioned by the founder of GST, the majority of biological and social systems are open systems and they have to be taken into consideration without ignoring the interactions with their environment. In this sense, Prigogine (1976) makes an important remark; as he argues that the study on the systems under the conditions of far from equilibrium, open the door for integrating micro and macroscopic studies. In other words, fluctuations, usually assumed "outliers" or "atypical", can change the macroscopic conditions of the system, which means the changes in microscopic conditions. Therefore, Prigogine realized that there is close relationship between nonlinearity of the system and self-organization at the far from equilibrium condition. His findings let him to extend the argument to a philosophical discussion with underlying the inability of linear view (or dominant view in science) to explain many phenomena.

Finally, studies by Prigogine and his colleagues have brought the important notion of emergence into the discussion of scientific literature. They argued that bifurcations are the important source of emergence, which can be seen as processes associated with the qualitative changes of the system. In line with these arguments, a concise overview of emergence and its consequences shall be presented below.

Emergence and Self-Organization

Emergence and self-organization appear as a result of interactions of constituents, and those distinguish the CS from other types of systems. However, in general, both notions are used interchangeably to explain the other in the literature. In this sense, characteristics and explanations on both concepts shall be presented in this section. Discussions on their differences shall be made in Conclusion of this Chapter, also benefiting from other discussions to be made in this thesis.

Emergence is an important concept that has been considered as one of the important shocks for 20th century science (Capra, 1997). It may be speculated that it is one of the most attractive concepts for the researchers in the field of complex systems, the reasons of which can be traced in the inability of linear view and tools to consider the phenomena, as well as the opportunities provided by computers to study on emergence. Dissipation and emergence can be seen as two sides of the same coin. As discussed by Fromm (2004), dissipation decreases the order and organization in an open system. To compensate this situation, the system needs to increase its order and organization. In other words, a system needs to decrease its entropy, which is provided with the notion of emergence.

In fact, the meaning of 'whole' in the proverbial 'the whole is more than the sum of its parts' used to describe complex systems, is emergence. Accordingly, the behavior shown by the system cannot be attributed independently to actors, and to interactions of actors within the system and with their environment (Anderson, 1972). Emergence seen in global level appears as a result of local instable interactions. Bossomaier and Green (2000) articulate emergence as the point when "the system diverges from its initial state and after a transient period settles into some attractor state", which process produces new patterns and properties for the system. In other words, emergence is “the combination of elements with one another [which] brings with it something that was not there before” (Mead, 1932, cited in Mihata, 1997). Therefore, emergence refers to the global level behaviors and properties shown by the system and resulted from the interactions of the constituents of the system (Goldstein, 1999 and Holland, 1998). It cannot be determined via investigating any of the constituents or relations among those. The difference between emergence and connectivity is discussed by Casti (2002), who argues that the difference between those is determined by the nature of interactions, though “[i]n practice it is often difficult (and unnecessary) to differentiate between connectivity and emergence, and they are frequently treated as synonymous surprise-generating procedures”.

Some points regarding emergence needs to be highlighted. **First** of all, emergence cannot continue its existence if sufficient constituents are removed from the system. **Second**, emergence is not an aggregate of the constituents, which means that it cannot be obtained by summing up all constituents. **Thirdly**, there is no unidirectional relationship between emergence and constituents, which implies that emergence has impact on the constituents, with an ability to increase or decrease the freedom of some parts. Moreover, Fromm (2004) makes a distinction among types emergence, “there are different forms of emergence: temporary emergence due to fluctuations and clash of opposite forces, and other types of emergence leading to a permanent increase in complexity”. Within the similar framework, Bar-Yam (2003) separates emergence into two levels. At the first level there is local emergence “where collective behavior appears in a small part of the system” and the second level, global emergence, where “collective behavior pertains to the system as a whole”. Furthermore, Bar-Yam (2003) makes an interesting discussion on the characteristics of complex system: “[w]e can characterize complex systems through the effect of removal of part of the system”. He argues removal of small part of the system has two natural outcomes. One is “properties of the part are affected, but the rest is not affected” and the other is “properties of the rest are affected by the removal of a part”. He speculates that the second option is much more acceptable for complex systems than the first and states “[t]his concept becomes more precise when we connect it to a quantitative measure of complexity” (Bar-Yam, 2003). In addition, Holland argues that emergence may be studied either in a bottom up or top down manner (Holland, 1998).

Another notion usually mentioned in emergence discussions is *self-organization*. The most attractive part of this notion is that a system shows an internal and independent process to self-organize itself, even though the existence of external forces cannot determine process itself, which may trigger or influence the self-organization process (Mainzer, 1997 and Cilliers, 1998). The capacity for self-organization is described by Cilliers (1998) as "a property of complex systems which enables them develop or change internal structure spontaneously and adaptively in order to cope with, or manipulate, their environment". Again, the notion of self-organization can be explained using the Bernard experiment. At the beginning of the experiment, a liquid is started to be heated from the below. For a while, due to lack of relatively huge heat differences between heated bottom and cool top, we cannot observe a notable macro motion in the liquid. With the increase in the heat difference, the movement in the liquid becomes unstable, chaotic, and then turns out to be ordered, allowing us to observe notable macro motion in the liquid. Moreover, if the liquid is poured into a round vessel, we observe that hot liquid goes up at the center and cold liquid falls at the wall of the vessel. Therefore, although this process seems to be managed by external forces, it is order that appears spontaneously by way of self-organization, a phenomena which contradicts with the linear view but shows consistency with our intuitive world view.

Agent- Based Models

While working on biological self-reproduction, von Neumann (1966) established the basics of *cellular automata*, which simply consists of identical and locally interacting constituents, without using the computer. A cellular automation, studied in such different fields as mathematics, chemistry, physics, biology, geology, etc. is consisted of cells on a grid, each of which can have finite number of states, e.g. "on and "off", and can be in any finite number of dimensions. Automation evolves through discrete time steps; for instance, t=0 at initial state, t=1 at following state, and also in accord with a set of rules, which are usually mathematical functions. The most known example of cellular automata is *Game of Life*, developed by John

Conway and popularized by Gardner (1970) who wrote "[t]he game made Conway instantly famous, but it also opened up a whole new field of mathematical research, the field of cellular automata ... analogies with the rise, fall and alterations of a society of living organisms". One of the characteristics of this game was that evolution is determined by its initial states without intervention of outside. Wolfram (2002) also performed important studies on cellular automata, whose study on complex systems shall be mentioned later. In consequence, studies on cellular automata are important for the studies on complex systems due to the ability of this concept to link local simple rules, governing agents with the notions of emergence and self-organization.

Although von Neumann's study on "a kinematic automaton" can be seen as a historical example for artificial life (called *alife*) and techniques of cellular automata are extensively used in this field; it can be speculated that studies on artificial life were mainly triggered by the work of Chris Langton (1990 and 1995), who was mainly inspired from the Holland's and Kauffman's studies. Langton developed computer programs that can show lifelike characteristics such as reproduction, co-evolution, etc. This field of study concentrates on systems related with life and benefit from simulations to observe its evolution. One of the important differences of this field is that it does not only focus on life as we know it, but also on what life might (have) be(en). The reason behind this separation is that while traditional model is focusing on biological system and its most important characteristics; alife concentrates on life in order to decrypt its most basics and general characteristics. In short, it is believed by the supporters of this view that not only the physical structure, but also the process establishes the essence of life (Adami, 1998). Among others, Reynolds' (1987) above-mentioned study is arguably the most used example to discuss complex systems within the framework of alife studies.

Applications of natural evolution to the artificial systems are usually denoted with generic names such as evolutionary algorithms or evolutionary computation; with the exception of a few studies with more ambitious labels like strategies, genetic algorithms, evolutionary programming, to name a few. Holland's (1992 and 1998) works on generic algorithms, associated with Santa Fe Institute, is presented as a common example of this type of studies. A *generic algorithm* is established by individuals called *genome* that are able to encode a possible solution in a given problem space, which is usually known as *search space* containing all possible solutions of given problem. A classical process of generic algorithm is given as follows: individuals are generated randomly in accord with the aim of the research. In each step, called generation, individuals are evaluated in accord with some predefined criteria; a process called *fitness* or *fitness function*. The individuals, which will establish a new population, are selected according to their fitness. As a result, after several iterations, individuals, which have high "fitness", have chance to reproduce. Moreover, variation is introduced with crossover of two individuals via exchanging their genomes (i.e. encodings). Therefore, genetic algorithm focuses on evolution and adaptation of biological entities, though Holland (1995) extended his studies by using generic algorithm approach into ecological, cognitive, and economic systems. More specifically, process of variation, selection, and retention is a topic of this approach by means of computational model. In terms of its relation with complex systems, Holland's model concerns emergence of global scale behavior from the interactions of local agents. Holland (1998) also uses the ant example to show global behavior resulted from the aggregation of local behaviors. Although a colony can cope with many hazards by means of building blocks, which can be recombined with different patterns to cope with the new situation; the constituents of the colony, ants, usually die due to discordance of their stereotyped behavior and changing conditions.

Therefore, generally, *Agent- Based Models* (ABMs) or *Complex Adaptive Systems* (CAS) as called by the members of Santa Fe Institute, are used for simulating the actions and interactions of "autonomous" agents, which are "boundedly rational" (Simon, 1955), to understand the outcome those interactions at the global level or vice versa. In other words, it is mainly used for observing the notion of emergence and effects of emergence on the lower level. The basic motto, which is accepted by many authors benefiting from ABM is "keep it simple and stupid", first voiced by Axelrod (1997), who defines ABM as the third way of doing science vis-à-vis methods of induction and reduction. Like other computer-based techniques, von Neumann's study of a theoretical machine with the ability to reproduce can be regarded as an important milestone for ABM, and Game of Life can be considered as the antecedent of this field. However, one of the most speculative examples was developed by Thomas Schelling (1971), called *segregation model* and another one developed by Joshua M. Epstein and Robert Axtell (1996), called *Sugarscape*, which established the basis for investigating different social phenomena such as migration, trade, etc.

Casti (2002) outlines three characteristics of CAS. The first one is the number of agents. Although there is no rule to decide to whether the number of agents is high or low, he argues that "complex systems have a number of agents ... to create interesting patterns of behavior". Second is the characteristics attributed to agents, which are intelligent and adaptive. Those agents not only can take decision in line with the rules, but also change/develop rules depending on the available information. Final characteristic is local information. It is argued that none of the agents has the chance to obtain all information in a global sense and decisions are taken based on the local information available.

One of the basic arguments of authors, working on CAS, is that it is possible to find general principles that govern all CASs behaviors. To prove this, Holland (1995) argues that "[t]he best way … is to make cross-disciplinary comparisons of CAS, in hopes of extracting common characteristics. With patience and insight we can shape those characteristics into building blocks for a general theory". For this purpose, they benefit from models and simulations in order to observe similarities between different CASs, in which repeated iteration of (simple) rules in a population consisting of interacting agents leads to a global behavior.

Another well-known member of Santa Fe Institute, Kauffman, developed the NK model to understand the evolution of biological systems at the level of genes, though he extended its scope to study different fields ranging from computer science to social sciences (Kauffman, 1993). The name NK denotes N elements interacting with K others. It is boolean, as N variables take 0 or 1. Although the model assumes that the number of connections, K, are the same, the dynamic characteristics of the model mainly comes from the structure of the coupling of elements. Kauffman found two patterns, which are ordered (linear) and disordered (chaotic). Order arising from disorder in complex system is called *anti-chaos* by

Kauffman (1991) as “disordered systems spontaneously crystallize into a high degree of order”. As an interesting note on order, Kaufmann (1995) states “[o]ur intuitions about the requirements for order have, I contend, be wrong for millennia. We do not need careful construction; we do not require crafting. We require only that extremely complex webs of interacting elements are sparsely coupled.”

It means that neither too few nor too much connections among the agents lead to order. Since too few connections cause frozen behavior and too much connections cause chaos. Langton (1990) discovered a third regime, which is between order and chaos, called edge of chaos. A similar finding was also revealed by Wolfram (2002), who focuses on cellular automata. He found four classes of behavior: fixed, periodic, chaotic, and complex. The last class of behavior overlaps with the Langton studies on NK model. Moreover, having been intrigued by Wolfram’s studies, Langton (1990) developed a lambda parameter, which is a number that can be used for predicting whether a CS will fall in one of the four classes. His study let him conclude that complex behaviors can be associated with a phase transformation between chaos (where values get closer to 1) and order (where values get closer to 0). In this sense, it is believed that maximal complexity occurs at the edge of chaos, as depicted in Figure 2 . Finally, the interesting point is that, although techniques used in the study of complexity in NK model and cellular automata are different from each other, both approaches place complex behavior at the transition point between order and chaos.

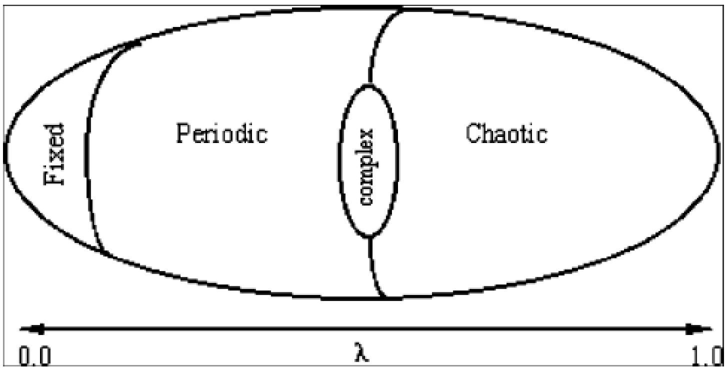

Figure 2 Langton's Behavior Schematic for Cellular Automata
Source: Flake, 1998

On the other hand, like other approaches, ABMs and/or CASs are not exempt from criticism. Among several other critiques mentioned in the literature, one focuses on the decision regarding agents to be included in the model; that is, scope of the model, which, depending on the researcher's aims like any other research activity, opens up the question of subjectivity. The relationship between structure and the process, second critique, enabling that structure is problematic when complexity is analyzed by means of modeling. Holland (1992) uses the phrase "watching the pot boil" to describe the way to be followed when a model is used for explaining the phenomenon. However, this situation raises question marks in terms of relationships between generality and modeling. Another problem is equfinality (Bertalanffy, 1973). It is possible to obtain the same structure by using different models. In this sense, caution should be paid when a model is constructed. Last one dwells on the question of validation as another major problematic area. For instance, one of the basic notions of complexity is emergent outputs at the global level. Consider what a researcher will do when faced with an emergent outcome. On the one hand, emergent outcome is unexpected and they are not foreseen during the construction of model. In this sense, should it be dismissed due to the lack of place for emergent outcome in the theoretical/preparation step is another problem. In other words, should the researcher expect the unexpected? Again, we need to validate the outcomes of model via using theories, empirical observation as well as different perspectives.

Networks

Although computerization of data facilitates study on networks, at least, studies on networks can be started with the Seven Bridges of Königsberg written by Leonhard Euler in 1736 (Alexanderson, 2006), whose studies played a critical role for the development of graph theory. Rind (1999) states very well how a complex system is generally assumed in the literature: "[a] complex system is literally one in which there are multiple interactions between many different components". In other words, the number of the connections is taken as an important factor to examine complex systems. The basic presumption is that if the number of connections is high, this system is assumed to produce chaos and if it is low, this system is assumed to be in a cyclic state or frozen state, i.e. ordered; and finally, complexity is expected from systems, which have a number of connections between those too high and too low (Kauffman 1993 and 1995; Lewin 1992; and Bak 1997 to name a few). In this sense, "we might expect systems to exhibit increasingly complex dynamics when changes occur that intensify interaction among their elements" (Axelrod and Cohen, 2000). Therefore structure of the system is deemed as important and a triggering factor for complexity. The number of connections is also considered as an important factor for determining complexity by these scholars.

Cilliers (1998) argues against rule-based approaches and offers distributed methods such as neural networks to model complex systems, underlining the importance of relationships. The reason behind his suggestion is that neural networks are entities that can get and encode information about their environment in a distributed form as well as they are able to self-organize themselves. Furthermore, he states that "to think in terms of relationships, rather than in terms of deterministic rules, is not a novelty for science, but it has always been seen as part of qualitative descriptions and not as part of the quantitative descriptions deemed necessary" (Cilliers, 1998).

Degtiarev (2000) proposes an approach aimed to analyze structural complexity of system, in which structure of the system is taken fixed. This approach is based on Q-analysis (polyhedral dynamics) developed by Atkin (1972). Degtiarev's (2000) approach is based on the investigation of how the simplices (subsets of the whole system or whole simplicial complex) are linked to each other by means of chains of connectivity. Degtiarev (2000) argues that that as an advantage his approach "can be constructed even at the initial stage of systems analysis, when a researcher has only quite general a priori information about the system, i.e. parts (elements) of the system and connections between them". However, his approach also assumes the general assumption equating high connectivity to high complexity. Another study based on directed graphs, proposed by Turney (1989) to measure complexity, argues that complex directed graphs are less stable than the simple directed graphs, whereas "[s]implicity is stability. Stability is the ability to resist damage due to random accidents". His studies remind others mentioned above, which considers the most ordered system as the most stable. In addition, the intersection of studies on graph theory and statistical mechanics (Albert et al. 2001) initiated important researches for complex networks analyses (Newman et al, 2006), scale-free (Barabási and Bonabeau, 2003), and small-world (Watts, 1999) networks, to name a few.

These achievements also sparked new expectations from network studies. Put differently, as discussed by many well-known authors, we need to take further steps to move from the structure of networks to dynamics of networks, which address at how nodes, links and overall structure of networks change over time. As stated by Orsenigo et al. (1997), "the theory of the dynamics of networks is still in its infancy and does not yet provide robust conclusions", this situation is also affirmed by Latora and Marchiori (2003):

> "[i]n fact, we have recently learned that the network structure can be as important as the nonlinear interactions between elements, and an accurate description of the coupling architecture and a characterization of the structural properties of the network can be of fundamental importance also to understand the dynamics of the system".

Overall, the acceptance of high connectivity among constituents of the systems as complex is a general problem observed in studies based on networks. That is to say, there is no difference between counting the links and counting the bits, if further assumptions are not made to measure complexity. Besides, these studies are usually criticized in terms of structure and lack of openness. One is the changes in the structure of system, which shall be taken into consideration. Since differences in connections have a potential to change the behavior of the system. Second results from the lack of input entrance to the system from the outside. This implies the necessity of a study on open networks; otherwise, focusing on closed systems only cannot be of much help to our knowledge on complex systems; nor on how they behave against external inputs. More discussions concerned with network studies in this frame will be mentioned in Section 2.1 *Complex Systems* and Chapter 3 *Data and Methodology*.

Chaos

A related and confusing study field with complex systems is chaos, mainly popularized by Gleick's (1988) best-seller work is seen in models of real systems and in idealization, rather than in the system itself (Zimmer, 1999). Its centrality in the discussion of complex systems does not only arise from numerous studies dedicated to the notion itself preceding those on complex systems, but also due to importance of the notion of chaos: "chaos is essential to the second law. If chaos does not exist, neither does the second law" Byrne (1998). To discuss chaos within the framework of complex systems, we need to separate its use into two different categories: chaos in daily use and deterministic chaos in the framework of chaos theory.

Chaos in daily use

Dictionary definitions for chaos are more or less similar: "complete disorder and confusion"[9], or "[a] condition or place of great disorder or confusion"[10]. Yet, Chaos should not be confused with randomness. Random phenomenon is not only unpredictable but also irreducible. On the other hand, when we talk about chaos in the framework of chaos theory, we are faced with the problem that although the long-term behaviors of individual trajectories share unpredictable in practice, overall behavior of the system is not. Thus, within the framework of the theory, chaos can be called as deterministic, which implies that it is not random, though chaotic behaviors can be shown by deterministic dynamic systems, whose models are usually simple and behaviors cannot be distinguished from random behavior

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[9] Oxford dictionary. 'Chaos'. Accessed 26 March 2013.
http://www.oxforddictionaries.com/definition/english/chaos.

[10] The Free Dictionary, 'Chaos', The Free Dictionary, 2 May 2013.

(Jensen, 1987). In other words, "a system in which a few things interacting produce tremendously divergent behavior; deterministic chaos; it looks random but it's not" (Langton, 1995).

Chaos in the framework of chaos theory:

A succinct explanation delineates Chaos theory as "a collection of mathematical, numerical, and geometrical techniques that allow us to deal with nonlinear problems to which there are no explicit general solution" (Çambel, 1993). Basically, to better understand chaos in this framework, we need to make a distinction between chaos in space and chaos in time. Fractal is deterministic chaos in space. A fractal is geometric figure made by human kind or nature such as a mountain, human body, a healthy old tree, etc. and has non-integer term, which makes its difference from Euclidean geometry. Some fractals show high self-similarity when they are investigated from different scales e.g. a tree, and other do not e.g. human body. Assume that an initial state of a system is divided into two regions and each divided state has the same long-term behaviors. If a system is not chaotic, the borders between states can be depicted with simple and smooth curves, e.g. arcs of circles or even straight lines. Otherwise, the curves separating two regions are called fractals, e.g. Mandelbrot set (1983), which is a well-known depiction, shown in Figure 3 .

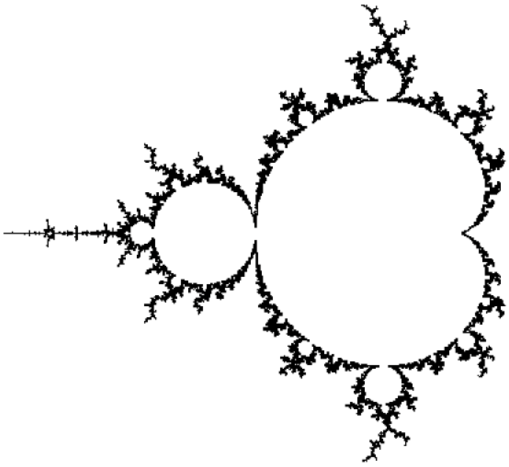

Figure 3 Fractal
Source: Mandelbrot (1983)

Another type is chaos in time. Assume two systems whose configuration change with time, known as dynamical system consisting of equations and variables. Even if these systems have the same characteristics, they differ from each other exponentially due to sensitivity to initial conditions. The basic characteristic of deterministic chaos in time is its sensitivity to initial conditions, discovered by Poincare working on the three-body problem, popularized with the notion of "butterfly effect" developed by Lorenz (1993). It basically says that even the smallest fluctuations in air pressure somewhere have a potential to trigger huge changes in air in another part of the world. Because of this chaotic process, the accuracy of prediction will decline as the time goes on from the moment of prediction. To predict the weather conditions, scientists/researchers need to know the finest details. However, this is impossible; in other words, they cannot monitor every butterfly flapping its wings. A classic example given to deterministic chaos is double pendulum. When two pendula make a little a journey from their rest point, they behave like coupled and show regular periodic behavior. However, the longer the journey made by those two pendula, the more the non-linear relations seen between their behaviors. In other words, both show different type of behaviors and look random, though they are exposed to the same external forces. Érdi (2007) gives an example for chaos in time, which is U.S. presidential elections held in 2000, in which, a small design change in ballot papers made by the designer residing in Palm Beach consequently required the Supreme Court decision to determine the winner of the election. Finally, in terms of relationship between chaos in space and time, it can be said that a fractal is a product of long (relatively) time-chaos action. Therefore, "a system with orderly disorder" (Kellert, 1993) is called *deterministic chaotic system*. Since, although a system looks like deterministic, it turns out be completely unpredictable, due to the existence of non-linearity and sensitivity to initial conditions.

Another concept related with studies on deterministic chaos is attractor, which is important not only in terms of its role in understanding deterministic chaos but also due to its relation with the complexity of the system. In other words, complexity of the system depends on what its attractor allows (Rocha, 1998), since "[d]ynamical systems are attracted to attractors the way fireflies are attracted to light" (Çambel, 1993). Definition of attractor is related with the notion of state space[11], which is the set of all possible states of a system, with the description of behavior, where a system acts as if it were attracted physically to a region called basin of attractors, which environs attractor, throughout time (Kay, 2000 and Flake, 1998). In other words, trajectories of complex systems in phase spaces depict patterns, which depend on initial conditions, relationships among the constituents, values, norms, etc., and those patterns converge into a specific area in the phase space over time. As an illustration for the concept of attractor, imagine a ball, which stayed at the top of the hill and started to roll downs towards the valley. Although we do not know its velocity, mass, etc., it will reach at the bottom of valley – attractor. These areas are called attractors and when a system enters into the attractor; its freedom to get to the states outside the attractor is reduced. At the same time, due to increasing information (or decreasing uncertainty) about the system state, its entropy (Shannon's measure of uncertainty) decreases.

Therefore, we can say that a complex system locates itself around the attractor in a way which allows its opportunities to self-organize against perturbations. Moreover, "[t]he stability of an attractor is proportional to its basin size, which is the number of states on trajectories that drain into the attractor" (Kauffman, 1991). It means that different basins of attraction drive the system into different directions as well as large attractors are relatively much more stable than small ones.

In an effort to sum up the discussions made above on deterministic chaos and related notions, examples used by Williams (1997), prove to be simple yet very useful to understand the overall notion. These examples are also usually given to demonstrate how linear systems may become complex and then chaotic only by changing the key parameters. Therefore, imagine a standard logistic model of population growth, which looks very simple:

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[11] Çambel (1993) argues that "if x, y, z are distances, their derivates will be velocities. However, the state variables may be other entities, such as population or economic indicators. Spaces made up of states and their derivates are called phase spaces. The two terms are frequently used interchangeably, and this does not do any harm as long as we know with what we are dealing."

$$X_{t+1} = aX_1(1 - X_t) \quad (1)$$

where future population (X_1+1) depends on the current population (X, 0<X<1) and the growth rate parameter (a, 0<a<4). Based on May's (1976) study, the notion of attractor can be explained using this formula. When the parameter values range from 1 to 3, interestingly, the population settles on a value, 1-1/a, no matter what the initial size of the population is. In other words, when a=2,5, after several generations, we observe that the population settles on the value 0,6. So, the value 1-1/a is called an *attractor*, a value to which system variables is attracted over time. There are other attractors for this system. One is population expanding, seen when a>4, where X approaches infinity; and the other is population dying, when a<1, where X becomes 0.

The notions of positive and negative feedbacks can also be explained using that simple formula. In this case, when the population settles on the attractor 1-1/a, we can observe the notion of negative feedbacks, since negative feedback brings the system into its initial conditions. On the other hand, when population grows infinitely (or dies), we observe the role of positive feedback. Due to self-reinforcing characteristic of positive feedback, values cannot turn back to initial values.

By using the simple formula above, the notion of sensitivity to initial conditions can also be demonstrated. As seen from the discussions, small changes in the value of a between 1 and 3 (1<a<3) makes small changes on the overall results. Moreover, the system turns out to be completely insensitive if the value of is less than 1 (a<1) or is more than 4 (a>4). However, when the value of a ranges from 3 to 4 (3<a<4), we can observe the notion of sensitivity to initial conditions, as the system oscillates between multiple attractors. The small shifts in value lead population to move throughout cycles of bust and boom, which means that the periodicity of the population changes completely, even though the shifts in the initial conditions are minor. Finally, there is a value, where a equals to 3.8 (a=3.8), population variable X, becomes completely chaotic and random without any discernible attractor. From the perspective of chaos theory, this system is not chaotic indeed, since a single deterministic equation governs the apparent random behavior; so this system is called *deterministic chaotic*. As a summary of above discussion, it can be stated that:

- At $a \leq 1$, there is fixed attractor with the value 0
- At $1 < a < 3$, there is fixed attractor whose value is over 0 but less than 0.667
- At $3 < a \leq 3.569946$, the number of attractors as following 2, 4, 8, etc., which means that fluctuations are realized in accord with the number of attractors.
- At $3.569946 < a \leq 4$, the system is in chaos state, where there is no noticeable order.

All in all, why chaos is important for us? Except for their beauty, a critical expectation from the studies on fractals is that if a mechanism is discovered in an observed scale, this may let us understand other scales as well (Mandelbrot, 1983). However, self-similarity may pose important problems for complex systems, as evaluated in the discussions on chaos in *Conclusion* of this Chapter. In terms of chaos in time, knowing the exact initial conditions helps us only to know a little more about the system for a little more time due to dependence on initial conditions, which means long term predictions are not valuable as it is expected from the studies based on Newtonian view. In fact, sensitivity to initial conditions can be considered as an important factor, undermining reductionism. Since, due to existence of uncertainty at the beginning of the process, we cannot predict the trajectory of the system even if we know current state of a system. For instance, consider the science of meteorology. The topic of this branch is weather, which is completely unpredictable in the long term. However, meteorologists can make good forecast for short periods as they have already realized the characteristics of systems and so they try to improve their models to make greater understanding of particular complex phenomena. In this sense, it makes sense to work on the alternative situations of the investigated topic based on complex systems framework. For attractors, it can be speculated that an investigation on attractor regarding its dynamics and forms helps us to understand complex systems, and correspondingly Çambel (1993) states that "chaos theory…can provide guidance for short-term prediction under certain circumstances when the attractor has only few dimension." However, it is still problematic to define low-level rules that play a role in the appearance of type(s) of attractor. Therefore, by means of investigation of attractors, we can obtain knowledge regarding complex systems, though we cannot know precisely what will occur in the system (Byrne, 1998).

2.1.2 Conclusion

Despite the indecisiveness and ambiguity surrounding the field as discussed above, there are well-known studies that played a critical role in the establishment process of how complex systems are discussed in the scientific literature. For this purpose, an overview of the concepts and properties discussed shall be presented in this Section. In order to discuss and present the characteristics of complex systems based on an extensive review of the related literature, a *triplex* structure is proposed; in the sense that each helix in this triplex structure has affected and been affected by each other. One helix discusses basic requirements to make up a CS necessary to initiate any related discussion (T1); the second tier helix argues the distinct properties of CS that distinguish it from ordered and chaotic systems (T2); and the last helix strand focuses on the requirements for maintaining the complexity of the system (T3). At the end of this Section, it is aimed to present a comprehensive account on the basic characteristics of complex system. These characteristics will be used for establishing a metric to argue whether the system appeared as a result of Framework Programmes is complex or not in Chapter 4, *Framework Programmes and ERA*.

T1: Basic conditions for CS:

First of all, any talk of the CS requires a minimum of sufficient constituents. However, there is no linear relationship between the number of constituents and complexity. That is, at least theoretically, a minimum of two constituents are sufficient to initiate a talk on the possibility of complexity. Since, if they have enough diversity in their internal system and if they establish sufficient variety of interactions between each other, there is a possibility for complex behavior. In general, the increase in the diversity of the system creates more opportunities for the system to cope with challenges and helps develop resilience, for instance, against possible attacks. Moreover, while the increase in diversity provides an increasing fitness of the system in its environment, at the same time, it may cause a decrease in its global performance. Alternatively, redundancy (or tightly coupled constituents) provides more opportunities for keeping the existing conditions or alternative paths to establish similar building blocks for the system in a known environment. Yet, this advantage may turn out to be a disadvantage when unexpected conditions appear, due to the lack of flexibility.

Secondly, the interactions among constituents are not enough if they are linear. In other words, majority of interactions among the constituents should be non-linear, but this does not exclude the existence of linear relations. Moreover, these interactions should carry such notions as information, knowledge, etc. to others. Otherwise, it is not meaningful to focus on the importance of relations.

Thirdly, the type of links, i.e. *weak* or *strong*, plays an important role for complex behavior. The dominance of strong ties in the system may be associated with high degrees of interdependence among the constituents, as seen in ordered systems. Alternatively, the dominance of weak ties among the constituents in the system may be linked with the low degrees of interdependence among the constituents. This situation may be linked with chaotic systems. The balance between both types of ties among the constituents with the predominantly weak ties can be associated with complex systems. This issue is also underlined by Kaufmann (1995) "[o]ur intuitions about the requirements for order have, I contend, be wrong for millennia. We do not need careful construction; we do not require crafting. We require only that extremely complex webs of interacting elements are sparsely coupled."

Fourth, shared institutional infrastructures such as norms, values, beliefs, etc. among the constituents are not only important in terms of creating a basis among the constituents, realizing such behaviors as cooperation, coalition, competition, and conflict (Gharajedaghi, 2006) in general; but also shared institutional infrastructures can act as attractors, providing consistent and purposeful behaviors for the whole system. However, shared institutional infrastructure does not necessitate completely dependent elements, but rather it means that they interact with their environment and act relatively independent from other constituents.

Fifth, Holland (1995) argues for the aggregation of the local non-linear relations, which triggers the emergence of global level complex behavior. For instance, as discussed above, Holland uses ants as an example for aggregation, where individual ants die due to several hazards, though their local non-linear relations results in a global level complex behavior that lets the colony to survive. Moreover, it is possible to talk about several aggregations at different levels, which is a notion related with the concept of building blocks (Holland, 1995). It means that an aggregation at one level consisted of building blocks stemming from low level non-linear relations may serve as an input for an upper level aggregation. This level also serves as a building block for higher level, which process paves the way to hierarchical organization.

Sixth, starting at least with studies on Cybernetics, the role of direct and indirect feedbacks has been emphasized well in the literature related with complex systems. Feedback is the process whereby some portion of the output will be returned into the system as input(s). One of the feedbacks is negative feedback that keeps the system at given conditions or has a stabilizing effect, which keeps the system at its current attractor. In this sense, as discussed above, systems are accepted under the influence of negative feedbacks, which are at equilibrium or near equilibrium. The other one is positive feedback, which carries the system from given conditions to another set of conditions, or moves to a new attractor due to bifurcations, and that is why a system at the edge of chaos is considered to be under the dominance of positive feedbacks. Stacey (1995) suggests that when a system is in equilibrium, there is no need to spend much effort to keep the system in its current condition; whereas, when a system is at far from equilibrium, a huge effort is required to keep the system in its current position, which means that a relatively little effort is required to change it. In this sense, a balance between positive and negative feedbacks is required for complex systems to keep their robustness.

Seventh, another prominent characteristic is the structure of the system. In contrast to centralistic hierarchical authority, distributed control based on links among the agents over the agents is seen in CS. In such a kind of structure, agents continue to dialogue with others as much as in accord with local information/knowledge. In other words, there is no single point in the system that manages global behavior, though it is possible to control the actions of constituents. Furthermore, structure is also related with the boundary of the system. In accord with Byrne (1998), defining the boundary of complex system is not an easy task and is usually determined by aim of the analysis and/or position of the observer. However, determination of the boundary between a system and its environment should not be perceived as a demarcating sharp line; on the contrary, it should be accepted as permeable. In other words, rather than approaching the notion of boundary as a strict line that separates the system from the rest, it should be seen as gate that provides interaction between the constituents and system, and the environment.

T2: Distinctive Characteristics

Basically, it is the concepts of emergence and self-organization that distinguishes the CS from other types of systems. However, in general, both notions are used interchangeably to explain the other in the literature. In this sense, first, some criticisms by the author on the definition of emergence will be presented. Then, characteristics attributed to both concepts will be outlined, which have already been discussed scattered in different parts of the text. Finally, the difference between the two concepts will be portrayed.

In terms of emergence, two important points that need to be elaborated. First, it is argued that if a characteristic is not shown by the constituents of the system (micro-macro relations), that characteristic should be called as emergence. However, if everything is made of atoms or smaller particles, in this case, we have to interpret almost everything as emergent. Secondly, if a characteristic shown at global level cannot be explained from the constituents and their interactions, that characteristic is called emergent. However, this type of approach to the concept of emergence brings the discussion made above; i.e., is complexity created or discovered? For instance, Crutchfield (1994) argues that lack of knowledge at this moment prevents us to understand emergence from the constituents and their interactions. However, via increasing knowledge, one day there may arise a possibility for us to be able to explain emergence from the constituents and their interactions. In terms of self-organization, basic misunderstanding results from the relationship between system and environment. That is to say, self-organized systems are not isolated systems; they are organizationally closed but they interact with their environments for information, energy, etc. The key point is that they have complete autonomy, meaning, decisions are taken by such a system itself.

Besides these concerns, there are some characteristics shared by both concepts. Probably the most notable paper, which compares and contrasts those concepts is written by Wolf and Holvoet (2005). Basically, the aim of the paper is “to propose a working definition of both concepts” (Wolf and Holvoet, 2005). In this sense, the author of this thesis has no objection to their intentions to make “working” definitions, since this is totally at the discretion of the respective researchers. On the other hand, some of the characteristics they attributed to the concept of emergence and some others to self-organization, are considered to be problematic according to the reading made by this author, and also do not comply with the findings of the argument made in this Section. For the sake of the argument, the definition and attributions made by Wolf and Holvoet (2005) are presented briefly as follows:

- "Working definition of emergence": "A system exhibits emergence when there are coherent emergents at the macro-level that dynamically arise from the interactions between the parts at the micro-level. Such emergents are novel w.r.t. the individual parts of the system." To explain this definition more detail, they discuss "the most important characteristics found in literature" regarding the concept of emergence. These are:
- "Micro-Macro Effect:" A micro-macro effect refers to properties, behaviors, structures, or patterns that are situated at a higher macro-level and arise from the (inter)actions at the lower micro-level of the system".
- "Radical Novelty: The global behaviour is novel w.r.t. the individual behaviors at the micro-level, i.e. the individuals at the micro-level have no explicit representation of the global behavior".
- "Coherence: Coherence refers to a logical and consistent correlation of parts".
- "Interacting Parts: The emergents arise from the interactions between the parts".
- "Dynamical: In systems with emergence, emergents arise as the system evolves in time".
- "Decentralized Control: Decentralized control is using only local mechanisms to influence the global behavior".
- "Two-Way Link: In emergent systems there is a bidirectional link between the macro-level and the micro-level".
- "Robustness and Flexibility: Emergents are relatively insensitive to perturbations or errors… flexibility makes that the individual entities can be replaced, yet the emergent structure can remain".

Another discussion is made on the working definition of self-organization and characteristics attributed to it. For Wolf and Holvoet (2005), self-organization is a "dynamical and adaptive process where systems acquire and maintain structure themselves, without external control”. In terms of attributed characteristics, they argue with self-explanatory notions: “increase in order”, “autonomy”, “adaptability or robustness w.r.t. changes”, “dynamical, i.e. far-from-equilibrium” (Wolf and Holvoet, 2005). Despite the invaluable contribution by their discussion, as it is a very rare attempt, one point needs to be highlighted as the problematic area of this paper. All characteristics that they attributed to the concept of emergence can be discussed in the framework of self-organization as well. In other words, those characteristics are not exclusive to emergence but can also be attributed to the concept of self-organization. Take a human being as a case, who is able to self-organize him/herself under normal conditions. Changes in micro level, e.g. cells, construct the global behavior such as structure, patterns, functions, etc. This global behavior can also be radically new for the individual behaviors at the micro level. For instance, the ability to talk via the voice made by the vocal instruments of the body is a new behavior for the eyes, which are specifically deployed for the task of seeing. Moreover, except for cancer cells or similar, it is unreasonable to expect a combination of unrelated cells through interacting with each other to establish a higher-level building block within dynamic conditions. The body is not only controlled by the brain, but also by the local actors and there exists bidirectional relationships between those. Finally, minor damages in brain, the organization of which is distributed over a network of interacting neurons, does not prevent the brain to realize its functions and the damaged part is made up for the rest of the brain, though different parts of brain is specialized in different tasks.

Consequently, emergence and self-organization should appear due to interactions of constituents, and this outcome should have effects on the constituents. A behavior should result from evolution of the system and it should change in accordance with the evolution of the system. Yet, it should keep its characteristics until next bifurcations. A behavior that appears at the global level is to be unique, which means it cannot be shown by the constituents, as “the whole is more than the sum of its parts”. There is no authority or similar power that controls the behavior arising at the global level. Alternatively, lack of authority should bring both robustness and flexibility to the system. It means a system should be able to replace a part, the non-existence of which triggers problem for the system to continue its existence. Put differently, a system has to have a relatively high capacity to resist errors and perturbations. This capacity stems from three notions: First, those systems are flourished on fluctuations and randomness; second, relatively sufficient redundant paths, which makes up to distributed part(s); finally, balance of negative and positive feedbacks. Therefore, as discussed above and the in main text, there are many points shared by the concepts of the self-organization and emergence, which is a view rejected by Wolf and Holvoet (2005) stating "[b]ecause emergence and self-organisation each emphasize very different aspects of the system behaviour there are few similarities" as the reason.

Again, a critical point is how to distinguish between those concepts, if there are many similarities among others. The concept of emergence is the appearance of establishment of a behavior, structure, property, pattern, etc. at the global level with the spontaneous interaction of local constituents. It is the difference between the coming out and the rest at one time. However, it is the concept of self-organization that determines what the rest will do with the new one to become more organized without taking orders from the outside. In this sense, self-organization can be understood as an adaptation capability of the system to continue its functionality. Put differently, a system may reject the emergent or accept it via changing or not, so on and so forth, in accord with its own requirements, demands, necessities, etc.

Wolf and Holvoet (2005) assert "[b]oth phenomena can exist in isolation and they can co-exist in a dynamical system". Yet, the question to be asked is, can a system be called complex if one of those phenomena is absent? Regarding the discussion made in this Thesis, emergence can be analogized with chaos, and self-organization can be analogized to a system at near equilibrium. Again for Wolf and Holvoet (2005),

> Research in the multi-agent community and the complex adaptive systems community focuses on such systems. In very complex (multi-agent) systems, i.e. distributed, open, large, situated in a dynamic context, etc., the combination of emergence and self-organisation is recommended.

Regarding both quotations, it may be speculated that complex systems require both concepts, none prevents us to talk about CS. That is, existence of one is necessary but not sufficient to discuss CSs.

(T3) Maintaining Complexity:

As discussed earlier, complex systems stay between order and chaos; a *locus* denoted with different labels such as far from equilibrium (Prigogine and Stengers, 1984), edge of chaos (Holland, 1995, 1998; Kauffman, 1993, 1995; Langton, 1990), self-organized critically (Bak 1997). To keep its position in this locus, a complex system does not only depend on itself, but also on the outside. In other words, as noted in *Dissipative Structures* sub-section, "order" in complex systems is as much dependent on the environment of the system as it is on the system itself. To stay between ordered and chaotic regimes, it requires inputs such as energy, information, materials, etc. from the outside. These inputs, which have relatively low entropy, are used by the system and then exported to the outside of the system. From one point, it may be argued that dependence on the external inputs makes system weaker and more sensitive to outside. However, from the other side, these inputs make the system more capable for developing, growing, changing, and adapting. In this sense, flows and perturbations are important notions for CSs to survive. Moreover, a system's internal complexity, among others, depends on external complexity (Jost, 2004). In this context Bar-Yam (2003) argues that internal complexity of the system should be equal, at least, to the complexity of its surrounds (also known as Ashby's (1956) "law of requisite variety").

Another important notion is variety in complex systems. As discussed earlier, increasing variety is one way to increase complexity. In this sense, complex systems need to increase their internal variety as much as possible, even at the expense of lowering performance of the system. As variety is a notion directly related with evolution, CSs have to evolve to continue their existence at the edge of chaos, which provides abundance of stationary states to select one. However, selected alternative may bring the system into the zone of order or chaos, where overall performance of the system decreases or vanishes. To avoid both insufficient variety and wrong selection, a system needs three characteristics: flexibility, robustness and resilience. Flexibility is required to enhance system's capability to rearrange itself, to attain self-maintenance, and to adopt to changes its environment. Although it is difficult to determine what kinds of relations and constituents will increase the robustness of the system, as the notion is related with the feature of persistence of the system, increasing variety and flexibility seem to be a more attractive alternative to increase the potential of the system to survive. Finally, resilience, with the concept of robustness, makes a system relatively less sensitive to perturbations, and more capable to repair itself. Therefore, complex systems, staying between the ordered and chaotic states, can display robustness, adaptability and flexibility; however, at the expense of difficulty in control, low predictability, and even low performance.

As previously mentioned, complex systems lie between ordered and chaotic systems. However, there is a possibility for a system to fall out of its position, as not all non-equilibrium conditions supports continuity of the system; which means that some systems turn out to be chaotic or ordered. Prigogine compares a town and crystal to for a demonstration of dissipative structures (Prigogine, 2005). Following this example, it can be speculated that due to changing conditions, a system, similar to the town example, moves out of far from equilibrium conditions. It may move towards the *ordered* or *chaotic* conditions. If it moves to ordered conditions, the system may turn out to be closed system, which means energy and information can pass but matter, or isolated system, which means nothing cross its boundaries. Except for isolated conditions, a system may get rid of this condition, since energy and information may be driving power for the system. On the other hand, a system may move to the realm of chaos. In this case, with the help of the spontaneous process (emergence) of self-organization, a new survival strategy emerges from disorder (Kauffman, 1995).

In this sense, a need arises for a brief explanation to distinguish between CSs and Chaos Theory. This difference is clearly stated by Reitsma (2003):

> Chaos Theory deals with simple, deterministic, non-linear, dynamic, closed systems. They are extremely sensitive to initial conditions resulting in an unpredictable chaotic response to any minute initial difference or perturbation. Complexity Theory focuses on non-linear and open systems. Complex systems respond to perturbation by self-organizing into emergent forms that cannot be predicted from an understanding of its parts.

Characteristics of chaotic system is well stated by Çambel (1993) as

> (a) The system must be nonlinear and its time series should be irregular; (b) Random components must exist; (c) The behavior of the system must be sensitive to initial conditions; (d) The systems should have strange

> attractors, which generally means that it will have fractal dimensions; (e) In dissipative systems the Kolmogorov entropy should be positive; and (f) Perhaps the terse way of pronouncing a system to be chaotic is to determine that there are positive Lyapunov coefficients.

Therefore, taken in this light, chaos points at a system with a relatively low freedom, as its behaviors are determined in a nonlinear way which affects and amplifies the impact of initial conditions, resulting in its unpredictability; whereas, complexity is a relatively ordered condition with a higher degree of autonomy in which phenomena are determined by the numerous interactions among the constituents.

Again, a brief discussion on the concept of chaos regarding its role in the study of complex systems is needed. There are three important notions obtained from the studies on chaotic systems; chaos in time, chaos in space, and attractors. Chaos in time, also known as the butterfly effect, helps us to understand the ineffectiveness of long term predictions, which is discussed in previous sub-section with the example on the science of meteorology. It may be deduced from the chaos in time, modeling and simulation are prerequisites for dealing with complex systems. Second one is chaos in space, or fractals. Self-similarity characteristic of fractals may be accepted as an important catalyst for studying chaotic systems. On the other hand, when one takes into consideration characteristics of complex systems such as emergence, requirements for variety, etc., s/he can realize that if the number of fractals increases in the complex systems, this may bring important problems for the existence of CS. Finally, attractors are accepted important indicators for determining the characteristics of the chaotic systems. However, when the difficulties in the determination of attractors as well as of local rules triggering the emergence of those attractors are taken into consideration, by investigation of attractors, we can obtain knowledge regarding complex systems, though we cannot know precisely what will occur in the system.

All in all, complex systems, which can be traced back in modern times to the studies of GST, Cybernetics and Artificial Intelligence, starting from 1950s, appeared in the scientific literature in one form or another. Particularly, cybernetics and GST played a critical role for the establishment of a systemic approach. While GST underlined the importance of holistic approach, cybernetics mainly introduced the importance of negative feedbacks for the systems. Although GST did not aim to develop universal and generalizable models, it was understood in this direction. Inevitably, the developments of GST were locked-in to this type of discussion. On the other hand, cybernetics, like GST, argued the decomposability of systems, which can be understood via investigations of components in isolation as well as it is believed, in general, there were linear relations among the constituents. Afterall, both studies played critical role for the introduction of systemic approach into scientific literature; however, both were criticized for their overambitious aims.

During the 70s and 80s, Chaos theory became overly popular. Like previous approaches, researchers of chaos tried to implement their findings in almost all areas, aiming to develop universal principles, which are omnipresent ranging from sub-particles to social systems. Attractors, in particular, were used to explain phenomena. Throughout the 80s, in the hey-day of chaos studies, complexity and chaos were usually used as interchangeable terms, although they are rather different concepts, as emphasized earlier. On the other hand, dynamic systems, which evolve and self-organize, were started to be discussed increasingly in this period. In this sense, the concept of "autopoiesis" set an illustrative example for the dynamic systems. In addition, contrary to previous studies, inadequacy of reductionist approach and importance of non-linear relations were underlined boldly by the researchers. Likewise, the notion of open systems was welcomed in the studies, which initiated much more discussions on concepts such as entropy, information, bifurcation, emergence, etc. Many important studies such as Synergetics, Catastrophe Theory, Dissipative Structures, Self-Organized Critically, etc. were started to be discussed in different fields. While Synergetics, Dissipative Structures, Self-Organized Critically used both deterministic and stochastic models as well as role of fluctuations to explain phenomena, Catastrophe Theory stayed purely deterministic, which was not welcomed as much as the others in the literature.

After the establishment of Artificial Intelligence, different techniques based on the basics of Artificial Intelligence started to develop. Among others, studies based on cellular automata, Genetic Algorithm, Artificial Life can be seen as important cornerstones for the establishment of Santa Fe Institute, where complex systems are called Complex Adaptive Systems. At the same time, an important distinction from the past studies emerged, as a consequence of the wider availability of powerful computers. Especially starting from the late 1990s, computers have started to be used extensively. This process, especially, initiated development of ABM and/or CASs studies. CASs aimed to find shared characteristics among different CASs by means of highly developed mathematical techniques and extensive use of computation. Moreover, the importance of computers in terms of studies on CS is that it enables virtualization of many mathematical models and concepts, including emergence. This step has opened the door for social systems, e.g. SIs, since interactions of constituents and micro-macro relations started to be more easily modeled and virtualized.

At least for over the past three decades, there is a trend against the approaches called ‘meta-theory’ or “theory of theories’, etc. in social sciences. Concerning the penetration of studies on complex system into different fields ranging from molecular biology to sociology, complex system theory is the latest potential candidate for critiques. In this sense, as a growing and interesting field of study, complex system approaches are grappled with the generalization and specification. In other words, if a lesson learnt from one study in a discipline is implemented in another discipline without concerning the specific characteristics of the new discipline, such an approach would lead the studies on complex systems to become a theory of everything. On the other hand, without sharing and inferring general results found in different disciplines, this situation would lead the studies on complex systems to become too specific at the cost of drawing general conclusions. This danger is grasped by Wolfram (1983) who drew attention to the future of complex system studies. He states that

> Complex systems theory is now gaining momentum, and is beginning to develop into a scientific discipline in its own right. I suspect that the sociology of this process is crucial to the future vitality and success of the field. Several previous initiatives in the direction of complex systems theory made in the past have failed to develop their potential for largely sociological reasons.

Therefore, while a study of the systems of innovation from the perspective of complex system is conducted in this thesis, the embedded traps in the field mentioned above, shall be taken into consideration due diligently.

Finally, a metric to be used in Framework Programmes and ERA parts of Chapter 4 is presented below:

1. Sufficient number of constituents
2. Non-linear rich interactions among constituents
3. Sufficient interdependence among the constituents
4. Existence of positive and negative as well as indirect feedbacks
5. Existence of emergence and self-organization at different levels
6. Continuity of its existence under far from equilibrium conditions (or at the edge of chaos or self-organization critically)
7. Rich internal diversity
8. Evolution and adaptation
9. Dynamic characteristics
10. Cooperation, coalition, competition, and conflict behaviors among the constituents
11. A distributed memory and learning ability
12. Dominance of local information without excluding global information
13. Lack of centralized authority and distributed structure in terms of resources, relations and feedbacks, etc.
14. Autonomy (organizational closure)

2.2 Network Studies

Although there are valuable studies based on network approach aiming to reveal the patterns seen in the system, studies on complex system that make use of network approach are not mature yet or has not been accepted as a major approach in the study of complex systems (Watts, 1999). Then again, the notion of network and of network analysis has received considerable attraction from different research fields such as mathematics, physics, sociology, organization theory, management, health, etc. in recent decades with critiques about its abuse (Grandori and Soda, 1995). This increasing interest may be attributed mostly to the methodology offered by the network analysis, that is, the examination of the relationship among the constituents and structure. Network analysis methods have been developed not only as a combination of several theoretical progresses in different disciplines such as mathematics, statistics, social theory, and computer science; but also as a combination of practical studies, i.e. data examinations and tests to develop a model in order to explain the observed phenomenon. Among others, the following concepts can be seen as the main building stones of this approach: (1) actors and their behaviors are not independent; but on the contrary, they are accepted interdependent; (2) links (relations) among the actors are accepted as channels for transferring/sharing tangible or intangible things such as information, knowledge, energy, materials, etc. Moreover, using a network analysis, it is at least expected to understand: (a) the main characteristics of network; (b) distinctive types of network; and (c) dynamics of (over) the network. Therefore, actors and their relationships; the emergent structure (political, social, economic, SIs, etc) as a result of those interactions; evolution and impacts of those relations on actors and structure are the main concerns of network analysis.

Within the framework provided above, this Section basically deals with the question of "how", so that it focuses on one of the methods to be employed in this thesis, which shall be put into practice in Chapter 4. In this sense, a theoretical discussion – except for basic formulas or symbols related with network studies, all arithmetic operation and formulas are left to Chapter 3– will be made on the network studies.

2.2.1 Basic Studies

Birth of studies on graphs can be traced back to Leonhard Euler's solution to the Königsberg bridge problem published in 1736. The modern conception of the network studies today can be traced back to the studies on social networks started in early 1920s and focused on the relationships among its constituents. Wellman's (1926) study on the students' choice of companions; Mayo's 1930 work (mentioned in Roethlisberger et al., 1939) on the social interactions among workers; Moreno's (1934) analysis of the friendship networks within a small group; and Rapoport's (1957) mathematical model on friendship networks of school children can be given as examples for studies conducted in this initial period.

Moreover, developments in data acquisition, storage, management, computing, and virtualization abilities, as well as in the capacities and capabilities of computers have enabled and motivated the researchers to develop and propose new concepts and methods related with networks studies, in an extent unimagined in previous decades. The publication of two seminal papers in particular, those by Watts and Strogatz on small-world networks (Watts and Strogatz, 1998), and by Barabási and Albert on scale-free networks (Barabási and Albert, 1999) sparked a plethora of studies on networks, in a variety of topics ranging from biological to visual networks. Among these, a number of important studies, also benefited from in this thesis, are worth mentioning: Strogatz's *Exploring Complex Networks* (2001) article made important discussions on networks dynamics; both Albert and Barabási's (2002), and Dorogovtsev and Mendes' (2002) studies investigated different growth models via using statistical mechanics; Newman (2003) discussed the structural properties of networks and developed models and measurement techniques; as well as Watts (1999) and Hayes (2000a, 2000b) made important discussions on the structure and the dynamics of small-world networks. Moreover, Bornholdt and Schuster's *Handbook of Graphs and Networks* (2003), Pastor-Satorras et al.'s *Statistical Mechanics of Complex Networks* (2003), Ben-Naim et al.'s *Complex Networks* (2004), Pastor-Satorras and Vespignani's *Evolution and Structure of the Internet* (2004), Newman, Barabási, and Watts' *The Structure and Dynamics of Networks* (2003) are well-known books in the field, which investigate networks from such different aspects as evolution of networks, structural characteristics of networks, researches in fields ranging from intangible (e.g. WWW) to tangible (e.g. biological) networks, as well as discussion and presentation of some earlier important papers. Some studies became best-sellers of their own right; such as, Buchanan's *Nexus* (2002), Barabási's *Linked* (2002), and Watts' *Six Degrees* (2003). Finally, there are books written for specific topics: Bollobás' *Random Networks* (1985) and *Modern Graph Theory* (1998), West (1995) and Harary (1969) on graph theory; Wasserman and Faust (1994) and Scott (1991) on social network analysis; and Cormen et al. (2001), Sedgewick (1998) and Ahuja et al. (1993) on graph algorithm, especially for computer applications.

The ostensible simplicity of representing relations by mapping a network with nodes and links led to a torrent of studies on networks in many fields such as WWW, neural, social, biological studies, etc., which have been used for explaining structural, functional or other relationships among the constituents of the network. This representation, of course, is a very strong approximation when time, space and other dynamics influencing the nodes and links are taken into consideration. Nevertheless, even such a simple but helpful approximation provides important information about networks. Studies conducted in many different topics, triggered the need to move beyond reductionist approaches, and revealed that most of the real networks display some similar characteristics despite their inherent differences. Accordingly, among others, high clustering coefficient, small path length, and shape of degree distribution (fat tail) can be given as shared characteristics. These characteristics distinguish the real networks from the regular and random graphs studied in mathematical graph theory. In this regard, Meyers (2009) suggests at least two major reasons for such distinction of the notion of "complex networks" from graph theory. First, it differentiates from the previous graph studies by not solely depending on the theoretical framework; as one can focus on real and measured networks. Secondly, studies using real networks show important differences from the "classical random graphs" of Erdős and Rényi, (1947; 1959), explained below.

Therefore, the entire system operated collectively by all nodes and the ways in which patterns of relationship operate among constituents of the network become the main points of interest for understanding the structure and behaviors of the networks today. Thus, concentration mainly on patterns and relationships among constituents rather than just on constituents is the key to network approach or complex system studies, as presented in the previous Chapter, which concluded that the self-organization and emergence were important. Similar findings on complex systems by linking to the studies on networks are given in Meyers (2009)**:**

> "A few concepts explaining complex network structures were developed. Two of them – self-organization and optimization – were extensively studied during the last years. Modeling the creation of complex network structures is mostly based on these concepts. A significant part of real networks are evolving, usually growing networks, which strongly differ from equilibrium nets".

Thus, the key to a study of a network lies in the combination of two notions: structure and patterns, in addition to dynamics. When a structure is analyzed, things are measured and weighted. However, when a pattern is studied, it is mapped to analyze relationships. Finally, when a dynamics is studied, changes are taken into consideration. In this sense, structure contains quantity, pattern contains quality, and dynamics contain both quantity and quality. Under this light, the following part shall explicate the essential studies related with networks, which are used for analyzing the European Research and Innovation Network in Chapter 4.

2.2.2 Network Models

A number of network models focus specifically on reconstructing the functioning or evolution of real systems, among which those by Erdős and Rényi, Watts and Strogatz, and Barabási and Albert, come to the fore as the primary studies. Erdős and Rényi studied the random graph, which constructs a complex graph using a set of N disconnected vertices, where links are added with probability p to each pair of vertices (Erdős and Rényi, 1959; Bollobás, 2001). As a result, for large N the degree distribution follows a Poisson distribution with average degree $k = p\ (N - 1)$ and average clustering coefficient $c = p$; however, these random graphs, although uncomplicated, do not provide an appropriate model for the real networks because of their characterization with "heterogeneous connections and an abundance of cycles of order three" (Watts and Strogatz, 1998).

The problem of lack of cycles of order three (clustering) seen in the random graphs is overcome by the small-world networks developed by Watts and Strogatz; however, this approach cannot provide a "non-uniform distribution of connectivity" (Watts and Strogatz, 1998). A small-world network is constructed by starting off with a regular lattice of N vertices where each vertex is connected to k nearest neighbors, which process is followed by rewiring each link randomly with probability p; for which $p = 0$, there is an ordered lattice with high number of cycles of order three but also with large average shortest path length; and for when $p \rightarrow 1$, the network becomes a random network.

Barabási and Albert developed the scale-free network model (a.k.a. BA model), in order to explain the uneven distribution of connectivity observed in some real networks, taking two rules as the basis: growth and preferential attachment (Albert and Barabási, 2002). The model starts with a set of m_0 nodes, a growth of the network is observed as new nodes are added at each step, where for each new node, m new links are inserted which connect the new one to previous nodes. The selection of these new vertices with new links inserted is done based on a linear preferential attachment rule; that is, the probability of new node to link to an existing node is proportional to the degree of existing node. After this short introduction three main network models—random, small, and scale-free—will be discussed further in following pages, where a comparison among these shall be provided, as well as, studies focusing on types of networks will be examined.

2.2.2.1 Random

Erdős and Rényi (1959) focused on networks observed in communication and life sciences, suggesting that those networks can be modeled via linking nodes with randomly placed links. As such, their work renewed interest in studies on graph theory, especially on random graphs[12]. Erdős and Rényi (ER) defined random graph as N labeled nodes, which are connected by n links selected randomly from N (N-1)/2 possible links. Random graph is generally established in the following ways: Beginning with a set of N isolated nodes, links are added successively. During this process, graphs are obtained at different stages with increasing probabilities (p) and in the end, a full connected graph is obtained where n= N (N-1)/2 at p=1. The critical question in random graph studies is that at which connection probability (p) particular property of the graph can be obtained. The success of Erdős and Rényi is that many of the important characteristics of random graphs appear suddenly, which implies many graphs show some characteristics at a given probability. In other words, at a critical probability $p \approx 1/N$, random graphs change their topology suddenly from a loose collection of small clusters to a single giant (order) which

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[12] The term *random graph* is used to refer to the disordered nature of arrangements of links among the nodes.

dominates the network, due to the availability of communication among the whole system with a low cost requiring for few numbers of links per node. Furthermore, despite the random placement of links, random networks show a "democratic" link distribution: Most nodes will have approximately the same number of links. Indeed, in a random network, the nodes follow a Poisson distribution with a bell shape, and it is extremely rare to find nodes that have significantly more or fewer links than the average.

On the other hand, real networks usually differ from the random networks in terms of their degree distribution, which do not follow a power law. That is to say, random networks cannot explain the scale-free characteristics of real networks. For a better representation of real networks, ER model is extended in several ways, which approaches are usually called *generalized random graphs*. Among others, a non-Poisson degree distribution may be the most discussed approach in this type of studies, in which "the edges connect randomly selected nodes, with the constraint that the degree distribution is restricted to a power law" (Albert and Barabási, 2002) However, these scale-free random graphs show similarity with ER random graphs in terms of topological transitions (Newman, 2001), path length, and average clustering coefficient (Newman and Watts, 1999).

Random types of networks are investigated in different domains such as ecological (May, 1976; Cohen, 1978), genetic and metabolic (Kauffman, 1993), etc. However, inconsistency with the real networks leads researchers search for other types of network that may better explain the real networks.

2.2.2.2 *Small-World*

Studies on a vast number of networks revealed another important type of network (Watts and Strogatz, 1998; Newman, 2000) called *small-world property*, in which we observe the existence of shortcuts among the nodes, despite of their often large size. In fact, the existence of short-paths among nodes was first examined by Milgram in the 1960s (Milgram, 1967; Travers and Milgram, 1969; Korte and Milgram, 1970). In the experiment, Milgram asked randomly selected people in Nebraska to send letters to the individuals, identified only with their first names, vague locations, and occupations in Boston. Milgram saved the track of paths followed by the letters and found that a letter can achieve its final target with approximately six steps, though the general expectations for hundreds steps. Therefore, Milgram's study (Milgram, 1967; Travers and Milgram, 1969), though no actual networks were set-up in these experiments, gave the important message: 'we live in a small world and we are only six steps way from each other', in other words, short paths exists in the real networks. Similar experiment was also conducted by Dodds et al. (2003) using e-mails, the results of which confirms those of Milgram's experiment.

The small-word property has been found in many real networks (Watts, 1999; Watts and Strogatz, 1998; Newman, 2001a; 2001b), which is often linked with presence of high clustering, meaning a high value of clustering coefficient. Therefore, in their seminal paper, Watts and Strogatz (1998) described the small-world networks to have a small value of path length L, like random graphs, and high a clustering coefficient C, like regular lattices, as depicted in Figure 4. In other words, their model stands between an ordered, finite-dimensional lattice, in which clustering coefficient is independent from the size of lattice, whereas path lengths are long; and a random graph in which clustering coefficient is not independent from the size, but the value of the path length is similar to the path length value of real networks. Furthermore, when $p = 0$, each node has the same degree K in Watts and Strogatz (1998) model. However, with the increase in p, the degree distribution is broadened while keeping average degree equal to K. Finally, when $K > 2$, "there are no isolated nodes and the network is usually connected, unlike a random graph which consists of isolated clusters for a wide range of connection probabilities" (Albert and Barabási, 2002).

Characteristics of path length change in accord with the changes in p, as discussed by Watts and Strogatz (1998), the fast drop in the path length is the indicator of shortcuts among the nodes, which has an important impact on the characteristic of the path length of the whole graph. In other words, even if there are a small number of shortcuts among the nodes, we have a possibility to realize an important decrease in the path length; though locally the network is still highly ordered. Small-world networks, in addition to their short path length, have a relatively high clustering coefficient; however, although high clustering is a clue for SW, it is not sufficient on its own (Dorogovtsev and Mendes, 2002). When a network is regular, we obtain high clustering coefficient and when the network is random, we obtain very low clustering coefficient. However, between these two networks, we obtain high clustering coefficient and short path length, as seen in Figure 4 .

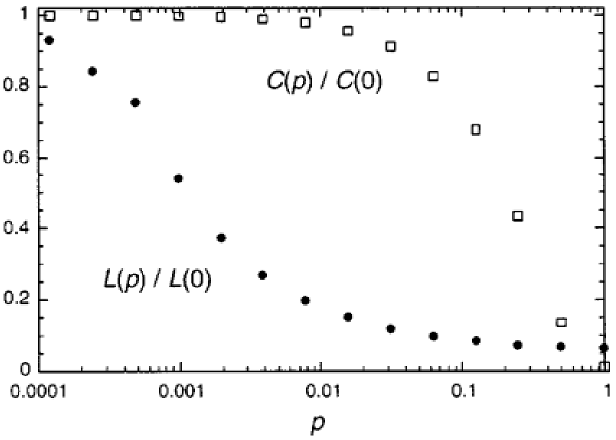

Figure 4 Watts-Strogatz Model
Source: Albert and Barabási, 2002.

Watts and Strogatz (1998) were the first to attain success in generating a graph with a small path length and high clustering coefficient. The process behind Watts and Strogatz's (1998) model is briefly as follows: Begin with a ring lattice having N nodes, in which each node is connected symmetrically to its first K neighbors. Rewire links each other randomly with probability p and delete duplicated links, which process produces long range links. In accord with the value of p, the network moves from random (when p=0) to regular (when p=1), depicted in Figure 5 .

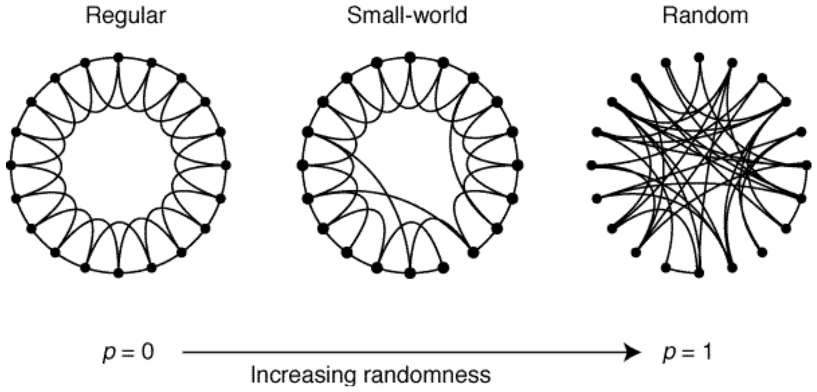

Figure 5 Random Rewiring Process of Watts-Strogatz Model
Source: Albert and Barabási, 2002.

Therefore, small-word networks gain efficiency when a network has few global links connecting local clusters consisting of large number connections. In a sense, small-worlds can be accepted as more economical than both regular and random networks due to their intrinsic characteristics (Latora and Marchiori, 2003). As another important outcome, Milgram experiment, as mentioned by Newman (2003), implied that ordinary people are rather successful in finding those short paths, which is to say small-words are much more suitable for navigation than both regular and random networks (Barabási and Oltvai, 2004), provided by weak ties (Granovetter, 1973; Lin et al., 1978). Moreover, these types of networks help us to understand two important notions; homeostasis and robustness, detailed below. However, a portion of WS (Watts and Strogatz) model turns out be disconnected due to the rewiring process. Because of this, Newman and Watts (1999) suggested a new model in which links are added with a probability instead of rewiring. Nevertheless, the main problem, the unknown rewiring probability p—if exists— in real networks, was not solved in the new model. In other words, although characteristics, short-path length and high clustering, can be obtained from WS model, degree distribution "more closely resemble the Poissonian degree distribution of random graphs than the scale-free degree distribution of real networks" (Christensen and Albert, 2006), which means that the small-world model becomes insufficient in terms of explaining the high variance of node degree.

2.2.2.3 *Scale Free*

While random and small-world can be accepted as models developed to obtain the correct topological characteristics of networks, scale-free model put the emphasis on the dynamics of the networks. In other words, the basic notion behind the scale-free network is that if one gets the dynamics of the networks mimicking the ruling dynamical mechanisms, s/he can obtain the topology of the network correctly. As seen in many examples regarding real networks, they are scale-free, meaning that their degree distribution follows a power law[13] for large k.

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[13] Power law is an important topic also in the discussion of complex systems; especially in the notion of 'self-organized critically'.

De Solla Price (1965) focused on network of citation between scientific papers and found that both in-and-out degrees have power law distributions, naming this finding as *cumulative advantage*. Then, Simon (1955a) discussed the appearance of power law when "the rich get richer" (Simon, 1955b). Today, the basics of cumulative advantage is used under different names, usually called *preferential attachment* in network literature (Barabási and Albert, 1999).

Barabási and Albert (1999) established their model through focusing on US power grids, Hollywood actors and World Wide Web (WWW)[14] on the notion of power-law degree distribution. They put forth two reasons for this distribution and argued that coexistence of those reasons is a prerequisite for their model. First, they argued that the number of nodes, which are randomly connected as seen in ER random model or rewired as seen in WS small-world model, are not constant; in contrast, networks grow in accord with the increase in the number of links and nodes, like WWW or publications. Second is related with the connection probability. It is assumed in both ER random and WS small-world models that the probability of connecting two nodes is free from the nodes' degree. By contrast, in real networks, this probability is not independent. In fact, we observe *preferential attachment*; which means that a node joining to the network does not link in an accidental manner, but tend to join to the existing popular node (hub). That is to say, the probability of connecting to a node in the network depends on that node's degree. For instance, web pages give link to other popular ones (high degree).

Regarding the basic characteristics of Barabási-Albert (BA) scale-free model, average path length in this model is smaller than that in random model, which implies the probability of two nodes close to each other is higher in scale-free networks than in the random networks with the same size and average degree. Clustering coefficient

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[14] Interestingly enough, Broder et al. (2000) reached a similar conclusion with a different interpretation of their own results in their study on WWW. They argued that if one removes all nodes with a degree greater than five, the web can be destroyed. As a result, they concluded that web was very safe against targeted attacks, seems to contradict with the result of the BA model. Both results are indeed parallel rather than contradictory to each other, as the number of nodes with a degree of greater than five makes only a small portion of all nodes.

is a less investigated issue in scale-free networks than Wattz and Strogatz model. However, “clustering coefficient of the scale-free network is about five times higher than that of the random graph, and this factor slowly increases with the number of nodes” (Albert and Barabási, 2002). Moreover, most studies on networks conducted in the previous decade show that many networks have a similar degree distribution. In other words, although some networks such as world-wide air transportation (Amaral et al., 2000), or distribution of power lines and substations in the North American power grid (Albert et al., 2004) demonstrate exponential degree distributions, many real networks, as exemplified below, have degree distributions and are scale-free, meaning that the degree distribution is power law[15]:

$$P (k) \sim Ak-y \tag{2}$$

where P is probability, A is a constant ensuring the P(k) values sum to 1, and the degree (k) exponent is γ .

2.2.2.4 *Real Networks*

In order to provide some concrete insight on the subject, a selection of studies that focused on complex networks to understand real networks will be presented below.

World Wide Web (WWW) and Internet Networks: The WWW and the Internet are interesting networks in at least two aspects: first, reliable data can be obtained although they have large sizes and their exact topologies are not known; and second, they are self-organized networks (He et al., 2004), for instance content and links of a web page is determined by its owner. The World Wide Web, despite its rather recent emergence, is a huge network with an almost uncontrolled growth through interconnected pages created by individuals and organizations; hence, comprises a challenging topic in complex networks studies. This uncontrolled characteristic makes it difficult for the search engines to map the WWW completely. Such web maps, created by “crawler” programs that identify the source and target of the web pages, are generally considered as directed networks in which each link

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[15] Regarding scale-free network, degree distribution means there are few nodes—usually called *hubs*—having a large number of links and large number of nodes having a few links.

points from one node; that is, the page containing the hyperlink, to another, the referenced page; or in some cases, web pages are taken at site level instead of pages and as such, sites are considered as nodes whereas sites are connected when a hyperlink exists between them. Due to the fact that WWW links are directed, two degree distributions (in-degree: receiving links by a node; and out-degree: outgoing links from the node) are used for the characterization of this network. Some studies consider WWW as a scale-free network, such as Albert et al. (1999), Barabási and Albert (1999), Barabási et al. (2000), and Donato et al. (2004). In their study of a network constructed by 325,729 pages from the nd.edu domain, Albert et al. (1999 and 2000) confirmed that its out- and in-degree distributions follow a power-law of the form, with exponents $\gamma_{out} = 2.45$ and $\gamma_{in} = 2.1$, respectively. Another study on a larger web map of 200 million pages by Broder et al., (2000) and Donato et al. (2004), yielded a $\gamma_{in} = 2.1$. PageRank, a webpage ranking method based on random surfer method used by Google search engine, gives values that follow a power-law distribution with exponent 2.1. Adamic (1999) studied the small-world effect in the WWW using 250,000 sites that present a high average clustering coefficient and low average distances between nodes. Using nd.edu web map, Bianconi et al. (2008), observed that WWW has more short loops than its randomized version, pointing as such at the small-world effect. Web-based social networks are studied by analyzing the networks of personal pages that hyperlink to other such pages of acquaintances, friends, etc., such as blogs. A study on the connectivity properties of a 200,000-page Chinese blog space showed a scale-free degree distribution and the small-world effect (Fu et al., 2006).

Internet, on the other hand, is the network of physical links among the computers and other constituents of it. The topology of the Internet is studied at two levels. One is the inter-domain level (autonomous system), in which each domain consisting of several routers and computers is accepted as a node and physical connectors are the links; the other is the router level, in which routers are accepted as nodes and physical connectors as links. Being among the earliest and most studied subjects in the field of complex networks, the Internet has various topological and dynamical features identified, which include a power-law degree distribution, the rich club phenomenon, disassortative mixing, etc. Accordingly, a number of models have been proposed for the Internet to reproduce some of its properties, whether experimentally or observed. Due to their constantly changing and decentralized nature, the internet maps are incomplete; however, the results of analyses made using such maps are consistent, yielding recurrent features, such as power-law degree distribution, small path length and high clustering as seen in Table 23 in Appendix. Although there still remains a more accurate methodology for data collection, the Internet studies in their current form, may benefit a lot from the recent discoveries and findings of the complex network studies.

Social Networks: Social relations established among people are among the key notions in understanding the cultural and economic changes in a given society since the ancient times in human history. All those hidden and evident human relationships provided the framework for such types of networks as social, political, diplomatic, and cultural networks, as well as relevant structural properties, including the role of strategic individuals in negotiations, or in the dissemination of ideological/religious thoughts within groups of people, etc., as observed in the analysis of some ancient networks Ormerod and Roach (2004).

Quantitative studies on social systems have been implemented since the seventeenth century; however, the systematic employment of mathematical methods in the study of social relations is dated to a 1926 study on school children's friendship (Wellman, 1926), followed by Mayo's (Scott, 1991) analysis of worker interaction in a factory. Along with the analysis of empirical data, the attention paid to "social networks" have also increased; which led to the development of the early methods used in social network studies now evolved and adopted by the complex network researchers. Also, there are some common issues addressed at by both the social researchers and the complex networks studies, including, but not limited to: Simon's (1955) study on modeling distribution functions, de Solla Price's (1965) study on citation networks, Freeman's (1977 and 1979) measurement of centrality (betweenness) in social networks, as well as the small-world effect of the Milgram social experiment (Milgram, 1967; Travers and Milgram, 1969). Today, social network studies have gained a specialty of their own, producing several books on the subject (Scott, 1991; Wasserman and Faust, 1994; Watts, 2003; and Degenne, 1999), as well as journals like "Social Networks".

Despite the contributions made by sociometric analyses of social network studies in understanding the societal dynamics, it still attracts criticisms due to the difficulty of an exact definition and association of social links and relations, as well as their levels of intensity, between individuals. There is an undeniable interdependence between social relations rooting from personal thoughts, feelings, trust, friendship and cultural, economical, and political context around the actors involved, besides other factors such as their ages, sexes, etc. It can be speculated for instance that if the Milgram experiment (Milgram, 1967; Travers and Milgram, 1969), a classical social analysis, had been conducted in another part of the world where social relations are less formal, then it would have to be redesigned accordingly, as the notion of acquaintance varies from one country to another. Similarly, a study on sexual networks conducted by Liljeros et al. (2001) reveals that men tend to exaggerate the number of their partners due to social reasons. Besides these, complex networks approach has also been applied to model regional interaction patterns in archaeological contexts, as it provides a network framework for the spatial relationships among sites (Evans et al., 2006; Knappett et al., 2008).

Techniques and methods such as extensive questionnaires and cross-comparison of their responses have been employed by the sociologists to overcome the above mentioned bias; however, these generated other difficulties due to their time-consuming and uneconomical nature, which complicate the process even more when applied on a meaningfully sized sample. Another attempt by the researchers has been to analyze systems with clearly defined relations among actors, such as the citation databases and collaboration social networks, examples for which are given below. These approaches, benefiting from the increasing popularity of the World Wide Web and related virtual social networks, provided a common ground to define the network (Watts, 2007). Virtual social networks, characterized by tools like blogs, messengers, e-mails, as well as the extensive electronic databases on specific subjects such as music, cinema, sports, etc.., although do not represent the whole world population, nevertheless provide important datasets as statistical samples and contribute to faster creation of social networks for researchers (Wellman, 2001). Yet, as usual, any attempt to derive social conclusions from such data, particularly regarding dynamic variables, should be undertaken meticulously.

Science Collaboration, Citation and Movie Actors Networks: Scientific collaboration, as a subset of personal relations, requires a special attention due to dissemination of information as it is also a subject of professional ties between scientists: common characteristics have been derived from the examination of a number of databases, the sizes and structural features of which vary depending on the discipline. Newman (2001a), for instance, compared the topological features in a given period of the networks built on the papers databases ranging from 10^4 to 10^7 in size. Information transfers are explained by diffusion processes that are dynamic; nevertheless, their quantities can also be measured from static structures, like citation networks. Citation databases both act as a filtering mechanism for the global information and provide an understanding of the flow of scientific knowledge. In such citation networks, scientific reports and papers are taken as nodes and citations among these papers, as directed links, whereas the in-degree represents citations from other reports, giving information on the importance of a specific paper. The citation network has an intrinsic characteristics created by the impossibility of a published paper to incorporate new references, as seen in the out-degree distribution of scientific papers. Studies in this area can be started with the work by Alfred Lotka in 1926, who found distributions of the number of papers written by an author follows a power law, called the *Law of Scientific Productivity*. In this regard, Redner (1998) studied the papers published in Physical Review D between 1975 and 1994, and Newman (2001a and b) found that scientific collaboration networks display general constituents of both scale-free and small-world networks. Interestingly enough, the analysis by Hajra and Sen (2004) on arXiv and PRL data, shows that most papers are cited within a period of 10 years after publication, which implies that this very same period is also relevant for the popularity of the trendy research topics after which they decrease in importance. Movie actors' network is mainly established by using the Internet Movie Database (IMDB), which includes information on almost all films and their casts starting from 1890. In this network, actors are accepted as nodes and links are established if those play in the same movie together. Although the number of movies, as evidenced in IMDB, is rather high, the network formed by the actors playing in those movies is a small-world having a high clustering coefficient, which implies the tendency of the actors to take roles with common partners. Examples are given in Table 23 in Appendix.

Cellular and Ecological Networks: Jeong et al. (2000) focused on the metabolism of 43 organisms, in which nodes are substrates (and such as H_20, ATP, ADP, etc.) and the links are the established directed chemical reactions among those. Wagner and Fell (2001) studied the biosynthesis and energy metabolism of the Escherichia coli bacterium. Another important study in this area was done by Jeong et al. (2001), who focused on protein-protein interactions. In their study, nodes are represented by proteins and binds among those are considered as links. In food webs, species are taken as nodes and links among those are represented by prey-predator relationships. Williams et al. (2002) studied the seven food webs and found that species are away from each other approximately 3.5 steps. The results of the studies by Montoya and Sole (2002) and Camacho et al. (2002) also demonstrate the existence of high clustering in food webs. However, it is still an unresolved issue whether to consider all food webs as scale-free networks or not (Barabási and Albert, 1999; Amaral, 2000).

Phone Call and e-Mail Networks: The analysis on telephone calls derived graphs from calls completed in a specified duration, where the telephone numbers are taken as the nodes, and a connection from node *i* to node *j* occurs in case of a call from *i* to *j* within the specified duration, with the resulting link in direction from head *j* to tail *i*. Nanavati et al. (2006) conducted a study on mobile phones where they examined local calls in four regions for one week and one month separately, and obtained results with a varying average degree from 3.6 to 8.1, and a clustering coefficient from 0.1 to 0.17; despite differences in social characteristics of the regions and in the time periods studied. Onnela et al. (2003) studied the phone calls records for 18 months, forming as a result a network with $4.6\ 10^6$ nodes and $7\ 10^6$ links; where nodes denote users, connection represent the calls and reception of calls between two users, and weights, the call period between two users, whereas the degree and strength distributions could be approximated by power-laws (respectively, $\gamma = 8.4$ and $\gamma = 1.9$). Several studies demonstrate that networks foster communication among people. Email, which has become a significant medium of communication, has also been an analysis topic in some studies constructing e-mail networks. Two ways for the construction of e-mail networks have been identified: (1) e-mail addresses are taken as nodes, where *i* sends at least one e-mail to *j*, a directed link from node *i* to node *j* takes place; (2) e-mail addresses are taken again as nodes, however, a directed link from node *i* to node *j* takes place on the condition that *j* is found in the address book of node *i*. One such study by Guimerá et al. (2003) converted a directional e-mail network to an undirected one by allotting connections between two people as they send and receive e-mails from the same person, and as a result, found out that such a network was a small-world with high clustering (0.25) in the giant component.

Grid (Power): The electric power transmission system, also known as power grid, is a complex human-made network, containing redundant paths to channel power from any generator to any load center, to make sure that every load center receives the required power and keeps network going even if one generator or a transmission substation fails. Despite this redundancy, electricity blackouts occur, resulting in huge economic losses. Having such an essential place in economy, these networks are considered as an important field of study. Earlier studies on power transmission systems depended on the creation of simple dynamical models that mimic network components in order to understand the blackout mechanisms, which were considered as immediate events led by the cascading failures in the transmission lines where the failure of one transmission line led to the redistribution of all power flow to other lines, a process which may also cause new failures due to overflow. The simulation of these dynamical processes indicated that the size of the blackouts followed a power-law tail; demonstrating big blackouts are not infrequent. However, despite its usefulness in estimating blackouts and detecting the critical components of the network, since it was based on simple network topologies, this approach was limited in understanding the real power transmission networks, which possess a small-world property, high clustering coefficient, and degree distribution in an exponential form. Analyses on the topology of such networks showed that the removal of a highly connected node(s), regardless of their type, could lead to blackouts in certain regions of the networks, whereas the number of shortest paths passing through each substation was thought to determine their transmission capacity. On the other hand, the study of Albert et al. (2004)

demonstrated that the blackouts could only be triggered by the removal of highly connected transmission substations, as the additional overload may lead to the failure of the others. In generator failures, however, the removal of even the highest connected generator cannot generate blackouts, due to the redundancy of lines in these networks, which allows providing additional power even if one generator fails. Watts and Strogatz (1998) worked on this type of networks and found that clustering coefficients of network is much higher than the random network and path length is close to random graph.

Other Networks: In their study of a scientific file sharing network, Iamnitchi et al. (2002) suggested that such networks might also have small-world characteristics, similar to the small-world topology of the scientific collaboration networks where links are the co-authors within the same paper, and hence, proposed a mechanism of data location that benefits from the local clusters. In line with this proposition, it is found out in other studies that three of the major data sharing networks, including a physics data sharing community, WWW data sharing between Internet hosts and Kazaa traffic between users, have small-world properties (Iamnitchi et al., 2003a and b; Leibowitz et al., 2003). More recent studies on the peer-to-peer (P2P) networks, the application level virtual networks using Internet infrastructure, identified some of its characteristics. A study analyzing the snapshot of Gnutella taken in late 2000 showed a power-law degree, although a more recent snapshot does not conform fully to pure power-law (Ripeanu et al., 2002). Another P2P network, eDonkey demonstrated a power-law for in- and out-degree distributions, where a directed link (i, j) exists if a host i makes a query related to a file provided by j (Guillaume and Blond, 2004**)**.

Computer viruses and their epidemic spreading has been a field of interest for at least three decades, and studies have been carried out using graphs and random graphs. Kephart and White (1991) benefited from epidemiological models in their 1991 analysis on the spreading of computer viruses, in which they used a directed graph to demonstrate that proliferation control can be achieved provided that the infection rate does not exceed a critical epidemic threshold. In their analysis of epidemic spreading in small-world networks, Moore and Newman (2000**)** found the exact values for the epidemic thresholds to be a function of the infection and transmission probabilities. In a more recent study, Small et al. (2004) demonstrated that the random fluctuation of the real data could only be explained with the introduction of a small-world topology in the epidemiological model. As opposed to the pure small-world lattices, the uncorrelated scale-free networks with exponent $0 \leq \gamma \leq 1$ do not have a critical threshold, as demonstrated in the study by Pastor-Satorras and Vespignani (2001), which meant that diseases spread in these networks regardless of the infection rate of the agents. In social networks with scale-free topology, the lack of epidemic threshold means that the disease can spread to all nodes of the network at any transmission rate; hence raises concerns. Such a case was demonstrated in the study by Liljeros et al. (2001), based on the sexual contact network in Sweden, where the strategy they proposed to stop virus dissemination in such networks was target immunization, that is, the immunization of the hubs of the network. Using computer simulation, this approach proved to be more efficient than random immunization; however, required global beforehand information on the structure of the whole network. Accordingly, Cohen et al. (2002), proposed acquaintance immunization; a local method depending on the random selection of a subset of nodes followed by the application of immunization based on the neighborhood relation of each node. Among all, the new immunization method in the study by Gómez-Gardeñes et al. (2006) is considered the most efficient, which is neither local nor global, as each node within looks at its neighborhood and immunizes the highest connected neighbor.

Sexual relations do not necessarily involve acquaintance relationships, however, sexual partners, can be social partners, and the reverse is also true. A study conducted by Liljeros et al. (2001) for a period of 12 months on a random sample of people aged between 18 and 74 in Sweden displayed a cumulative power-law distribution of partners with rather close exponents; 2.54 for women and 2.31 for men. The slightly higher exponent for men is explained with the tendency by men to inflate the number of partners. On the other hand, another cumulative power-law distribution was observed on the scale of entire lifetime, which displayed smaller exponents; 2.1 for women and 1.6 for men. It is suggested that the scale-free structure of such a network shares a similar paradigm to “the rich get richer”; as the number of previous partners increases, skills in having new partners also increase.

Religion is another point of interest due to its obviously important role in society throughout history. Choi and Kim (2007), using a directed network, examined the relation between mythological characters derived from a Greek and Roman dictionary. They assigned the outgoing links to a specific entry of a character in the dictionary, and the incoming links to those mentioned in the respective dictionary entry, the degree distributions of which resulted in power-laws with exponents between 2.5 and 3.0.

The network of trust can hierarchically be considered as a special sub-network of the acquaintances network, in which the strongest connections in the acquaintances network can be related to the connections of the network of trust. In order to overcome the lack of reliable datasets on trustful partnerships, Guardiola et al. (2002) focused their study on the electronic trust ties, using the PGP (Pretty Good Privacy) encryption algorithm, in which the first user makes a directional connection to the second one in case s/he trusts his/her statements. As a result, Guardiola et al., by looking at the in- and out-degree, detected a power-law degree distribution with exponents $\gamma = 1.8$ and 1.7, respectively.

Studies on transportation networks contribute to the analysis and improvement of the economy and infrastructure of countries. Such networks usually have small-world characteristics with scale-free degree distribution and hierarchies. For instance, in their 2002 study, He et al. (2004) analyzed the Chinese airport network, excluding the directions and the number of passengers in a flight; upon finding the node degree distribution to be exponential, concluded that this network is small-world without the scale-free property. Airport networks face several problems mostly related to the difficulties in air traffic such as those created by weather conditions (fogs, snowstorms, etc.). Li and Cai (2004) studied the errors caused by an attack to the US airport network with the aim to evaluate the performance of the network in such conditions. It is found that similar to other scale-free networks, the US airport network, tolerates errors and random attacks, where removing a few airports with a few connections makes almost no impact on the topological properties like average vertex degree, clustering coefficient, diameter, and efficiency; but is extremely vulnerable to a targeted attack at the hubs, where all these properties change dramatically with the removal of a few hubs.

In their study on the impact and prevention of terrorist attacks in a given network, Latora and Marchiori (2001) suggested a method to determine the critical nodes, which played the most important role for the network to function efficiently, relating the network efficiency to the shortest path between all nodes of the network. They made a case study using Infonet communication system; the US and European Internet backbones, by deactivating nodes one by one, as a result of which, they found out the most important nodes to be New Jersey and New York, as the deactivation of these nodes resulted in over 50% decrease in network efficiency. The results also demonstrated that the most important nodes are not necessarily the most connected ones, as the deactivation of Chicago with degree 15, leads to a decrease in network efficiency by 28%, whereas that of New Jersey and New York, both with degree 9, results in respectively 57% and 53% decrease network efficiency.

Latora and Marchiori (2001) applied the same method in another example using the data obtained from major newspapers where they built a network of terrorists directly or indirectly related with the September 11 attacks by setting the knowledge interplay among the hijackers as the links. Their study showed that even nodes with low connectivity could play a central role in network efficiency, as although the most critical node in their study had the largest number of connections with other terrorists, the second most critical node had a degree of only half of the highest. Similarly, Krebs (2002) analyzed a network of hijackers connected to September 11 events, stating that while it is difficult to use network theory to prevent criminal activity, it is still an important tool for prosecution purposes. For the solution of the node discovery problem in complex networks, Maeno (2008) suggested a method that can be used to identify an unobserved agent behind the perpetrators of terrorist attacks.

Sports make another field for social network analysis. Onody and Castro (2004) conducted a complex network study on Brazilian soccer players, for which, they first constructed a bipartite network composed of teams as one node type and the players as the other, where they found an exponential law $P (N) \sim 10^{-0.38N}$ in the probability that a player has played in a given number of clubs N. They merged these nodes to observe the topological properties by connecting two players only if they played at the same team at the same time. The exponential degree distribution of the resulting network gave $P(k) \sim 10^{-0.011k}$ and maintains small-world characteristic despite its becoming more than five times larger in size between 1975 and 2002.

Globalization made a deep impact on trade networks, as it led to the enlargement of economic relations with an increasing number of commercial partners as well as to the increase in trades at individual level due to e-commerce opportunities; however, the overall international market is still the arena of companies. Therefore, studies have been done with an effort to analyze this system of trade between countries, as that of Serrano and Boguna (2003), who studied the "world trade web" by building a network where each country was assigned a node, the in-degrees were taken as imports, and out-degrees as exports between countries. As such, the extensive trade activity between countries has a small-world property, a high clustering coefficient, and large average degrees.

Consequently, in real networks, the degree distribution deviates from the Poisson distribution seen in random graphs, and many real networks exhibit a power law tail with an exponent y having value between 2 and 3. Prevalence of such a scale-free degree distribution in real networks is closely related with the advantages brought by that type of distribution. The degree distribution of regular (lattice) network is constant; that is, all nodes have the same number of degree in regular network. In random graphs (Erdős and Rényi, 1959), the degree distribution follows a Poisson distribution for large N. However, similar to the small-world networks (Watts and Strogatz, 1998), scale-free degree distribution lies between random and regular networks (Bollobás, 2001 and Barabási, 2003), implying that travel and navigation is much easier than that in both random and small-world networks.

Moreover, this easiness, resulting in economical feasibility, may not be sufficient to select scale-free networks. Another advantage brought by scale-free networks is their higher resistance (or higher stability) to random errors than random networks, which, besides other reasons, results from their higher sensitivity in responding to different changes (Bar-Yam and Epstein, 2004).

Many examples provided in the in Appendix may give the impression that all complex networks such as WWW, internet, citation networks, etc. have a power-law degree distribution. However, a closer inspection would reveal that not all are exponential, as seen in C.elegans, power grids, etc. Also, their exponentiality does not mean that they are random; many models were developed to explain power-law degree distribution and exponentiality, which are based on notion of network evolution. In other words, BA model evidently is not devoid of criticisms. As an important difference between Price and BA models, in BA model, links are undirected; there is no distinction between in-and-out degrees, instead of directed, as seen in web pages and scientific papers. However, ignoring the notion of directedness, BA model is faced with the familiar question of how a node obtains its first link. Willinger et al., (2002) argue that preferential attachment, or more generally, self-organization model just explains "what" but not "how" and "why". In other words, BA model tries to explain "what" is observed in real-networks but do not explain the main causal mechanism for the existence of scale-free networks; which the reason for the insufficiency of the real empirical data produced by the model for real networks. Furthermore, path lengths and clustering coefficients of real networks are smaller than those of BA model (Bollobás and Riordan, 2004) and they do not have constant clustering coefficient distributions (Ravasz and Barabási, 2003). To overcome these problems and develop further models to explain real networks, various studies were conducted based mainly on the concept of preferential attachment and growth; producing several characteristics to be added to BA models, such as *nonlinear attachment* (Krapivsky et al. 2000), *fitness* (Bianconi and Barabási, 2001 a; b), *initial attractiveness of isolated nodes* (Jeong, Neda and Barabási, 2001), *aging* (Dorogovtsev and Mendes, 2003b), *accelerated growth* (Dorogovtsev and Mendes, 2003a).

Other models were also developed to explain real networks, which show that preferential attachment does not always result in a scale-free type of network(e.g. Newman 2005). Vazquez et al. (2003), Kleinberg et al. (1999), Kumar (2000), Sole et al. (2002) and Chung (2007) point out that there is a high potential of obtaining scale-free network if one duplicates the original network and rearranges its connections during evolution process. Similarly, in order to obtain power-law degree and clustering coefficient distributions seen in real world, Ravasz et al. (2002) established a model based on "self-similar growth pattern", instead of preferential attachment. In their model, a densely connected node, selected as the seed node, is replicated several times and each obtained node is connected to a central node. This process is repeated until the desired results are yielded. However, this model produces only certain clustering coefficients and degrees, which means, although the results obtained are very close to real networks for a small number of nodes, when the number of nodes are increased, the results do not match with the values of real network[16].

2.2.3 Robustness

According to Jen (2003) "[r]obustness is an approach to feature persistence in systems… robustness… represent changes in system composition, system topology, or in the fundamental assumptions regarding the environment in which the system operates". In this sense, robustness is the preferred terminology over stability in the study of complex (adaptive) systems. Robustness of the network can be linked with its structure; that is, if a network continues its function after damage to its node(s) or link(s), where a task is completed by other undamaged nodes and/or links, the network can be called robust. This type of networks can be considered as what Kaluza et al. (2008) labels as "self- correcting networks". However, robustness is an ambiguous concept, as a network may continue its function under some conditions but not under different conditions. In this sense, what is referred to with the notion of robustness, which usually depends on the damage to the network, should be determined before examining the network in these terms. Accordingly, damage can be classified as internal and external in this framework. For instance, if one wants to examine the robustness of the network in terms of link (and/or node) deletion (internal), s/he should delete one link (and/or node) among all and observe whether the performance of the network changes or not. This type of damage may be overcome via the network structure, as mentioned earlier. At this point, the

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[16] Optimization-based models have also started to attract authors in their efforts to explain real networks; see e.g. Willinger et al. (2002), Valente et al. (2004), Ferrer et al. (2001), Fabrikant et al. (2002), and Cancho et al. (2001).

robustness of BA model depicted above can be reminded to better illustrate the process. The answer to the critical question on scale-free networks regarding whether they are robust (or reliable), and if so, under what conditions, depends on the angle one prefers. On the one hand, malfunctioning (accidental failures) of most nodes cannot lead to a significant impairment for the operations of scale-free network; in this sense, they are robust due to their heterogeneous topology in terms of nodes' degree. This is because there is a much higher possibility for nodes than hubs, which are rare, to be selected if they are eliminated. Meanwhile, contrary to scale-free networks, if critical number of links are cut, many random networks come across important problems, or nodes turn out to be isolated island(s). Alternatively, scale-free networks cannot be considered robust if there is a planned attack on hubs. As such, not only keeping the hubs alive, but also knowing the hubs, which are relatively more important than the others, gains importance for researchers studying the topology and characteristics of networks. For instance, resistance to random attacks is important for the Internet (Albert et al., 2000) or cells networks (Vogelstein et al., 2000), which enables them to continue their functioning; while, scale-free networks are most vulnerable to attack on their hubs (Albert et al. 2000; Gallos et al. 2005). As mentioned above, robustness is dependent on how one perceives the concept. For instance, the study by Pastor-Satorras and Vespignani (2001) shows that when there is an epidemic spreading, if the network is scale-free, the effective threshold is zero, which situation also demonstrates that scale-free networks are very well connected for conveying messages.

Two elements of the network are called redundant if are structurally indistinguishable. Generally, a network is assumed robust when the network shows a low sensitivity to fluctuations, due to the existence of redundancy as stated by Albert and Barabási (2001): "[i]t is often assumed that the robustness of many complex systems is rooted in their redundancy, which for networks represents the existence of many alternative paths that can preserve communication between nodes even if some nodes are absent." However, studies, especially on biological systems (Edelman and Gally, 2001) reveal that redundancy is not the source of robustness, but degeneracy is, which denotes the functional commonalty shown by two structurally different elements under specific circumstances (Tononi et al. 1999).

Thus far, discussion on robustness has been maintained using a BA model in its static form; that is, the removal of nodes and/or links affected the others only in topological sense.Yet , the dynamical process on the network may well be functional, besides topological. In this condition, the performance of the network under different conditions should be examined to decide on the robustness of the network. In short, there are two possibilities for complex systems; either mechanisms of negative feedback will be run and network will turn to previous conditions (Bak 1997, as explained in the Section 2.1.1 above, used sand piles example to depict self-organized critically, a widely used example for explaining the role of negative feedback in complex system literature), or positive feedback run and network will evolve to new conditions (Prigogine and Stengers 1984, as explained in the first Section (2.1.1)), "dissipative structures" is highly organized but always in process systems, which means that each bifurcation they move in new conditions but keep their structure and functionality). For instance, the removal of a node in power grid can cause overload on the other nodes and links, which may result in the failure of the whole system, leading to a cascading effect (avalanche).

In order to study cascading failures, Moreno et al. (2001) suggested what they called a *fiber bundle model*, in which, the system was exposed to external fluctuations and system thresholds in terms of the diversity of nodes' capacities and topology of the network were determined using several quantities. According to this study, to prevent the failure and/or breakdown of the network, one has to know not only the situation in advance, i.e. whether a system is approaching to the threshold, but also the robustness of the system under repetitive failures. Of course, the critical question of what can be done to defend the network from such a cascading effect arises, and Motter (2004) argues that selective removal of nodes/links after the failure and/or attack before is the effective strategy to keep the network alive than the other possible methods such as the addition of new nodes/links, rewiring of nodes/links. An alternative approach is offered by Crucitti et al. (2004 a, b), in which they change Motter's (2004) approach to a little extent. In their model, it is argued that instead of removing links and/or modes permanently from the network, communication through these nodes/links are decreased, which provides no/rare communication through these nodes/links.

Crucitti et al. (2004b) studied both the ER random graph and BA scale-free graph, both of which have the same number of nodes (N=2,000 and K= 10,000), in terms of random removing (static) and load-based removing (dynamic) to determine their robustness. They found ER random graph to be more resistant than the BA scale-free graphs against cascading failures. Again, Holme et al. (2003), and Holme and Kim (2002) studied the evolving networks, in which network structures (nodes and links) change in accord with time under perturbation. They found that networks are more vulnerable to the cascading failures if the growth is ruled by preferential instead of random attachment. Watts (2002) also studied the impact of cascades on social networks via using binary model. His results demonstrate "in this model, the heterogeneity plays an ambiguous role. Indeed, increasingly heterogeneous thresholds make the system more vulnerable to global cascades, while an increasingly heterogeneous degree distribution makes it less vulnerable". Finally, Boccaletti (2006) concludes that "[t]he small-world wiring seems therefore to yield an enhancement of synchronization".

Thus, robustness basically means the ability of the networks to abstain from malfunctioning when a part of it is damaged. Robustness can be classified into two categories: static and dynamic. When a node or link is destroyed from the networks without taking into consideration its affect on the rest of the network, a network can be studied from static view. However, when affects of removing a node and/or link is taken into consideration with a focus on its affect on the rest of the network, a network can be studied from the dynamic view. While the former case, static analysis, can be employed via the network analysis techniques examined until now, the latter, dynamic analysis requires simulation. In this thesis, only first method shall partially be used, leaving out the second method, due to concerns on the validity of results, as explained in following parts.

New findings in any research are considered in terms of not only their theoretical implications, but also their potential use in real world data and problems. In this light, studies on networks with big and diversified data, as a relatively recent research field, have proved to possess a huge potential; particularly when coupled with their extensive use of formal theoretical fields such as statistical mechanics and graph theory, which provide a sound theoretical framework in the study of complex systems. Network studies take into consideration both the connectivity structure and intricate dynamics of such networks. In this sense, this Chapter focused on one of the methodologies to be implemented in the Thesis with an investigation on the widely known network models. Main characteristics of complex networks were presented in accord with the discussions in the literature. In brief, degree distribution in a random network has Poisson (or binomial) distribution in the limit of large graph. Almost all nodes have average degree distribution and few of them have less (more) than the average degree. Moreover, path length and clustering coefficient are small in random network. Small-world model was discussed, which displays the characteristics of high clustering coefficient and smaller path length, when compared with random and regular networks. These characteristics appear important when communication and interaction among nodes are concerned. In scale-free network, few nodes (hubs) have high degree and many nodes have low degree (few links). The degree distributions of the nodes fit to the power-law distribution (or scale-invariant property). Providing examples from different types of studies on networks, it was demonstrated that the distribution is ranged between $1< y < 2.5$ in biological networks and in $2 < y < 3$ in social networks. Similarly, the range of distribution (Dorogovtsev et al. 2003) was shown to play a critical role for self-organization and robustness of the network as well as for faster search through the network. Furthermore, preferential attachment and other mechanisms related to network growth were discussed in addition to network optimization models. Finally, basic models and their interpretations were presented in this Section. In Chapter 4, discussion of this Section shall be put into practice, enabling an analytical analysis. Subsequently in Chapter 5, policy recommendations shall be made via benefiting from discussions in this Section and in Chapter 4.

2.3 Systems of Innovation

The period starting from at the end of the World War II to 1970s onwards, could be summed up with the motto: ‘science for the sake of science’, ‘science and technology shape society’ and the concept of ‘defense technology’. These perspectives evolved out of an atmosphere of science and technology optimism in the years following the WW II and continued throughout the cold war period. Science and technology were defined globally for the first time in modern history, and considered as forces of socio-economic change that made a difference for society and economy. One important contribution to these perspectives was made by Vannevar Bush who was director of the OSRD and the U.S. President Roosevelt's advisor for scientific research and development. His 1945 report, 'Science, the Endless Frontier' has been a source of inspiration for the modern funding system for science. Bush argued that a 'basic science' would eventually have positive consequences for the economy. According to him, science should not be targeted directly by government; rather, funding should be determined by scientists themselves through a system of peer review. In addition, his argument was based on the 'defense technology' perspective, according to which the consideration of research and innovation as a linear process is a fundamental feature. Under this perspective, governments are reckoned as the main client of R&D activity. Large-scale national programs, justified primarily by political criteria, serve to fund the technologies that state needs for its public and military sectors. In the selection of research projects, two main criteria were taken as ground rules: scientific excellence, and political and/or military interests. The benefits of this perspective to industry and society are justified only by direct and indirect spin-off from investment in basic and military R&D. In fact, strategic military projects became the reason for important scientific projects that were managed, financed, and realized in state laboratories, as in the case of Manhattan Project, which ended up with atomic bomb, radar, rocket, ENIAC, etc.. However, this approach was criticized in two central aspects. First, there is too much concentration on R&D, which veils the importance of other inputs. Second, there is a lack of feedback links in this model because of its linear structure.

Suitable conditions for economic development nourished in 1960s. Firms tried to cope with increasing competition via diversification of their products. The sourcing for these new products was supplied by the market demand itself, which has been regarded as a booster of the innovation process; so, the model implemented between 1965 and 1975 was called 'market pull' (Kaplinsky, 1989). However, there are three criticisms to this model. Similar to the previous model ('science push), the emphasis is concentrated mostly on a single aspect, which is 'market activity' in this model. The other inputs of the innovation process are not taken into account. In addition, the importance of scientific and technological innovations is ignored. Finally, again, there is a lack of feedback links in this model as well, due to its linear structure.

Therefore, according to Rothwell (1994) the merits of the chain-linked model should be viewed in the light of previous science and technology -push- versus demand -pull- models of innovation that have often been referred to as *linear models*. Linear models view innovations as arising either purely from developments in the science and technology, or demand of customers and users in the markets. The presentation of 'the chain-linked model', by Kline and Rosenberg (1986), was important because it gave a specific form to an alternative to the linear model (Lundvall, 1998). However, although Kline and Rosenberg's model is so important in explaining many important aspects of the innovation process, it also comes with certain shortcomings. Mainly, it was criticized that even firms without the necessary resources to achieve in-house innovation can still benefit from establishing relationships with a network of other firms and organizations.

The emergence of innovation system approaches and their characteristics have been pondered upon by Edquist (1997). He identified innovation system approaches and their characteristics, deriving several conclusions. According to Edquist (1997), SIs place *innovation and learning process at the centre of focus*; which is based on the understanding that innovation is a matter of producing new knowledge, or combining existing elements of knowledge in new ways, and as such, a 'learning process'. *They adopt a holistic and interdisciplinary perspective*; in the sense that they try to encompass a wide array-or all- of the determinants of innovation that are important. *They are interdisciplinary*; implying that they include not only economic factors but also organizational, social, and political factors. *They employ historical perspectives*; since process of innovation developed over time and contains influences from many factors and feedback process, they are the best studies in terms of the co-evolution of knowledge, innovation, organizations, and institutions. *They stress the differences between systems, rather than the optimality of systems*; they make the differences between systems of innovation the focus, rather than something to be avoided. This means drawing comparisons among existing systems rather than between real systems and an ideal or optimal system. *They emphasize interdependence* *and non-linearity*; which is based on the understanding that firms almost never innovate in isolation but interact more or less closely with other organizations through complex relations that are often characterized by reciprocity and feedback mechanisms in several loops. This interaction occurs in the context of established institutions infrastructure such as laws, rules, regulations, norms, and cultural habits. Innovations are not only determined by the elements of the systems, but also by the relations between them. *They emphasize the central role of institutions*; in order to understand the social patterning of innovative behavior -its typically 'path-dependent' character - 'and the role played by norms, rules, laws, etc. as well as by organizations.

As a result, systems of innovation, as evolutionary systems in which institutions matter and learning processes are of central importance, have significant implications for the development of corporate strategies and public policies. In other words, they are not only related solely with the role of individual actors such as firms, universities, etc., but also with the interactions of those actors of innovations systems among the regional, national, sectoral and global level. In particular, innovation system approaches provide for a much more careful and detailed development of public policies for innovation than do variants of the linear approach discussed above. From the systems of innovation perspective, policy is partly a question of supporting interactions in a system that identify existing technical and economic opportunities or create new ones.

2.3.1 Systems of Innovation and Complex Systems

Among others, Freeman, (1987) defines SI as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies"; and Edquist, as (1997) "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations"; while Lundvall (1992) states that a SI "is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge". Although these definitions have changed in accord with selected boundaries of SIs studies such as national, regional, sectoral, and technological systems with changing emphasis on several notions; the basic characteristics of SIs are not changing: “[i]t is obvious that national systems of innovation are open and heterogeneous systems” Lundvall (1992) or “innovation systems are complex systems” (Katz, 2006).

Interestingly enough, although most studies related with the notion of innovation prefer the use the term *system*, even in their titles, , except for some studies on technological systems “the meaning of the term system is not analyzed in great detail” (Cooke and Memedovic, 2003). In fact, the meaning of or expectations from *system* change from one author to another. For instance, Nelson (1992), who shows a pragmatic approach, says “a set of institutions whose interactions determine the innovative performance…(with) no presumption that the system is consciously designed, or even that the set of institutions involved works together smoothly and coherently” on the one hand; Bathelt (2003), argues that a system has to replicate some of its basic structures and able to distinguish what is out of and in it on the other. Fagergberg (2003) states that SIs approaches have not “developed to allow for systematic empirical work. Arguably, to achieve this it would need to substitute its current vague appeal to ‘system-thinking’ with a more precise theoretical analysis of how these systems actually work”. As mentioned by Frenken and Nuvolari (2002), a system consists of its elements; output of a system is determined not only by characteristics of its elements but also through interactions among those elements; and changes in the elements of a system affect both the outcome of the system and the characteristics of its elements. In this sense, according to Lundvall (2007):

> “[t]here is a lot of theoretical work to do develop a more stringent system concept that makes it possible to understand the intricate interplay between micro and macro phenomena, where macro structures condition micro-dynamics and, vice versa, how new macro-structures are shaped by micro-processes. In a dynamic context this means that we need to understand systems as being complex and characterized by co-evolution and self-organizing.”

Similar concerns are underlined by Edquist (2001):

> “[t]he relations between organizations and institutions are very complex and often characterized by reciprocity. This emphasis on the complex relations between components constitutes a major advantage of the SI approach. However, it also constitutes a challenge since our knowledge about these relations is very limited.”

As mentioned, one of the main theories utilized by SIs approach is evolutionary theory, which criticizes neo-classical approach. According to Georgescu-Roegen (1971) and by Mirowski (1989), physics, particularly the theory of electromagnetic fields, played important role in the development process of neo-classical approach. Reflections of Laplacian dream (a reversible, deterministic and calculable world) can be found in neo-classical approach. In Leoncini's (2000) words,

> As within physics, the view of a deterministic, reversible and in principle calculable universe was gradually giving way to that of a complex, uncertain, irreversible and limiterily knowable universe, the same transition was not occurring in economics, or at least not in neo-classical economics.

In fact, concerns expressed by Leoncini have already started to be taken into consideration in many studies (among others, Nelson and Winter, 1982; Dosi and Nelson, 1994; Dosi, Silverberg, Orsenigo, 1988; Saviotti 1996; Silverberg 1990). Although many notable authorities made remarkable contributions to the development of evolutionary approach, being one of the mainstream theories used for developing SIs approaches, further studies are needed to investigate the relationships between micro and macro structures, as already posited by a number of authors. As stated by Niosi (2003):

> The evolutionary approach in economics uses many similar assumptions as the complexity perspective and its problems are the same… This paper suggests treating innovation systems as adaptive, complex and evolutionary systems thus linking it systematically to large currents of thought, and adding modeling, in order to improve its chances to provide public policy advise.

Hence, the earlier statement by Prigogine and Stengers (1984), which is also related with the notion of emergence, still keeps its validity:

> One of the most important problems in evolutionary theory is the eventual feedback between macroscopic structures and microscopic events: macroscopic structures emerging from microscopic events would in turn lead to a modification of the microscopic mechanisms.

As stated Section 1, there are many questions put forth by the researchers of complex systems, which can be crystallized to the ways in which complex systems are to be described and to how the interactions within and between systems are to be analyzed to explain global patterns. Although no exact answers have been provided to these fundamental questions yet, some characteristics attributed to complex systems are found, as stated at the end of the Section 1. Staying within the framework of characteristics mentioned there, similarities between SIs and CSs are elaborated below, with a summary of findings shown in Table 1.

Complex systems are set-up by several elements in interaction with each other reciprocally, and those cannot be modeled by using linear models, which means that the action of an element is responded by more than one element due to the existence of nonlinear relationships (referred to as the *resistance towards linear models* in SI literature). Moreover, even if we know the initial and boundary conditions (*path dependence* in SIs jargon), it is impossible to anticipate the behavior of system due to nonlinearity. However, this does not mean that they behave randomly in a haphazard manner. Also, similar events at different times have potential to trigger different reactions due to existence of current links and actors. This characteristic is usually echoed in SIs discussion, as seen in Edquist (2001), who aptly states:

> Innovations occur everywhere in a system - to a greater or lesser extent - and because of the evolutionary character of innovation processes, an innovation system never achieves equilibrium. We do not even know whether the potentially 'best' or 'optimal' trajectory is being exploited at all, since we do not know which one it would be. This means that the notion of optimality is irrelevant in a system of innovation context. We cannot specify an optimal or ideal system of innovation.

Furthermore, the characteristics of a complex system cannot be obtained just by focusing only on the constituents of the system through concentration on part of the system. That is, "[e]mergence is above all a product of coupled, context-dependent interactions. Technically these interactions and the resulting system are *nonlinear*: The behavior of the overall system cannot be obtained by *summing* the behaviors of the constituent parts" (Holland, 1998, *italics* in original). Emergence is associated with novelty (innovation) and results in changes in characteristics of elements and their relations in the system and thus self-organization capability of the system. That is, emergence can be summarized as the process that occurs "when we proceed from the microscopic to the macroscopic level, many new qualities of a system merge which are not present at the microscopic level" (Haken, 2000). Hence, order in a system results from the characteristics of elements and their nonlinear interactions.

The system is able to self-organize itself spontaneously. Changes in the system are usually accompanied by changes in the environment (or in the "fitness landscape", a term used by Kauffman (1993 and 1995), in which other complex systems continue their activities. Co-evolution is seen as a signal for system development capability due to challenging requirements of agents. That is why, complex system view, like evolutionary approach, underlines both competition and cooperation. They permit local variety within acceptable limits to be able to adapt to changing circumstances; however, some variations trigger major variations that change the basin of attractor, which is a process that cannot be known in advance due to unpredictability during bifurcation process. In other words, like Schumpeter's creative destruction process, at that stage, when a system shows creative process, current state is destructed by creative process and this process causes the creation of new state, which is unpredictable. However, this should not be seen as a random process. On the contrary, the new order results from within the system itself; and pre-established rules that determine relations cannot keep their validity, which means that agents faced with the new situation have to organize themselves and their relations in accord with the new situation. In short, they exchange information, energy and matter with their environment, as "[they] absorb (similar to discussion on absorptive capacity in innovation literature) information from their environment and create stores of knowledge that can aid action" (Foster, 2005). At the edge of chaos, complex system does not only store required information but also forget that information and/or transform it to deal with changing conditions (similar to discussion on the role of learning and unlearning in literature of SIs).One important characteristics of complex systems, as stated by Garnsey and McGlade (2006) is that

> [T]hey display power law structures; change occurs at all scales, incrementally and as avalanches…Generally speaking, it has been observed that real, large systems with many autonomous but interacting components are characterized by power law distributions. Dissipative structures subject to amplification effects are typically subject to skewed distributions (for example, [internet], firm and city size).

On a similar note, Kauffman (1991) states that

> Interesting dynamic behaviors emerge at the edge of chaos. At that phase transition, both small and large unfrozen islands would exist. Minimal perturbations cause numerous small avalanches (similar to incremental innovation in the SIs perspective) and a few large avalanches (similar to radical innovation in the SIs perspective). Thus, sites within a network can communicate with one another -that is, affect one another's behavior- according to a power law distribution: nearby sites communicate frequently via many small avalanches of damage; distant sites communicate less often through rare large avalanches.

As such, they display different characteristics and these differences are not only the source of innovations but they also increase abilities of the system to respond changing circumstances. As discussed by Prigogine (2005) "[b]ifurcation points exist certainly in social or economic systems [which] requires autocatalytic processes" and "bifurcations can be considered the source of diversification and innovation, which leads innovation though they are unpredictable" (Coleman, 1998).

Cilliers (1998) argues that attractors can be seen as a stable state of the system. Although attractors show relatively stable characteristics, they change when state space changes. In this sense, movement from one actor to another is called 'phase transition', and phase between two attractors is labeled as 'transient states' in system theory. In this sense, it may be argued that a complex system tries to stay around its attractors to continue its existence against changes (similar to the discussion on the institutional infrastructure in innovation literature). Furthermore, each attractor is surrounded by a basin of attraction and the size of this basin of attraction can determine the stability of attractors, i.e. large attractors are much more stable than small attractors. In terms of complex systems, the relation between attractor and system may be explained as follows: local interaction among elements determines the global pattern; however, changes resulting from local interaction push the system in less number of states where similar attractors are in force. That is why a system looks as if unchanging. Then again, some positive feedbacks[17] may

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[17] On the other hand, negative feedback locks systems in conditions of static equilibrium, which means there is no chance for the system to evolve. Smith's view on supply-demand relationship says price will incline where demand equals to supply. This relationship can be

shift the system to a different attractor, which change the rules in the system or destroy it. These shifts may be articulated as 'punctuated equilibrium' (Gell-Mann, 1995; Coveney and Highfield 1996: 232) in the terminology of evolutionary economics. Therefore, complex systems show a sensitive balance between local states and global stability, which phenomenon also reveals the relevance of studying SIs from the perspective of network studies. In order to achieve this, a complex system permits local variety to escape from rigidity on the one hand, while limiting the variety to avoid chaos, on the other. Otherwise, little or overblown efforts have a potential to push the system into chaos or equilibrium. In other words, as Prigogine and Stengers (1984) argue, forces and fluxes can be used for classifying action taking place in the system. Within the discussion of SIs, forces can be seen as innovations; whereas diffusions, transfers, etc. can be seen as fluxes. In this sense, "[c]omplexity science leads us to believe that stability is death and that survivability is in variability. The tension between stability and variability is similar to the tension in the social sciences between exploitation and exploration (March, 1991). We often think of exploitation as a strategy for maintaining stability and exploration as a strategy for exploiting variability. We may need a balance between exploration and exploitation, stability and variability, convergence and divergence within a state" Jordan (2005)**.**

Table 1 Similarities between Complex Systems and Systems of Innovation Approaches

Complex Systems	Systems of Innovation
Complex systems are set-up by several elements in interaction with each other reciprocally, and those cannot be modeled by using linear models, which means that the action of an element is responded by more than one element due to the existence of nonlinear relationships	There are many actors such as firms, universities, organizations, etc. in systems of innovation, which have non-linear relations.

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given as an example for negative feedback. For example, when price goes away from equilibrium, it will be brought back to equilibrium by supply-demand relationship. Alternatively, Arthur's (1989) discussions on increasing returns can be associated with discussions on the role of positive feedbacks.

Table 1 (continued)

Complex Systems	Systems of Innovation
Even if we know the initial and boundary conditions, it is impossible to anticipate the behavior of system due to nonlinearity	Path dependence and lock-in
The behavior of the overall system cannot be obtained by *summing* the behaviors of the constituent parts" (Holland, 1998)	SIs are constituted by different types of organizations, which means that investigation of some of them are not enough to define overall characteristics of the system
They permit local variety within the acceptable limits to be able to adapt to changing circumstances; however, some variations trigger major variations that change the basin of attractor, which is a process that cannot be known in advance due to unpredictability during bifurcation process.	Like Schumpeter's creative destruction process, at that stage, when a system shows creative process, current state is destructed by creative process and this process causes the creation of new state, which is unpredictable.
They exchange information, energy and matter with their environment, as "[they] absorb information from their environment and create stores of knowledge that can aid action" (Foster, 2005).	Similar to discussion on absorptive capacity in innovation literature (Cohen and Levinthal, 1990)
At the edge of chaos, complex system does not only store required information but also forget that information and/or transform it to deal with changing conditions .	Similar to discussion on the role of learning and unlearning in literature of SIs.
Kauffman (1991) states that "[i]nteresting dynamic behaviors emerge at the edge of chaos. At that phase transition, both small and large unfrozen islands would exist. Minimal perturbations cause numerous small events (similar to incremental innovation in the perspective of SIs) and a few large events (similar to radical innovation in the perspective of SIs) cause large destructions	Minimal perturbations cause numerous small avalanches (similar to incremental innovation in the perspective of SIs) and a few large avalanches (similar to radical innovation in the perspective of SIs) cause large destruction

Table 1 (continued)

Complex Systems	Systems of Innovation
Cilliers (1998) argues that attractors can be seen as a "stable" state of the system. A complex system tries to stay around its attractors to continue its existence against changes.	Similar to the discussion institutional infrastructure in innovation literature, which is not changed in a short time.
Prigogine and Stengers (1984) argue that forces and fluxes can be used for classifying action taking place in complex system. In this sense, "[c]omplexity science leads us to believe that stability is death and that survivability is in variability." Jordan (2005)	Within the discussion of SIs, forces can be seen as innovations; whereas diffusions, transfers, etc. can be seen as fluxes. The tension between stability and variability is similar to the tension in the social sciences between exploitation and exploration. We often think of exploitation as a strategy for maintaining stability and exploration as a strategy for exploiting variability (March, 1991).

2.3.2 Systems of Innovation and Network Approach

Scholars in the field of innovation studies work intensively on the impact of the network structures over production of information and knowledge, as well as their transformation into new products/services and production/service processes (Powel and Grodal, 2005). Andersen (1996 and 1997) benefited from graph theory and simulation models within the SIs framework. Some researchers examined the geographical distribution of the innovation network or the relationship of geography with the network (Beccatini, 1990; Camagni, 1999, Cooke, 1996; Marshall, 1961; Piori, 1984; Storper, 1997; Asheim and Gertler, 2005); while some were involved with the structural characteristics of the network (Das and Teng, 2002); or with the governance of the network structure (Pietrobelli and Rabellotti, 2009; Gereffi et al., 2005, Sturgeon et al., 2008); while others were concerned with the cognitive distance among the participants of the network (Gilsing et al., 2008); and with the strength of the ties among the said participants (Granovetter, 1973), the production/ transfer of knowledge/ information and their impact on the emergence and/or development of innovations (Nooteboom, 2004). Many authors analyzed the impact of inter organizational networks on innovation (DeBresson and Arnesse, 2001; Freeman, 1991; Hagerdoorn, 1990 and 1993; Nooteboom, 2004; Powell et al, 1996, Soh and Roberts, 2003). As also evident from the abundance of the studies in the area, starting from the last decade, role of networks in the areas of science, technology, research and innovation policies have been discussed increasingly. The main idea behind this discussion is related with the emphasis on the importance of interactions among different actors, which is accepted as the most important factor for developments in science, technology, research and innovation. In other words, instead of focusing on a single actor and its behaviors; policymakers started to focus on the importance of cooperation, collaboration and communication among the actors. In fact, expectations of policymakers were already articulated in the notable works (Freeman 1991; Lundvall 1992; Metcalfe 1995; Foray and Lundvall, 1996) deemed as the building bloc of SIs approach.

For instance, some of the historical reasons for selection of and the characteristics attributed to the notion of system are stated by Lundvall (2007) as, "[t]he original choice of the term 'system' (rather than 'network' for instance) referred to a few simple ideas. First that the sum of the whole is more than its parts, second that the interrelationships and interaction between elements were as important for processes and outcomes as were the elements and third that the concept should allow for the complex relationships between production structure (hardware), institutions (software) and knowledge". In addition to Lundvall's description as an important contribution in terms of connecting the dots among complexity, system and network relationships, innovation, is also understood as a social and evolutionary process today (Edquist, 2004). In this sense, Dosi (1988) highlights the role of internal and external actors as well as the importance of interaction among these actors in the process of innovation. Similarly, Lundvall (1992) not only underlines that innovation (system) should be seen as a social system, as learning is the most important issue in the innovation process and involves interaction between people, but also points out the importance of knowledge in modern production systems to continue and/or improve innovativeness. Therefore, production and diffusion/ dissemination/ distribution of knowledge result from actors and their interactions among each other via networks mainly determine success or failure of any types of SIs.

Being the basic input of innovation, knowledge cannot be produced by a single actor only but has to be obtained from the network established by the actors of SI; a notion that can be seen in the chain-linked model (Kline and Rosenberg, 1986), in which, innovation is seen as a non-linear and interdependent process. In other words, innovation processes involve the generation and application of knowledge, where the success or failure of any SIs depends mainly on how the knowledge of actors is integrated via networks (Foray, 2004), setting the structure of SI. With these networks, actors not only achieve dispersed specific and diversified knowledge, but also obtain more opportunities to increase their internal knowledge level (Kogut and Zander, 1992; Powell et. al., 1996). The reason for this, as emphasized by Allen (2001), is that the diversity among the actors of a system increases the effectiveness of the system. Diversity of actors of SI in terms of their knowledge base helps the system to adapt to the changing conditions. Since it is diversity which enables actors to evaluate and respond to the requirements of not only market, but also (actors of) system itself.

Unless new knowledge is introduced into the system, regardless of whether it is produced within the system or not, the actors of the system's "cognitive distance" (Noteboom, 1992 and 2005) start to become similar and the system encounters inertia or lock-in, a situation also called as core rigidities (Leonard-Barton, 1992), blind spots (Porter, 1980) and competency traps (Cohen and Levinthal, 1990), to name a few. To produce or access to new knowledge beyond, the system stimulates "symmetry-breaking" (Cilliers, 2001) in SI and inhibits it from excessive homogeneity in terms of knowledge, etc.

Therefore, the role and structure of network on the production and diffusion/ dissemination/ distribution of knowledge resulted from actors and their interactions, started to gain traction in the literature. For instance, Latora and Marchiori (2003) state that "[i]n fact, we have recently learned that the network structure can be as important as the nonlinear interactions between elements, and an accurate description of the coupling architecture and a characterization of the structural properties of the network can be of fundamental importance also to understand the dynamics of the system", as well as Cowan (2004), who argues that the studies on networks done by a number of well-known authors from diverse fields, such as Powell et al. (1996), Orsenigo et al. (1997), Uzzi (1997), Lazerson and Lorenzoni (1999) and Saxenian (1991) among others, "[a]ll of them observe that the "peculiar" properties of these industries can be understood by analyzing the agents' behaviour as part of a network structure, and that an important part of the way these industries function is determined by precisely who interacts with whom". As a result, related with networks' relations with knowledge, it can be said that networks should contribute to systems of innovation to obtain maximum benefit from knowledge diversity, interaction intensity, and knowledge production, which is depicted below as a well-known inverted U shape (Nahapiet and Ghoshal, 1998). The triangle shows the maximum point for knowledge production in Figure 6 .

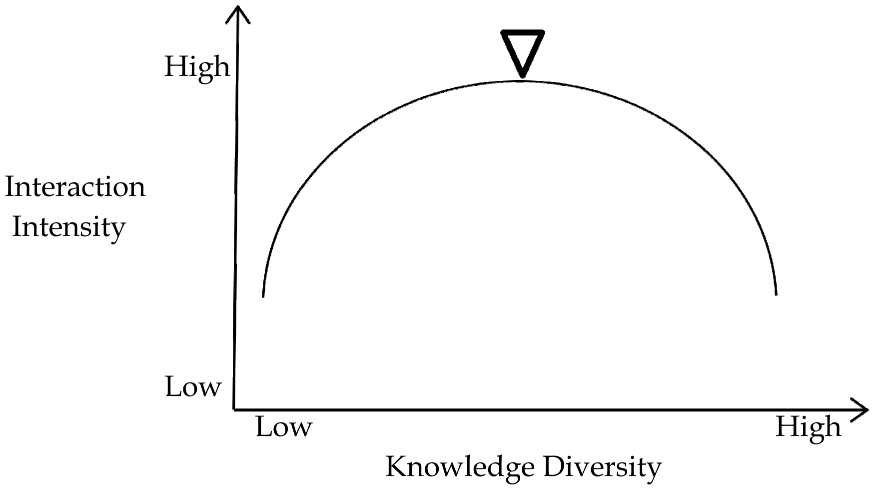

Figure 6 Role of Network for Knowledge Production and Diversity
Source: Nahapiet and Ghoshal, 1998

Therefore, in this Section, some basic points and touchstones of systems of innovation approach have been presented deliberately without diving deep into details; much effort has been spent to show relationships between SI, CSs and network studies. As can be seen in the above discussion, the studies conducted in the fields of SIs, complex systems and networks proceed in close theoretical tangent with each other and put forth similar arguments in different frameworks and contexts. In other words, similar to the historical evaluation of complex systems, Systems of Innovation approach shows an evaluation from the linear view to the systemic view, as discussed at the beginning of this Chapter. Put differently, we see that there is a growing emphasis on the importance of interactions among constituents of the Systems of Innovation, which is strongly emphasized in complex literature via discussions and analyses on micro-macro relations. Discussions on micro-macro relations in complex system push the authors studying complex systems to find appropriate tools for analyzing complex systems. Among others, network analysis gains importance in the analysis of complex systems. Similarities between complex systems and Systems of Innovation approach let the author of this thesis investigate whether there is a possibility to benefit from network analysis, like in complex systems, to analyze systems of innovation or not. Appropriateness of this question is discussed by focusing on the role attributed to the links in both systems of innovation and network studies. It is found out that both approaches underline the role of links in the production and diffusion/ dissemination/ distribution of knowledge.

Therefore, relationships among the Systems of Innovation, complex systems and network analysis were shown. Output of this relationship shall be used as an important component of the technical analysis to be made in Chapter 4, as well as the policy recommendations to be suggested in Chapter 5. Finally, a joint study that takes advantage of the efforts made in these three fields could not be found in the literature. The reason for the lack of such a study could very well be the absence of data, besides the obvious difficulties in putting together the studies done in three, in fact different, fields. In this study, while taking these concerns into account as much as possible, the effort has been made to benefit from the arguments of the SIs, complex systems, and networks literature. Thus, it is considered to have made a contribution to the related literature.

2.4 Framework Programmes and ERA

Following the World War II, in an effort to reconstruct Europe, a series of inter-governmental agreements and treatises were signed, and supra-governmental institutions were established in consequence. Among these, the European Coal and Steel Community was established as a consequence of the Treaty of Paris (1952), whereas the Treaty of Rome (1957) led to the formation of the European Economic

Community, and European Atomic Energy Community (EURATOM), enabled limited scientific co-operation among the participants. However, even in 1960s, there was no responsible unified structure at the European continental level to cope with the increasing technological gap between Europe and the US. In other words, throughout this period, research policies were mainly developed along different national paths and cooperation among countries was established via inter-governmental agreements. In response to this situation, the notion of 'European Science Area' was proposed (Thomas, 2002), which process resulted to the formation of the COST program (European Cooperation in the field of Scientific and Technical Research). Although it was implemented as an intergovernmental framework, this has been the first step for the establishment of European research activities, which aimed to reduce the fragmentation of research investments in Europe and allowed the coordination of nationally funded research at European level.

With the liberalization movements, the role of state and its relation with industry began to change. Power has started to shift from national levels to European level and on to the global level. In parallel with this shift, European level Programs started to change their logic as well. For instance, in the telecommunications sector, ESPRIT in FP1 and RACE in FP2 projects played critical roles in the determination of the common technology and communication standards, which helped producers to develop European telecommunication equipment (Umberto, 1994). Meanwhile, in 1985, EUREKA was established in order to increase competitiveness of European industry via supporting R&D, which in turn would produce products to be supplied to the market in a short time. Similar to the FPs given as example above, support shifted from the creation of national champions, to meeting the requirements of wider stakeholder groups via facilitating cooperation and competition, determining thematic areas (for instance, PREST proposed seven areas for scientific and technological cooperation in 1967), etc. Indeed, the first three FPs show more or less similar structures in terms of thematic areas. As such, the first three FPs focused on ICT, material technology, industrial technology, safe and clean (environment friendly) energy production and the like.

Following the Maastricht Treaty (1993), which enabled the Commission to lead the coordination of national research and technology development policies, and thus, widened the scope of FP, the aims for FP 4 (1994-1998) were set forth to encapsulate the basic and applied research as well as technology development and demonstration. The White Paper titled "Growth, Competitiveness, and Employment. The Challenges and Ways Forward into the 21st Century" (COM, 1993: 700), hereinafter "White Paper"), argued for the requirement of a more holistic approach. In other words, not only creation of jobs, improving the quality of education, training, opportunity for job flexibility and coordination for spending on research and development were underlined, but also, the "European paradox", which denoted the low performance for converting scientific knowledge into technological and industrial success, was taken into consideration in the mentioned report. The second important step in terms of breaking the previous approaches implemented before the FP5 was the Green Paper on Innovation (COM, 1995: 688), hereinafter "Green Paper"). Published in 1995, Green Paper on Innovation clearly argued for the importance of innovation for Europe and made propositions to overcome barriers hindering the awaited innovation performance. These propositions ranged from human resources, financing to research activities and legal issues as well as the role of public in innovation. Green Paper was followed by the First Action Plan for Innovation in Europe (COM, 1996: 589, hereinafter "First Action Plan"), which identified three main areas for action: creation of suitable conditions (framework) for innovation, fostering the innovation culture and emphasis on research and innovation. Specifically, the emphasis has been on the interaction of actors as a locus of innovation; in other words, establishment and sustainability of networks has been put at the center of policies. Arguments of these two major studies were reflected in FP 5 (1998-2002), in which, wider social benefits came to the agenda.

The European Research Area (ERA) was incepted by European Commission in the year 2000 to integrate scientific resources via providing and guiding multinational cooperation. Similar to the discussions during the first FPs, Communication on the ERA (COM, 2000: 6) argued the success of USA and Japan in the area industrial competitiveness, as well as ability of those to more effectively benefit from the results of research activities in social and economic areas. To deal with this situation and improve the competitiveness of EU, a unified research area was proposed which would in effect behave like a common market for goods and services. Therefore, ERA aimed to create "a unified research area open to the world based on the internal market, in which researchers, scientific knowledge and technology circulate freely"(ERA). At the Summit in Lisbon in 2000, EU "set itself a new strategic goal for the next decade: to become the most competitive and dynamic knowledge-based economy in the world", which is also known as Lisbon Strategy. In addition to Lisbon Strategy, at Barcelona in 2002, EU leaders agreed that "European research and development (R&D) must be increased with the aim of approaching 3 % of GDP by 2010, it also called for an increase of the level of business funding to two-thirds of total R&D investment"(CORDIS, 2009a), which is labeled as the 'Barcelona Target' and became an essential part of the ERA concept. According to Majo (2000), 3% target is not determined scientifically; on the contrary, it is appeared as a result of pragmatic recommendation by an expert panel:

> The Panel is convinced that the percentage of GDP spent in the EU on public and private RTD should rise to at least 3% over the next ten years. Higher levels will be necessary without parallel efforts to avoid duplication of effort across the EU. Private sector RTD expenditure will need to be stimulated if Europe is to keep pace with its competitors. The Panel recommends the use of indirect measures such as RTD tax incentives across the EU in order to flag to the rest of the world that Europe is an attractive place to conduct RTD.

Furthermore, discussion on the role of European Research Area continued in following years and finally, ERA 2020 vision (2008) stated that "by 2020 all actors should benefit fully from the "Fifth Freedom" across ERA: the free circulation of researchers, knowledge and technology." In other words, achievement of world-class research infrastructures, excellent research institutions, mobility of knowledge and researchers, opening of the ERA to the world are the main ambitions in the vision of ERA.

In 2007, European Research Council (ERC) was launched in Berlin to set up support for investigator-driven frontier research. Providing encouragement and support for the best scientific efforts, it aims to trigger scientific excellence in Europe. In the following months, Commission opened up a broad debate with the help of Green

Paper, "The European Research Area: New Perspectives", in order to create a unified and attractive European Research Area that would fulfill the needs and expectations of the scientific community, businesses and citizens. Lead Market Initiative (LMI) was started at the end of the 2007 with the collaboration of Member States, European Commission and the industry. It focuses on lowering the barriers in six sectors (bio-based products, renewable energies, sustainable construction, e-Health, recycling and protective textiles) to bring new products/services to the market. In 2008, European Institute of Innovation and Technology (EIT) was set up in Hungary to "address Europe's innovation gap"(EIT). It is EU's flagship education institute and aims at assisting innovation, research and growth in the European Union.

Therefore, probably, one of the important reasons for starting the FP was the observed gap between, USA and then Japan, especially in the area of information technology. Since then, the changing nature and conditions of global competition played a critical role in the evolution of FPs, from networking of the some sectors to become instrument, aimed to fund and coordinate scientific and technological research efforts. Especially, after the articulation of European Research Area (ERA) in 2000, FP has become one of the important tools of European research and innovation policy making. In accordance with these changes, the notion of European Added Value (summarized in Table 2) has also shifted from networking and scaling in order to add value to national efforts, to the coordination of Member States' policy activities, and supporting the EU-level policy development. More specifically, the framework of European Added Value was drawn by the Maastricht Treaty: action should provide efficiency, avoid duplication and rationalize effort, e.g., nuclear energy; provide more benefits which could not be obtained with by Member State alone; be transnational, e.g. in terms of communication or environmental issues. Until the FP6, the above stated vision was implemented with the exception of FP5, which only showed small differences. However, starting from FP6, and particularly in FP7, the number of participants in FP projects increased. This change is summarized best in their own words with the following statement by Achilleos (2005):

> Until now we have defined European Added Value as the collaboration of teams. Now it is time to bring a new definition to European Added Value, one that incorporates the principle of allowing a researcher in any of our member states to compete with all other researchers to win funding. Competition therefore becomes an essential new, forward-looking definition of European Added Value.

Finally, it should be stated that despite changing priorities, tools and thematic areas, several EU organizations succeeded to benefit from FP supports over many years on the whole. The shift from the technology gap idea, or 'technology push' model as well as the concentration on the creation of technology champions, to providing additional resources to members and creating a 'leverage' effect by enabling resource sharing via encouraging cooperation, may be considered as one of the important improvements in FP development. Currently[18], the following three criteria, based on the well-known 'market failure' argument, can be articulated to formulate theoretical rationale for subsidizing collaborative, precompetitive R&D in FPs:

1. Pre-competitiveness: In short, EU support does not include development of new products, process, etc. –i.e., the commercialization of knowledge. Rather, it supports activities related with basic research, demonstration, knowledge creation and dissemination, etc.

2. Subsidiary Principle: Activities shall be carried out at European level, if it brings more advantages than the implementation of those activities at member level.

3. Pre-normative Research: To develop norms, standards, regulation, etc., research activities related with knowledge production and technical know-how are supported.

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[18] In general, FPs are pre-competitive and collaborative programs, meaning many outputs of the projects funded under the FPs are usually to be used for increasing knowledge and networking; not for direct commercialization.

Table 2 Evolution of 'European Added Value'

Dimensions of European Added Value	**FP 1**	**FP 2**	**FP 3**	**FP 4**	**FP 5**	**FP 6**	**FP 7**
Scale too big for Member States (MS) to handle alone	X	X	X	X	X	X	X
Financial benefits: a joint approach would be advantageous	X	X	X	X	X	X	X
Combines complementary MS efforts to tackle European problems	X	X	X	X	X	X	X
Cohesion	X	X	X	X	X	X	X
Unification of European S&T across borders	X	X	X	X	X	X	X
Promotes uniform laws and standards	X	X	X	X	X	X	X
Mobilising EU potential at European and global level by coordinating national and EU programmes				X	X	X	X
Contributes to implementing EU policy					X	X	X
Contributes to societal objectives (later 'grand challenges')					X	X	X
Exploits opportunities for the development of European science, technology and industry					X	X	X
Structures the EU R&D community and 'fabric'						X	X
Improves quality through exposure to EU-wide competition							X

Source: ABAC 101908, 2011

2.4.1 Current Situation of Europe Union

Currently, FP7 (2007-13) has a €51 billion budget and several tools to improve the competitiveness of EU (SEC(2011) 1427 [2011]). In order to fill the gap between research and innovation, "Competitiveness and Innovation Framework Programme (CIP) was initiated for the period 2007-2013. Despite such efforts, evidence shows that the EU research and innovation system is not on par with its major competitors, as there are substantial differences between Member States in terms of capabilities and performance levels. These facts shall be presented in detail below; by benefiting from the IUS 2013 (Innovation Union Scoreboard 2013) study.

Although several rankings place EU Member States like Sweden, Finland, Germany, Denmark, and UK among the world leaders in terms of innovation performance, the rest of the Member States remain mid-range, and the aggregate performance of the EU27 lags behind that of US and Japan, despite their significant prevalence over the BRIC countries. In addition, China and India are quickly catching up with the former displaying a particularly rapid rate of relative improvement; where, if China keeps its last five years' rate of improvement, the performance gap with the EU27 shall diminish in a short term (Archibugi et. al 2009). Moreover, other Asian countries, which recently became to be dubbed as the new innovation hot-spots, such as South Korea and Singapore, are also on their way; for which, the Innovation Union Scoreboard 2013 depicts South Korea besides US and Japan to have a performance lead over the EU27. The US and South Korea fares better than the EU27 in 7 indicators, and Japan in 6 indicators. Emerging economies like Brazil, China and India with their increasing emphasis on R&D also point out to the fact that Europe began to lose its relative headway in the production of knowledge, as well as its share in publications, not necessarily because Europe does less, but rather, others do more. Europe is already behind US in worldwide excellent research with 32.4 % of the top 10 % most cited scientific publications in the year 2007, while the latter produced 34.2% thereof (European Commission, 2011). Soete et al. (2010) states that US also fares much better in terms of expenditure on higher education as a percentage of GDP with 3.3%, which is 1.3% in the EU27, which is mostly an outcome of the private sector funding of education in the US, paid at large by the student fees besides fewer philanthropic contributions (1.8% of GDP compared to 0.2 % in the EU). For instance, 2009 'Shanghai Ranking' lists 27 European universities among the top 100 of the world's universities, with 55 US universities therein (Shanghai, 2009). EU's academic research system, compared to that of the US' is less focused on high-tech related fields and emerging scientific disciplines or some scientific fields considered being the 'most dynamic' (Soete et al., 2010). There is apparently a potential shortage of R&D focused researchers in Europe to meet the R&D intensity target of 3% of GDP, for which, the Commission services (DG Research) estimate 1 million net additional researchers by the year 2020.

Parallel to these findings, EU inventive activities are more specialized in medium technology fields such as general machinery, machine tools, metal products and transport than in high technology fields such as pharmaceuticals, computers, office machinery, telecommunications and electronics (European Commission, 2007). As an important indicator of the productivity levels, business investment in R&D in the year 2008 was 1.21% of GDP in the EU, whereas 2.0% in the US; only Finland and

Sweden ranked above US[19]. For the same year, the 0.99% of the GDP was appropriated for R&D in the US budget, where the corresponding figure was 0.71% for the EU[20]. The R&D expenditure as a share of GDP, denoted as R&D intensity was 1.9% in the same year, despite the 3% target set at Barcelona; lacking behind both Japan (3.44% for the year 2007) and US (2.76% interim figure for 2008) and although exceeded that of China, which was 1.44% by the year 2007, it is a fast growing country as mentioned[21]. The 2009 targets set by the US and China for R&D investments were already in parallel to those of the EU, which is 3% of the GDP; for which the US already exceeded the EU and China seemed rapidly reaching thereof. By that time, India also initiated a programme called 'decade of innovation' to encompass huge investments in research, education and entrepreneurship. In 2007, the percentage of R&D personnel to total employment was 1.57% in the EU (57% in the public sector and 43% in the business sector), for which, the corresponding figure was 1.81% in faster growing Japan (38% in the public sector and 61% in the business sector)[22]. As seen in these figures, the US and Japan as the global innovation leaders perform much better than the EU27 in terms of business activity. This is an indicator of EU's weaker presence in industry; especially in the new-technologies-based sectors (such as ICT, nanotechnology, Biotechnology, molecular biology, and genetics) due to Europe's comparative incompetence in developing competitive new technology-based business practices. This, accompanied with the fact that despite the 53% standing figure for the year 2007 of 'innovative' companies in the EU, discerned by their introduction of new or improved products, processes, services, marketing methods or organizational changes; only 25% achieve these innovative adjectives in other national markets than their own, implying a failure to make use of the single market efficiently (European Commission, 2009).

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[19] Eurostat. 'Introduction'. European Commission - Eurostat. Accessed 1 October 2012. http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction.

[20] *ibid.*

[21] *ibid.*

[22] *ibid.*

Research investment in Europe also falls fairly behind of its major competitors; in the year 2008, the US invested 2.79% of GDP (283 billion Euros PPP), while the EU allocated 1.92% thereof (201 billion Euros PPP)[23]. In consideration of this fact, the European Council themselves stated in 2010 that the overall R&D investment level should be increased to 3% of EU GDP as Europe relied on a future with a largely research and innovation dependent growth.

On a similar account, knowledge production is concentrated in the hands of a certain number of Member States, as demonstrated in 10% of the most cited scientific publications and patents applications by country of application (European Commission, 2011). These figures are in a positive correlation with the ratio of public R&D expenditures made in these high ranking Member States compared to the rest. The portion appropriated by Germany, France, Italy, and United Kingdom for R&D from the 2010 budget made up to 64% of the total budget appropriations on R&D in the overall EU[24]. A distribution pattern similar to these countries can also be observed among regions as well (as shown in RIS 2012); for which, with the intensified global competition, it is necessitated to implement "smart specialization" approaches to strengthen the existing 'hot spots' of innovation, which would give the regions the edge needed both to determine niche developmental strategies that would allow them to meet local needs, and to survive through this evolutionary phase of knowledge-based societies (Foray and Ark, 2007; Soete et al., 2010). By and large, Europe's underachievement, as demonstrated in the RIS 2012 and IUS 2013 data, indicates not only the low performance in growth and jobs, but also the impediments hindering the completion of ERA. As such, the highly variable and fragmented way of structuring research in Europe at present is considered to lack a sufficiently encouraging approach towards open innovation, which is fundamental to improve the competitiveness and attractiveness of the European economy. In order to reduce this fragmentation among the research systems of Member States, and thus, remove the barriers against competition and cooperation, a more

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[23] *ibid.*

[24] 'OECD'. Accessed 2 January 2014. http://www.oecd.org/.

coordinated approach is obviously required; which, in turn, would foster the effectiveness of research at all levels (region, state and European level). Such an undertaking to reduce fragmentation and enhance effectiveness becomes even more significant when severe budgetary constraints are necessitated, e.g. in economic crises, which amplifies the importance of the returns on research investments in terms of innovation, economic, social and environment.

All in all, ERA and FPs today are accepted as the main drivers of research activities in Europe; even if EU-funded research comprises only about 5% of the entire funded research activities at the EU level. Another important challenge to be overcome by the notion of ERA is with regards to the huge inequality among the regions, which is clearly stated in EURAB (2005): "In order to achieve the Lisbon objectives, European policies should be focused on supporting all regions to achieve their potential for research and innovation". In this sense, Structural Funds is probably considered as the chief, tool for reducing disparities among the regions and increasing research and innovation capabilities of regions. However, at this time, how different tools can be used optimally is still a debatable subject; while one tool focuses on such notions as the most excellent, competitive, unique, etc., another emphasizes regional development. In short, currently, these instruments serve different audiences, and it is only hoped that Horizon 2020 provides a meaningful means for their integration.

2.4.2 Expected Future of European Union

Horizon 2020 (EU Framework Programme for Research and Innovation) is basically the new Framework Programme to be initiated after FP7. A general overview of the results from Horizon 2020's own website[25] and readings of numerous related publications shows that the aims set in Horizon 2020, along with the related assessments and analyses, are in line with those of most current programmes such as FP7, CIP, and EUREKA. In fact, Horizon 2020 combines "all research and innovation funding currently provided through the Framework Programmes for

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[25] 'Horizon 2020 - European Commission'. Horizon 2020. Accessed 2 January 2014. http://ec.europa.eu/programmes/horizon2020/.

Research and Technical Development, the innovation related activities of the Competitiveness and Innovation Framework Programme (CIP) and the European Institute of Innovation and Technology (EIT)"[26].

In other words, a cursory assessment of Horizon 2020 reveals that, as a programme to be implemented at the Union level, it aims for amplifying the value added by the Union to the Member States by adopting the targets and deeds that otherwise would not be easily undertaken as efficiently by the individual states per se. As such, a union level involvement in innovation and research framework strengthens the position of Member States 'via an optimal use of resources by coordinating efforts and reducing redundancy. As also underlined in the previous programmes, Union level intervention facilitates competitiveness at the continental scale through the selection process of the most appropriate proposals, which, in turn, contributes to the improvement of the levels of excellence in addition to the visibility of research and innovation practices. Such a scale also assists the trans-national mobility of researchers besides research itself; and the ability thereof to undertake high-risk and long-term R&D projects due to the risk distributive structure, promotes additional public and private investments in research and innovation, and thus, improves the European Research Network by expediting the free circulation, diffusion and commercialization of knowledge, technology and innovation. The targets, as such, can be put briefly as follows:

(1) European Union aims at establishing a sound European Research Area ("ERA") to reinforce the Union level technological and scientific foundations, which facilitates free circulation of both researchers and research subjects, i.e. scientific knowledge and technology; and in turn, flourishes a more competitive environment. This requires the EU to undertake activities to improve cooperation at the international scale, as well as to accelerate the implementation, development and dissemination technological and scientific research results (COM, 2012, 392).

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[26] *ibid.*

(2) Another aim of the European Union is the assurance of the required competitiveness conditions for the industries at the Union level. To achieve this aim, the EU needs to utilize better the industrial potential inherent in the innovation, research and development policies.

(3) Europe 2020 strategy (COM, 2012: 2020) is a key performance indicator for the European Union as it provides a set of objectives ranging from a knowledge-and-innovation-based economy, labeled as the "Innovation Union", to sustainable and inclusive growth; meaning a greener, more environment friendly union with a high rate of employment driven by the emphasized role of research and innovation in attaining social and economic welfare in addition to environmental sustainability. The target here is to attain by the year 2020 an R&D spending of 3% of the GDP in line with an innovation intensity indicator to be developed, for which, the so-called "Innovation Union" initiative lays out an integrated and strategic approach towards the subject matter and provides the framework thereof. As such, research and innovation leads all other Europe 2020 initiatives such as "resource-efficient Europe", which focuses on fostering European industrial policies, as well as European digital agenda. In this regard, research-and-innovation-related Europe 2020 objectives require more than ever the competence of the Cohesion policies to be effective in capacity building and achieving levels of excellence. As a result, Horizon 2020 concentrates on supporting activities covering the entire spectrum from research to market. As stated in COM, 2011; 48:

> Europe needs to make a step change in its research and innovation performance. As the Innovation Union pointed out, this requires research and innovation to be better linked. We should break away from traditional compartmentalized approaches and focus more on challenges and outcomes to be achieved, linking our research and innovation funding closer to our policy objectives.

Within this framework, it is expected from Joint Research Centre (JRC) to provide customer-driven scientific and technical support to the Union policies; from Knowledge and Innovation Communities, under the European Institute of Innovation and Technology, to contribute to the integration of research, education and innovation. Therefore, leveraging sufficient additional funding for research, development and innovation, it is expected that Horizon 2020 contributes to building/ developing an economy based on knowledge and innovation across the entire Union. In this way, it will not only support the Europe 2020 strategy and other policies to be implemented by the Union, but also contribute to the targets of European Research Area (ERA) stated as "[t]he Innovation Union must involve all regions. The financial crisis is having a disproportionate impact on some less performing regions and hence risks undermining recent convergence. Europe must avoid an "innovation divide" (COM, 2010: 546) between the strongest innovating regions and the others". Furthermore, Europe 2020 innovation headline indicators were determined to figure out whether the general objectives explained hereto are achieved or not. Three specific objectives are determined in order to attain the general objectives, which are: Excellent Science, Industrial Leadership and Societal Challenges.

Excellent Science: The basic aim of this specific objective is to improve the scientific capabilities and capacities of Union to force excellence, dynamism, and creativity of European research, which is in consolidation with the aims of European Research Area. The logic behind this specific aim is related with the economic model aimed by the Union to be based on smart, sustainable and inclusive growth. It is considered that in order to achieve the necessities of this model, there is a need for more than incremental improvements in current technologies. In other words, science-based innovation is thought to not only provide radical new knowledge, but also help Europe to be a leader in the technological paradigm that enables the productivity growth, competitiveness, wealth and social progress in the future. In this sense, Future and Emerging Technologies (FET) activities shall be used for fostering scientific collaboration on radically new, high-risk ideas and accelerate the development of the most promising emerging areas of science and technology[27].

Industrial Leadership: The second specific aim to be realized to achieve smart, sustainable and inclusive growth is Industrial Leadership or leadership in enabling and industrial technologies. To achieve this aim, this specific objective shall support

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[27] 'European Commission : CORDIS : FP7 : ICT : Future and Emerging Technologies (FET)'. Accessed 2 January 2014. http://cordis.europa.eu/fp7/ict/fet-proactive/home_en.html.

the activities such as research, development, validation, piloting, etc. in the field of ICTs, nano-technologies, advanced materials, biotechnology, advanced manufacturing and processing, and space. To specialize in these areas and become a world leader, supports shall be prioritized in the following Key Enabling Technologies (KETs), which are basically composed of micro-and nano-electronics, photonics, nanotechnology, biotechnology, advanced materials and advanced manufacturing systems (COM, 2009: 512) .

Societal Challenges: The aim of this specific objective is to develop/stimulate the critical mass of research and innovation efforts in order to tackle with the policy priorities and societal challenges identified in the Europe 2020. In this sense, support shall be provided in the following areas:

(a) Health, demographic change, and well-being;

(b) Food security, sustainable agriculture, marine and maritime research, and bio-economy;

(c) Secure, clean, and efficient energy;

(d) Smart, green, and integrated transport;

(e) Climate action, resource efficiency, and raw materials;

(f) Inclusive, innovative, and secure societies.

2.5 Conclusion

First Section of this Chapter took a considerable amount of time and effort to organize different and sporadic views into a coherent whole in lieu of an introduction. Put differently, a discussion on complex systems (CSs) in the scope of an academic effort is much more problematical than using the word ‘complex’ in everyday speech. In general, this part aims to make one of the theoretical discussions that will set the bases for the following Chapters of the thesis. What is complex system? What are the characteristics of complex systems? Reviewing the literature on complex systems, these are the key questions that I realized have been asked by many authors, but provided with no consensual answers; which set up the the basis of my argument in this study.

Despite different definitions and approaches to explain complex system, it is difficult to say that complexity is a theory in its entirety; however, it can at least be suggested that it is an approach reality, usually associated with networks and dissipative systems. Although criticized for inconsistency with Newtonian view, arguments by Prigogine and Stengers (1984) clearly stated that complexity approach brings new understanding the relationships between science and nature, reflected in the unpredictability and impossibility of stating general and indisputable laws about its dynamics and structure. In accordance with the statement of Prigogine and Stengers (1984), who underline the fresh view, at the end of first Section (2.1.1), a metric, related with the basic characteristics of complex system was developed, which will be used for establishing a metric to argue whether the system appeared as a result of Framework Programmes is complex or not in Framework Programmes and ERA in Chapter 4.

After a detailed discussion on CSs and developing a metric, literature on systems of innovation was taken into consideration within the framework of CSs. In other words, attention was drawn to the resemblance between systems of innovation literature and complex systems literature. In fact, this analysis is mainly triggered by widespread expression in systems of innovation literature, 'system of innovation is complex system'. On the other hand, there are a few studies, focusing on the complexity of system of innovation as well. As such, many concepts are conferred from complex system literature, such as, non-linearity, path dependence, ubiquity of innovation, open system, competition, cooperation, variety, selection, creative destruction, learning and unlearning, absorptive capacity, incremental and radical innovation, institutional infrastructure, punctuated equilibrium, diffusions, exploration and exploitation, unpredictability, to name a few (a summary of these findings was given in Table 2).

In other words, similar to the historical progress of complex systems, Systems of Innovation approach shows an evolution from the linear view to the systemic view, as discussed at the beginning of Section 3 (2.2.3). Put differently, we see that there is growing emphasis on the importance of interactions among constituents of the Systems of Innovation, which is strongly emphasized in complex literature via discussions and analyses on micro-macro relations (Morçöl, 2011). Discussions on micro-macro relations in complex system push the authors studying complex systems to find appropriate tools for analyzing complex systems. Furthermore, similarities between complex systems and Systems of Innovation approach also let the author of this thesis investigate whether there is a possibility to benefit from network analysis, like in complex systems, to analyze systems of innovation or not. Appropriateness of this question is discussed by focusing on the role attributed to the links in both systems of innovation and network studies. It is found out that both approaches underline the role of links in the production and diffusion/ dissemination/ distribution of knowledge. Therefore, relationships among the Systems of Innovation, complex systems and network analysis were shown. Output of this relationship shall be used as an important component in the technical analyses to be made in Chapter 4.

Network analysis has started to become an important ingredient for policy development and implementation phases as increasing number of actors, blurred boundaries and roles among actors, dispersed -especially tacit- knowledge, increasing interdependencies, etc., make network analysis techniques a good candidate for a policy development and implementation tool. In other words, while policy analysis "is finding out what governments do, why they do it, and what differences it makes" (Dye, 2013); network analysis enables policymakers to study on the structure and relational configurations. On the other side of the coin, any systematic failure (including market failure) is a potential topic that policymakers have to deal with (OECD, 1998). In this framework, network facilitation has recently been taken into consideration in innovation policy, despite little accumulated experience and know-how in this area. For instance, Peterson (2004) states "policy network analysis is never more powerful as an analytical tool than when it is deployed at the EU level' and 'few … would deny that governance by networks is an essential feature of the EU". In this sense, reduction of the failures stemming from network, or use of network at its most, to increase competitiveness and innovativeness, necessitates development and/or implementation of appropriate policies. In other words, networks "are an important component of national systems of innovation. An important function of science and technology policy is to strengthen existing innovation-related networks and to help build networks in areas where they are lacking." (OECD, 1992).

Today, the presumption of a linear relationship among science, technology, innovativeness, and competitiveness is deemed invalid, as discussed in Section 3. Instead, systematic approach is assumed, concerning how and where the performance of innovation system is weak (Edquist, 1997). For instance, Borrás and Edquist (2013) point at different types of instruments of innovation policy and makes three large categories of instruments used in public policy: "(1) regulatory instruments, (2) economic and financial instruments, and (3) soft instruments." However, except some international studies, it should be accepted that intervention policies of governing bodies are not developed within the framework of network approach (Hyötyläinen, 2000). In other words, although governing bodies have been implementing policy measures to obtain utmost benefit from the networks, research on networks has shown little interest in policy questions related with networks, though these policies have a high potential to be important ingredients in the development of appropriate policies.

Among many reasons that could be stated for this little interest in research on networks, in addition to the reasons for studies on networks being a new phenomenon explained in Section 2 (2.2), there are two other reasons why network analysis and policy relationship are understudied by researches. First is that a network may constitute of different ingredients; that is, policies developed/implemented may have to include: (1) different geographical dimensions, ranging from local to international; (2) different actors ranging from firms to universities; (3) different sectors ranging from furniture sector to biotechnology; or, (4) combinations of these. Second one is, as stated properly by Carlsson (2000) and Flap et al. (1998), network approach suffers from the explanatory power. Although it lets researchers to conduct analytical investigations, it has limited power to deduce clear assumptions to explain differences in policy outcome or change; in other words, they have limited ability to be an explanatory variable in constructing policy analysis. Therefore, making policy analysis benefiting from network approach is rather similar to taking a photo of the current situation; whereas how this picture is interpreted using network analysis has rarely been discussed by the body of literature on network and innovation. As a result, network analyses shall be used as an ingredient for policy recommendations within the Thesis scope in Chapter 5. To achieve this aim, FPs and ERA were discussed.

In Section 4 (2.4), a summary is provided on the "real politics" of EU with regards to the past and future of Framework Programs and European Research Area. There were two main reasons why FPs and ERA were discussed. First of all, thousands of networks are formed with the contribution of Framework Programmes. These networks both contribute immensely to European innovativeness and competitiveness, and provide the network data, which enabled the author of this thesis to make network analysis. Secondly, this data is critical not only for integrating complex system and systems of innovation approaches with network analysis techniques; but also to be used in network analysis for developing policy recommendations. Therefore, Section 4 enables the author of this thesis to make analytical studies with references to real policies of EU within the framework of complex system and systems of innovation approaches.

In short, EC started European Strategic Programme for Information Technology (ESPRIT), which then became a model for later programmes. In 1984, existing and/or proposed programmes were gathered under the First Framework Programme (FP1). Following the termination of FP1 in 1987, the Second (1987–1991) and Third (1990–1994) Framework Programmes were implemented, demonstrating the characteristics of technology-push model. At around the same time, systems of innovation view started to pervade policy advisory circles (Soete and Arundel 1993). In fact, reflection of this situation was seen in FP4 (1994–1998), in which, particular support were provided for such areas as diffusion of technology, integration of SMEs, training, and mobility. Employing a user-oriented approach, FP5 (1998–2002) was shaped specifically for solving societal problems and socio-economic challenges, as well as for increasing research capacity and capacity in cutting-edge technologies. In the last two decades, the role of innovation in the context of European development has grown in importance. Especially after Green Paper on Innovation (1995) and the First Action Plan for Innovation in Europe (1996), innovation policies have been taken into agenda as a tool for economic growth, competitiveness, and social cohesion (European Council, 2000; European

Council, 2005).Concurrently, the transition in innovation literature from linear view to systematic is also reflected in the Commission document[28]. Persistence of innovation literature on the role and importance of actors in the systems of innovation, led policymakers to provide support for cooperation among different actors; which process encouraged many networks to be established in EU. In this context, FP6 (2002–2006) may be regarded as an important break with previous FPs. It put the emphasis on S&T excellence and, technology push view in a somehow similar fashion to FP2 and FP3, through introducing new instruments (integrated projects and networks of excellence) and encouraging the increase in the number of partners in the projects to obtain critical mass. Moreover, it also endeavored to facilitate ERA in overcoming underinvestment in R&D, fragmentation of research, and coordination problems at different levels. FP7 aims to strengthen the scientific and technological base of European industry as well as encourage its international competitiveness, while promoting researches that support EU policies. Finally, "Europe 2020" launched by the European Commission in March 2010 as the 10-year-strategy, aims at smart (fostering knowledge, innovation, education and digital society), sustainable (making production more resource efficient while boosting competitiveness), and inclusive (raising participation in the labor market, acquisition of skills and fight against poverty) growth[29]. It has five targets consisted of, research and innovation; employment; climate change and energy; education; and social inclusion. With regards to ERA, "European Council has called for ERA to be completed by 2014" (COM, 2012: 392) to achieve Innovation Union targets. Therefore, ERA aims at the creation/development of an internal market, in which, researchers, scientific knowledge and technology circulate freely. It has five priority areas, which are "more effective national research systems", "optimal transnational cooperation and competition", "an open labour market for researchers", "gender equality and gender mainstreaming in research" and "optimal circulation, access to and transfer of scientific knowledge".

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[28] This transition can be explicitly seen in COM,2003:112.

[29] 'Europe 2020 – Europe's Growth Strategy - European Commission'. Accessed 2 January 2014.http://ec.europa.eu/europe2020/index_en.htm.

According to Horizon 2020[30] is the financial instrument in the implementation of Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. It is stated that Horizon 2020 will be complemented by further measures to complete and further develop the European Research Area in accordance with five priority areas, stated above. In other words, according to 2013 Progress Report (COM, 2013: 637), ERA is key to making research and innovation activities more efficient, and supporting smart, sustainable and inclusive growth. Therefore, integration of research and innovation in order to secure Europe's global competitiveness is becoming one of the more important agenda items with the Innovation Union. The repercussions of this situation from the point of this thesis are examined below. As discussed in Section 3 (2.3), the notion of innovation is best understood via benefiting from systems of innovation approach. Roles of and expectations from networks, founded with former FPs up till now, shall be changed with Horizon 2020. That is to say, the key focus is not just research but innovation with research in Horizon 2020, as one of the important tools for the Innovation Union. In consequence, policy development by analyzing networks established in previous FPs, the relationship of these networks with the innovativeness of countries/ regions, and the establishment/ development of ERA within the framework drawn by complex system and systems of innovation perspectives, not only contribute to academic research uniquely, but also to the discussions on innovativeness of Europe Union

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[30] 'What Is Horizon 2020?' Horizon 2020. Accessed 3 March 2014. http://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020.

CHAPTER 3

DATA and METHODOLOGY

The previous Chapter reviewed the body of literature related with this study. This Chapter presents the data, tools and methods employed in this Thesis, which shall be used in the analytical analysis to be done in Chapter 4.

As stated at the beginning, this Thesis focuses on the innovativeness of European Union with the purpose of developing policy recommendations in the end for increasing the innovativeness of European Union from the perspective of network analysis, systems of Innovation and complex systems approaches. In this sense, the first Section, *Data*, shall dwell upon the role and importance of data for making analytical studies. How data was obtained and handled for the aims of this study shall be presented. The three different databases that were rendered for the analysis shall be briefly explained and their role in this Thesis shall be presented.

This is followed by Section 3.2 on the tools that are used for developing Thesis methodology. First, concepts related with network analysis, as well as the software packages to be used for calculations of network characteristics shall be presented in this Section (theoretical bases for usage of network analysis within the scope and aim of the Thesis was explained in Section 2.2, *Network Studies* in Chapter 2). Then, the two major approaches to entropy, those of Boltzmann's and Prigogine's, shall be discussed, relating them to the arguments in this study.

Finally, blending database and tools, the Thesis method is presented along with the limits and boundaries to this research. In this way, method to be used in the analysis of the structure and evaluation of European Research and Innovation Network to be examined in Chapter 4, can be put forward.

3.1 Data

Data cleaning and standardization are time consuming processes that required redundant efforts during the preparation of data, but added comparatively little value to the thesis. On the other hand, it is obvious that precision of any analytical study is essentially based on accuracy of data. In this sense, data from Innovation Union Scoreboard (IUS), Regional Innovation Scoreboard (RIS), and CORDIS.are cleaned and prepared with the utmost care in order to make an analytical analysis of European Research and Innovation Network. The database constructed using thse three resources made possible the analysis to be used for developing policy recommendations in the final Chapter.

Basically, CORDIS "is the European Commission's primary public repository and portal to disseminate information on all EU-funded research projects and their results in the broadest sense"(CORDIS, 2009b). Participants of European Research and Innovation Network, modeled at three scales, are those, which participated into EU-funded research projects. Each participant has location information on regional and/or national level. IUS and RIS databases will be used to set up a relationship between the network established by CORDIS participants and the notion of innovativeness. IUS provides the innovativeness values of many Europe countries, as well as relative innovativeness values of some important countries vis-à-vis European countries. RIS, on the other hand, gives the innovativeness values of many European regions (NUT-2). Combining these three resources, a database was obtained for the Thesis, allowing us to focus on the innovativeness of European Union and develop policy recommendations for increasing the innovativeness of European Union from the perspective of network analysis, systems of Innovation, and complex systems approaches. How these three data resources are cleaned and used is elaborated separately.

3.1.1 Innovation Union Scoreboard (IUS)

Performance indicators were developed in response to a request made in the Lisbon Summit. They are expected to provide "a broad comparative overview of the performance of Member States in relation to the four themes, using currently available and internationally harmonised statistics" (European Commission, 2003). At present, the scoreboard consists of 3 main types of indicators (Enablers, Firm Activities and Outputs*)* in addition to 8 innovation dimensions, capturing a total of 25 different indicators[31].

Enablers specifies the main drivers of innovation performance external to the firm and contains 3 innovation dimensions. *Human resources* includes 3 indicators and measures the availability of a high-skilled and educated workforce. *Open, excellent and attractive research systems* includes 3 indicators and measures the international competitiveness of the science base. *Finance and support* includes 2 indicators and measures the availability of finance for innovation projects and the support of governments for research and innovation activities.

Firm activities indicates the innovation efforts at the firm level and contain 3 innovation dimensions. *Firm investments* includes 2 indicators of both R&D and non-R&D investments that firms make in order to generate innovations. *Linkages & entrepreneurship* includes 3 indicators and measures entrepreneurial efforts and collaboration efforts among innovating firms and also with the public sector. *Intellectual assets* captures different forms of Intellectual Property Rights (IPR) generated as a throughput in the innovation process.

Outputs indicate the effects of firms' innovation activities and contains 2 innovation dimensions. *Innovators* includes 3 indicators and measures the number of firms that have introduced innovations onto the market or within their organizations, covering both technological and non-technological innovations and the presence of high-growth firms. The indicator on *innovative high-growth firms* corresponds to the new EU 2020 headline indicator, which will be completed within the next two years. *Economic effects* includes 5 indicators and captures the economic success of innovation in employment, exports and sales due to innovation activities.

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[31] These data and the related IUS reports are available from European Commission website at 'Innovation Union Scoreboard - Industrial Innovation - Enterprise and Industry'. Accessed 1 May 2012.

http://ec.europa.eu/enterprise/policies/innovation/policy/innovation-scoreboard/.

3.1.2 Regional Innovation Scoreboard (RIS)

Regional Innovation Scoreboard (RIS) provides information on the innovation performances for regions. For instance, innovation performances of 190 regions were provided at RIS 2012. The objectives of RIS reports are similar to those of IUS reports at national level. Among 25 indicators in RIS, 12 are same as those used in IUS, 7 indicators are similar with IUS, and 5 indicators show some differences from those in IUS. Table 3 below gives a comparative summary of the indicators included in IUS and RIS.

Table 3 A Comparison of the Indicators Included in IUS and RIS

Innovation Union Scoreboard	Regional Innovation Scoreboard
ENABLERS	
Human resources	
New doctorate graduates (ISCED 6) per 1000 population aged 25-34	No regional data available
Percentage population aged 30-34 having completed tertiary education	Percentage population aged 25-64 having completed tertiary education
Percentage youth aged 20-24 having attained at least upper secondary level education	No regional data available
Open, excellent and attractive research systems	
International scientific co-publications per million population	No regional data available
Scientific publications among the top 10% most cited publications worldwide as % of total scientific publications of the country	No regional data available
Non-EU doctorate students as a % of all doctorate students	No regional data available
Finance and support	
R&D expenditure in the public sector as % of GDP	Identical
Venture capital (early stage, expansion and replacement) as % of GDP	No regional data available
FIRM ACTIVITIES	
Firm investments	
R&D expenditure in the business sector as % of GDP	Identical
Non-R&D innovation expenditures as % of turnover	Similar (only for SMEs)
Linkages & entrepreneurship	
SMEs innovating in-house as % of SMEs	Identical
Innovative SMEs collaborating with others as % of SMEs	Identical
Public-private co-publications per million population	Identical

Table 3 (continued)

Innovation Union Scoreboard	Regional Innovation Scoreboard
Intellectual assets	
PCT patent applications per billion GDP (in PPS€)	EPO patent applications per billion regional GDP (PPS€)
PCT patent applications in societal challenges per billion GDP (in PPS€)	No regional data available
Community trademarks per billion GDP (in PPS€)	No regional data available
Community designs per billion GDP (in PPS€)	No regional data available
OUTPUTS	
Innovators	
SMEs introducing product or process innovations as % of SMEs	Identical
SMEs introducing marketing or organizational innovations as % of SMEs	Identical
High-growth innovative firms - indicator not yet included	No regional data available
Economic effects	
Employment in knowledge-intensive activities (manufacturing and services) as % of total employment	Employment in knowledge-intensive services + Employment in medium-high/high-tech manufacturing as % of total workforce
Medium and high-tech product exports as % total product exports	No regional data available
Knowledge-intensive services exports as % total service exports	No regional data available
Sales of new to market and new to firm innovations as % of turnover	Similar (only for SMEs)
License and patent revenues from abroad as % of GDP	No regional data available

Source: RIS 2012

3.1.3 CORDIS

European Union has launched seven Framework Programmes for research and technological development since 1984. These Framework Programmes consider funding activities as key to link Europe's research excellence with transnational R&D networks; converging and integrating research activities within the Union, they have improved international research collaboration in Europe to a considerable extent (Luukkonen, 2001). The database used in this thesis was constructed from the entire raw data publicly available at the CORDIS website[32] of the European Commission, in addition to the CD containing CORDIS data, which was specifically requested and obtained from the Commission for the purposes of this study.

The CORDIS data underwent into a two-stepped process to be prepared for use in the Thesis database. In the **first step**, the publicly available raw data on the CORDIS website of the European Commission was scraped and dumped to set the basis for the Thesis database. In the **second step**, these results were checked and confirmed against the CD data provided by EC. Accordingly, a raw Thesis database was constructed, containing the following information: Programme Acronym, Project Start Date, Project End Date, Project Duration, Project Status, Project Title, Project Total Cost, Project Total Funding, Project Contract Type, Project Subject Index, Organization Size, Organization Type, Organization County, Organization City and Project Unique ID. The vast amount of data came with its own problems. It did not take long to realize, for instance, that researchers used different languages when entering in their project info, e.g. Munich or München, for the same German city. After a long process of correction and standardization, Open Refine[33], an open source software for cleaning big data was used in order to consolidate entries and minimize mistakes. Otherwise, same node in the network would have been counted as two different nodes, which would lead to data duplication and thus, serious miscalculations in terms of network characteristics. In this way, a total of 216,324 records were cleaned. Then, comparing the address and city information with the NUTS codes provided by Eurostat[34] (Table 32), NUTS-2 code of each entry (node), which were provided as an address and a city information, was obtained.

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[32] In their own words, "CORDIS - Community Research and Development Information Service, is an information space devoted to European research and Development (R&D) activities and technology transfer" European Commission. 'European Commission: CORDIS: FP7'. CORDIS. Accessed 9 January 2014. http://cordis.europa.eu/fp7/projects_en.html.

[33] Formerly known as Google Refine. Community Developers. Open Refine, n.d.http://openrefine.org/.

[34] Eurostat. 'Introduction'. European Commission - Eurostat. Accessed 1 October 2012.http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction.

Finally, before running the network analysis programs, the data obtained was rearranged in such a way that if a project has only one participant; if some essential information related with participants and/or project are missing as lack of coordinator name, funding, date, etc.; those projects were eliminated from the database, to be used in the network analysis. To make network analysis, database was rearranged. In other words, in order to select participants of projects as nodes and project among those participants as links, thousands pairs established. For instance, if A, B, C are the participants of the project, each of them is paired with others in order to prepare data to network analysis programs.

3.2 Tools

Relationships among entropy, network analysis, systems of innovation and complex systems were shown in Chapter 2, with discussions on the role, importance and use of entropy and network analysis in systems of innovation and complex systems studies. This Section deals with the tools used for developing the method. Starting with an overview of the basic characteristics of network analysis, it will present the software packages employed to analyze the network obtained from the Thesis database detailed in previous Section (3.1). Two approaches to entropy will then be summarized and used as inputs for analyzing the relationships among network structure, entropy and innovativeness.

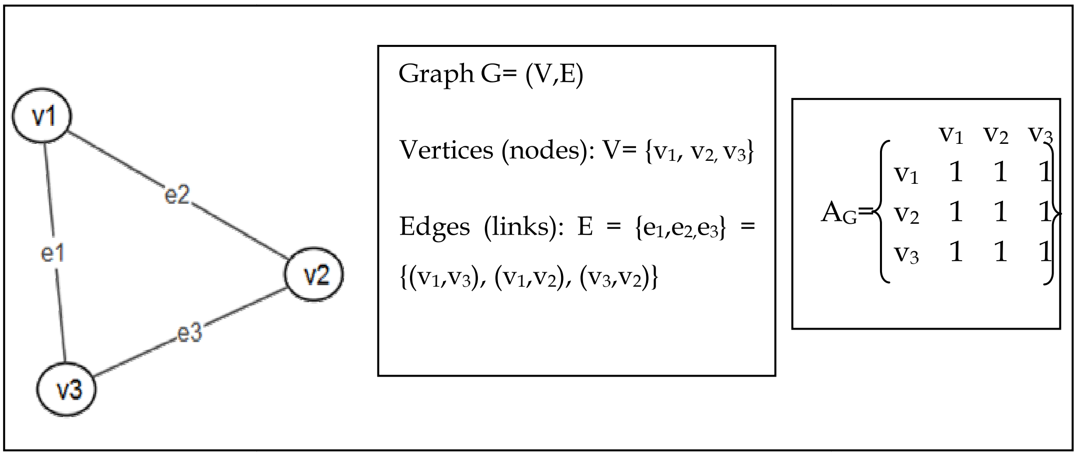
3.2.1 Network Characteristics

Network (Graph) is a set of nodes linked with each other by directed links (called *directed graph*) and/or undirected links (called *undirected graph*). A graph is an ordered pair of disjointed sets (V, E), where $V=\{v_1, v_2, v_3, \ldots v_n\}$ shows the set of vertices and $E=\{(v_1,u_1), (v_2,u_2), (v_3,u_3), \ldots, (v_n, u_n)\}$ shows the set of arcs. E is the subset of the Cartesian products VxV. If E is symmetrical, it is called *undirected.* Adjacency matrix (A_G), is used as a standard way to show a graph, as seen in Figure 7. Basic concepts used in network analysis and in this Thesis are itemized below.

Node (vertex, actor): The main unit of a network

Link (edge, tie): A line connecting two nodes

Directed Link (arc): A link is called directed if it goes only in one direction; e.g. gene-regulatory networks.



Graph G= (V,E)

Vertices (nodes): V= $\{v_1, v_2, v_3\}$

Edges (links): E = $\{e_1, e_2, e_3\}$ = $\{(v_1,v_3), (v_1,v_2), (v_3,v_2)\}$

$$A_G=\left\{\begin{array}{cccc} & v_1 & v_2 & v_3 \\ v_1 & 1 & 1 & 1 \\ v_2 & 1 & 1 & 1 \\ v_3 & 1 & 1 & 1 \end{array}\right\}$$

Figure 7 Basics of Network

Undirected Link: A link is called undirected if it goes in both directions, e.g. protein-protein interaction networks and social networks.

Degree: Represents the number of links linked to a node. Note that a directed graph is represented/measured by both in-degrees (incoming links) and out-degrees (outgoing links) for each node.

Degree Distribution: The degree distribution P(k) is defined as the probability of nodes with degree k in the network. For instance, while ER random graphs show Poisson distribution, many networks display highly heterogeneous distributions. In line with the classification of small-world networks behavior by Amaral et al. (2000), three types of classes can be defined: (1) when the degree distribution is low, the link distribution is single-scaled, showing a Gaussian distribution, e.g. power grid systems (Albert and Barabási, 2002); (2) as it grows, power law with sharp cut-off is obtained, e.g. protein interaction maps (Jeong et al., 2001), electronic circuits (Ferrer-Cancho et al., 2001); and (3) scale-free nets are observed when it gets larger, e.g. internet topology (Albert et al., 2000), scientific collaborations (Newman, 2001c). The topological characteristics of the last two cases, in particular, are investigated in terms of networks robustness (Albert et al., 2000; Albert et al., 2001), as explained below.

Path Length (Geodesic Distance): Represents the number of links that passes through when travelled between two nodes. *Shortest path length* is the length of the shortest route the between the two nodes. *Average Path Length*, used as a characteristic global property of networks, is the average of all shortest path lengths in a network, and is usually preferred to understand and measure the navigability of small-world characteristics of the network.

Clustering Coefficients: Clustering occurs if neighbors of a node are linked to each other and clustering coefficient C is the probability of neighbors of a given node being also neighbors of each other. Simply, *average clustering coefficient* gives the average of the clustering coefficients for all nodes.

Assortativity (Homophily): Characteristics of nodes also play a role in determining the establishment of links, which means that probabilities of connection between nodes usually depend on the types of nodes. This kind of selective linking is called *assortative mixing* (or *homophily*) and is usually seen in social networks. A special case of assortative mixing is called *degree correlation*, which analyzes the probability of establishing links among nodes with similar level (high, low, etc.).

Betweenness Centrality: The betweenness centrality of a node n is the fraction of the shortest paths between any pair of nodes in the network which pass through the n^{th} node. In other words, betweenness centrality points out to the node's importance in the overall connectivity of the network (labeled as *structural hole* by Burt (1992)), while number and strength of connections of a node is the measure of local centrality. For instance, Holme et al. (2003) show that although many substrates in biochemical pathways do not have the highest degree in the network, they usually have the highest value of betweenness centrality.

Closeness Centrality: Denotes the sum of theoretical distances from a node to all other nodes in a network (Freeman, 1979).

Eigenvector Centrality: A measure of node importance in a network based on a node's connections. In this sense, the eigenvector approach is an effort to find the most central actors (i.e. those with the smallest distance from others) in terms of "global" or "overall" structure of the network.

Hubs: Nodes with the highest degree but the least abundance are called *hub*s.

Graph Density: Measures how close the network is to become a complete (fully connected) network. A complete graph has all the possible edges and its density is equal to 1[35].

3.2.2 Software Packages

A number of software were used to make the necessary calculations and render graphical representations in the network analysis, the most relevant of which are listed below:

NodeXL: It is an open-source and free network analysis and visualization software package, run inside Microsoft Excel 2007/2010. It is preferred in this Thesis due to its ease of use.

Gephi: An open-source software for the visualization and analysis of large network graphs, with which networks for each region and country in all FPs were generated (see Appendix 2). It is preferred in this Thesis as it masters data visualization better than others tested by the author of this Thesis.

OutWit Hub: This is a tool to extract data from webpages, used to scrape publicly available project data from CORDIS website.

ORA: This is a dynamic meta-network assessment and analysis tool developed by CASOS at Carnegie Mellon University. It was used for rendering small scale simulations on the European Research and Innovation Network.

Radatools: A set of freely distributed applications to analyze Complex Networks, used to make assortivity calculations in the Thesis.

Region Map Generator: It is a tool to make map at regional and country levels with self-definition color, developed by CCIYY software.

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[35] There are many studies that explore the mathematical basis of network studies, such as Ted G. Lewis's "Network Science: Theory and Practice" (Lewis, 2009).

ArcGIS: A geographic information system (GIS) for working with maps and geographic information developed by ESRI. It was used for compiling geographic data and analyzing mapped information.

3.2.3 Boltzmann's Entropy

Basically, a macrostate of a gas is described by temperature, inner energy, pressure and volume, while a microstate of a system is portrayed by momentum (p_x, p_y, p_z) and spatial coordinates (x,y,z) of each point fulfilling the macrostates. There are many microstates and entropy measures the number of macrostates (or conditions) that can be fulfilled. Put differently, when entropy is 0 (zero), there is only one microstate, implying full predictability, which means there is no possibility for another microstate. On the other hand, when the entropy is higher, there are more possibilities for microstates, bringing a lower degree of predictability. From the SIs view, this situation can be explained as follows: the existence of more possibilities for microstates, indicating higher entropy, means that entities are capable to innovate. In other words, the higher the entropy, the higher the capability for innovation.

The explanation above can also be depicted in Boltzmann's entropy formula, a probability equation relating the entropy S of an ideal gas to the quantity W, which is the number of microstates corresponding to a given macrostate. Provided below, Boltzmann's formula shows the relationship between entropy and the number of ways atoms or molecules of a thermodynamic system can be arranged:

$$S = k \log W \text{ or } S = -\textstyle\sum_i w_i \ln(w_i) \qquad (3)$$

For instance, assume that there are events i (i = 1, 2, 3, …, n) occurring with probabilities w_i, $\sum_i w_i = 1$ and $0 \le w_i \le 1$. If an event is realized with absolute certainty $w_i = 1$, we obtain $S=0$ ($\ln 1=0$). Accordingly, the less probable an event is, the more entropy we obtain. Put differently, probabilities of w_i can signify the capability of genes to change/adopt a system; or occurrence of innovation in a system. Therefore, entropy is lower when probability is less distributed; or entropy is higher when probability is distributed evenly. As a result, lowest entropy means either maximum order (all microstates in one macrostate) or maximum certainty for outcome; while, highest entropy (equal distributions of microstates all macrostates) means either maximum uncertainty of outcome or maximum possibility for innovation. Assume that there are 8 events with different probabilities in three cases:

Table 4 Three Cases

	Case 1	**Case 2**	**Case 3**
Probability of w_1	0.02	0	0
Probability of w_2	0.02	0.01	0
Probability of w_3	0.02	0	0
Probability of w_4	0.02	0.02	0.16
Probability of w_5	0.02	0.08	0
Probability of w_6	0.02	0.04	0
Probability of w_7	0.02	0	0
Probability of w_8	0.02	0.01	0
Entropy (S)	0.0668	0.0590	0.0460

As seen in Table 4, the highest entropy is obtained when the distribution is equal. Boltzmann's entropy formula shall be mixed with methods used for network analysis in order to support policy suggestions to be made in Chapter 5.

3.2.4 Prigogine's Entropy

Based on discussions by Prigogine and Stengers (1984), it can be argued that in a closed system, we cannot see any exchange at all through the boundaries of the system due to lack of gradients, and consequently, the system reaches *equilibrium* (maximum entropy); a process which is irreversible. This means that the ability of a system's energy to perform work is terminated; in other words, entropy of an isolated system never decreases due to the second law of thermodynamics, resulting in a lock-in or *entropic death* (Saviotti, 1988). Furthermore, *dissipative structures* developed by Prigogine (1976) and other members of "Brussels school" are open systems. When open systems are included in the discussion of complex systems, we need to focus more on the production of entropy. Prigogine explained that sum of entropy is constituted by imported and produced entropy in open systems. In "dissipative structures", entropy is dissipated out of the system, which process increases the organization of the system at the expense of increased disorder in its environment. The existence of a dissipative structure is dependent on its openness to flux and self-organization capability for renewing itself. Therefore, open systems, which show the ability for self-organizing by exporting entropy via fluctuations and work under the far from equilibrium are called *dissipative structures* (Prigogine and Stengers, 1984). In other words, a dissipative structure denotes a system which is highly organized but always in process and the existence of which depends on the flux of inputs. In this framework, as one of the unique contributions of this thesis, relationship between entropy and European Research and Innovation Network is investigated from the view of Prigogine's discussions on the importance of open system.

3.3 Method

In terms of method, this Thesis achieves its unique approach via a blend of the database and tools constructed for its purposes. In this regard, a network modeled at three scales, called European Research and Innovation Network, is formed by using the database established for this Thesis in order to analyze and discuss the innovativeness of Europe, ERA, and complexity.

European Research and Innovation Network is analyzed at three different scales. The first scale, which will be called 'open network', is modeled by the network formed at the country level, in which nodes are all participants of the FPs (both European and non-European). As seen in Figure 8, drawn as an example to explain 'open network', there are 11 countries (nodes), 5 of which are outside Europe and 6 in Europe. As a second scale, a network, called 'closed network' is established by setting the countries, which are mentioned in IUS 2013 document as nodes. In this network, depicted in Figure 8, all countries are selected from Europe, which are also included in 'open network'. Finally, a network formed at NUTS-2 level is called 'regional network' (Figure 8) in which the same 6 nodes (NUTS-2 regions) are included.

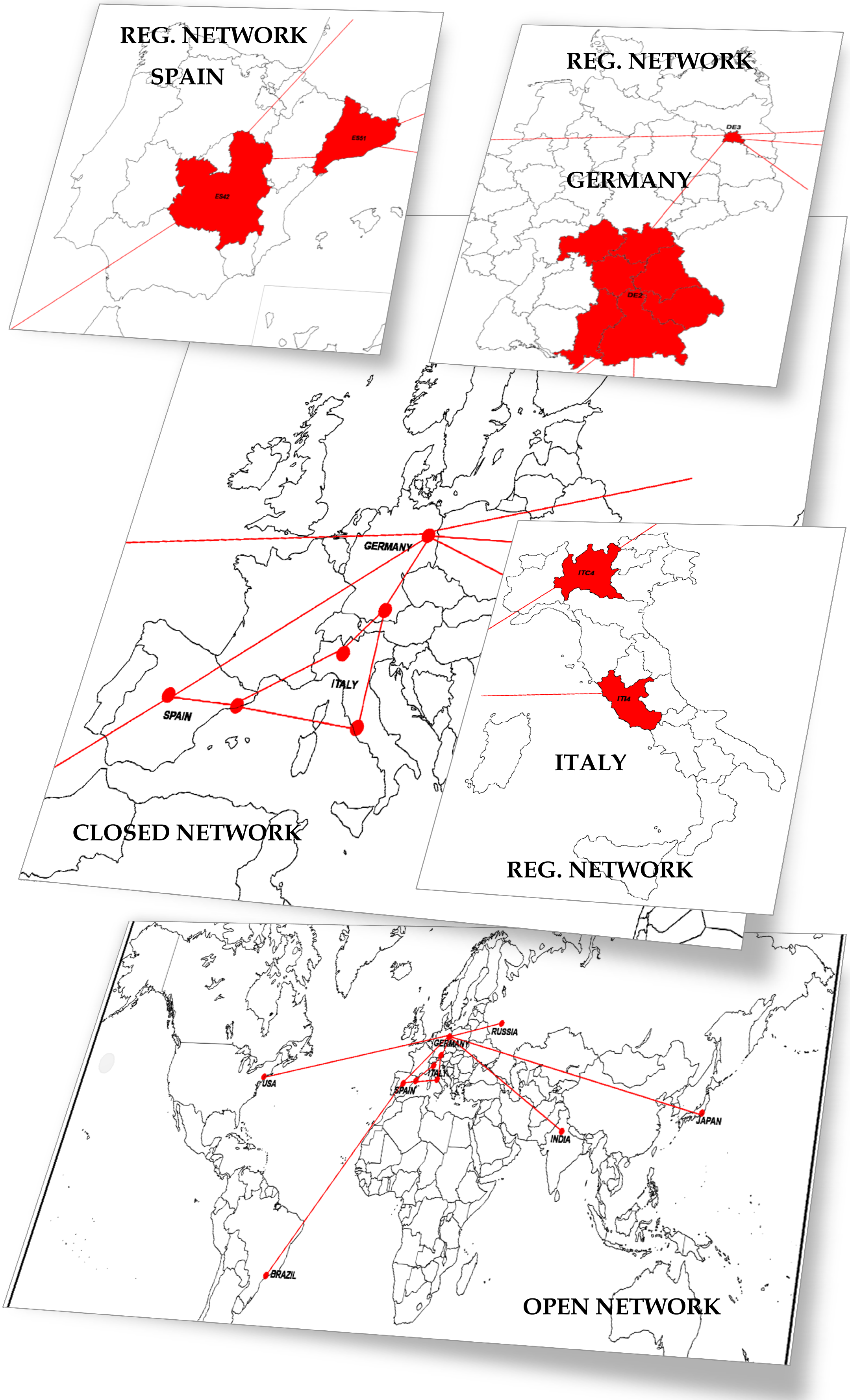

Figure 8 Three Types of Network

After modeling the European Research and Innovation Network at three scales, standard measurement techniques are applied to inspect network characteristics like path length, clustering coefficients, etc., which will be then be employed to explore this network in terms of innovativeness; as well as for analyzing ERA in terms of cohesion and competitiveness of Europe and for the complexity discussion. For an exploration of the relationships between characteristics of network and innovativeness of countries and regions (NUTS-2), which are also nodes in the European Research and Innovation Network, innovativeness values of countries and regions obtained from IUS 2013 and RIS 2012 respectively, are correlated with network values of 6 years.

Concerning ERA analysis in terms of whether it is as integrated as expected from FPs' network (or European Research and Innovation Network) to achieve, it is assumed that countries and/or regions can collaborate with other countries and/or regions without concerning geographical distance. While this assumption may seem too strong to capture whether ERA is integrated, it is appropriate when the integration and collaboration expectations from FPs and ERA are taken into consideration.

Regarding complexity, an analysis of the system labeled as European Research and Innovation Network in this thesis, which emerged as a result of policy and program implementations at the regional, national, and European levels, shall be made with reference to whether the mentioned system is complex or not, in accordance with the metric developed in Chapter 2.

Finally, the Thesis benefits from the notion of entropy in analyzing the innovativeness of Europe with an approach that highly diverges from the general usage and interpretation of the concept. As stated in Chapter 2, many studies focus on network entropy from the point of distribution of links among nodes. For instance, Mowshowitz (1968) developed an approach based on graph invariants such as vertex degrees, distances etc., and on an equivalence criterion to benefit from information-theoretic measures. Nishikawa et al. (2003) quantified the heterogeneity of complex networks using the standard deviation of degree. Sole et al. (2004) proposed using entropy of remaining degree distribution for heterogeneity, which is also discussed by Bar-Yam (2003), as detailed in Chapter 2. Wang et al (2005) suggested using entropy of degree distribution to measure the heterogeneity of complex networks. Wu et al. (2010) offered entropy of degree sequence as a measure of the heterogeneity of complex networks. Entropy is used for measuring the system's degree heterogeneity, which is defined as the *degree distribution* of the network (Albert and Barabási, 2002; Albert et al. 2000)[36].

Basically, if a network is consisted of telephone machines and lines, or web pages and links, where there are stable links among nodes; it may be meaningful to consider the role of links in terms of entropy analyses. As observed in these network examples, if there are concrete nodes and links among constituents of networks, it is meaningful to make probability calculations in line with Shannon's formula to find out the entropy of a network. On the other hand, when we talk about innovation, we cannot see concrete nodes and links among the constitutions of network. In this sense, as one of the unique contributions of this thesis, relationships between entropy and IUS are investigated from Boltzmann's and Prigogine's views.

Therefore, how theoretical discussions in Chapter 2 are put into practice in this Thesis is the topic of this Section, so as to set a base for the analytical studies to be conducted in Chapter 4. In terms of data, three types of databases were merged in order to obtain the Thesis database. Subsequently, European Research and Innovation Network are obtained via using data obtained from CORDIS. Characteristics of the network are calculated by benefiting from software packages. These characteristics are correlated with innovativeness values of nodes (either country or region), which are nodes in the network. In this way, Thesis can develop argument on innovativeness value of Europe. Again, distances among the nodes and number of projects are taken into consideration in order to put argument on whether ERA is completed or not. Then relationships among network structure, entropy, and innovativeness are discussed with benefiting from Boltzmann's and Prigogine's views (summary of methodology is given at the end of the Chapter 3).

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[36] For further reading on methods for measuring the entropy of graphs, please see Dehmer and Mowshowitz (2011).

In terms of research boundaries, it is fair to say that this Thesis has some unique characteristics, which are summarized below:

- It focuses on the system dimension of SIs, making use of the literature on complex systems. There are a few studies focusing on this issue.
- European Research and Innovation Network formed from database, consists of CORDIS, IUS and RIS, appeared as a result of policy and programme implementations at the European level, is investigated in terms of metric developed in the Thesis in order to analyze whether it is a complex system or not.
- "Often, network analysts are able to confirm that many FP networks have structural characteristics that should in principle enable them to perform certain roles well but are unable to relate these observations to evidence about actual performance." (Arnold et al. 2011); moreover, "[n]etwork evaluations look (still) mainly at the effects at network level, not at the impacts on the research and innovation system" (Weber 2009). In this context, the methodology developed in this thesis shall also contribute to the elimination of the valid criticisms brought up above.
- It is probably the first time a study discusses and makes policy suggestions for the innovativeness of EU by benefiting from the discussions and studies on CSs, SIs, and network studies.

Literature on topics and concepts discussed in this Thesis has been expanding rather rapidly; rendering any attempt to review related literature insufficient. On the other hand, utmost care was given to reach sufficient resources in order obtain a relatively stable theoretical framework. Moreover, academic resources were reviewed periodically during the preparation of the Thesis. In this sense, it is reasonable to assume that studies excluded in this Thesis shall not require important alterations to the results of the Thesis for a while. The discussion made in Chapter 2, not only reveals the impossibility of exact prediction in policy making via mathematical methods; but also argues that complex systems may become simpler or more complex during the phase transitions. In this sense, a set of policy recommendations were elaborated based on the data used and prepared as explained in Chapter 3, while cautiously refraining from any exact mathematical relationships. Regarding the network, established at three scales in this Thesis, the missing data in CORDIS database shall not be included in the database used for network formation. However, rest of data (details are given in Chapter 4) let the author make sufficient analysis for determining the characteristics of network. Moreover, analysis focuses on topological characteristics and evolution of European Research and Innovation Network, implying that specific characteristics and functions of single constituent, node of network, are disregarded (in short, all nodes are accepted equivalent and their types such as university, firms, etc are neglected). Finally, links among those nodes are accepted as undirected and unweighted as well as it is assumed that links connect nodes instead of any parts of them (department, people, etc.).

CHAPTER 4

ANALYSIS

Divided into six Sections, this Chapter shall present the analytical studies based on the discussions and explanations made in previous Chapters to provide support for the underlying argument of the Thesis. It is difficult to find researches making use of analytical studies to prove the theoretical arguments within the scope of this Thesis. In this sense, this Chapter may be accepted as one of the major contributions of the Thesis.

The first Section, 4.1 *Complexity*, will provide a metric, obtained from the review of complex system literature, in order to assess whether European Research and Innovation Network is complex or not. Among others, one of the items in metric, i.e. *Existence and Dominance of Central Authority*, will be discussed in terms of innovativeness of Europe and fulfillment of ERA.

The main focus of Section 4.2, *Network Structure* will be European Research and Innovation Network, where nodes are formed by countries and regions (NUTS-2). This section will start with an overview and critique of some studies conducted on networks established under the FPs. Based on the explanations on network in Chapter 3, *European Research and Innovation Network* will then be analyzed at two scales; *open network*, established by all participants of FPs, and *regional network*, established by regions (NUTS-2) stated in RIS 2012.

In the Section 4.3, *Network Structure and Innovativeness*, in addition to regional network explained in Section 2, as a third type of European Research and Innovation Network, undirected network (closed network) shall be established as well with the countries listed in IUS 2013 and participated into FPs. In this Section, discussion will be made on the relationship between innovativeness of countries and regions with network structure.

Section 4.4 *European Research Area* deals with ERA and seeks for some answers regarding whether ERA has been on the right track, or the system is as integrated as expected from FPs to achieve. In this regard, notion of distance will be used with network characteristics obtained in Section 4.2, *Network Structure*.

Section 4.5, *Network Structure, Entropy, and Innovativeness*, benefits from network analysis and entropy calculations in order to analyze the innovativeness of EU. In this Section, not only important finding is found related with increasing innovativeness of Europe and cohesion of ERA but also relationships between European Research and Innovation Network and important rivals are analyzed within the scope of the Thesis, which provided important finding for increasing the innovativeness of Europe and competitiveness of ERA.

Final Section (4.6) presents and discusses the main findings of the Chapter.

4.1 Complexity

Several studies related with complex systems were reviewed in the Section 2.1, *Complex Systems*, in order to obtain basic characteristics of complex systems, which enabled us to develop some sort of a metric. This metric was used to make the analyses in this Thesis within the theoretical framework provided in Chapter 2, in line with the approach followed by the author to fulfill the scope of the Thesis. However, the same metric could also be developed and employed with different models, as it is *approach-neutral* in the sense that it is not bounded to a single approach. For the purposes of this Thesis, an analysis of the system labeled as European Research and Innovation Network in this thesis, which emerged as a result of policy and program implementations at the regional, national, and European levels, shall be made in terms of whether the mentioned system is complex or not, in accordance with the metric developed in Chapter 2. Outcome of this analysis shall be used in Chapter 5 as an ingredient for policy recommendations. Relevant items from the metric obtained in Chapter 2, are grouped below with appropriate explanations.

1. Sufficient Number of Constituents and Rich Interactions among Constituents: As stated previously in Chapter 2, there is no value to be used for determining whether sufficient number of constituents in a network exists or not. According to Fifth FP7 Monitoring Report (2012), there were 79,167 grant holders and 706,888 links established between the years 2007-2011 in FP7. Therefore, it is safe to say that European Research and Innovation Network has sufficient number of constituents and rich interactions among constituents.

2. Existence of Emergence and Self-Organization at Different Levels: This assumption is not only the most important among those developed in Chapter 2.1, *Complex* Systems, but also probably among the most challenging of all assumptions made in the body of complex systems literature. Basically, networks are emergent structures at the macro level, resulted from the interactions of constituents at different levels. In this sense, FP7 is analyzed as a case to prove the existence of emergence and self-organization characteristics in a network. In this analysis, networks, established by the same nodes, are categorized in accordance with sub-programs. As observed in Table 5, although constructed by the same nodes, sub-program networks display different characteristics.

Table 5 Emergence and Self-Organization

FP7 and SUB-PROGRAMS	CLOSED NETWORK		REGIONAL NETWORK	
	Average Geodesic Distance	Average Clustering Coefficient	Average Geodesic Distance	Average Clustering Coefficient
FP7 NETWORK	1.06	0.943	1.80	0.68
COORDINATION	1.813	0.517	3.191	0.082
ENERGY	1.456	0.740	2.466	0.296
ENVIRONMENT	1.379	0.832	2.280	0.403
EURATOM-FISSION	1.523	0.742	2.752	0.242
EURATOM-FUSION	2.294	0.270	3.039	0.022
HEALTH	1.322	0.821	2.177	0.458
ICT	1.216	0.879	2.045	0.531
IDEAS-ERC	1.867	0.551	3.219	0.078
INCO	1.818	0.711	3.095	0.121
INFRASTRUCTURES	1.366	0.808	2.327	0.368
JTI	1.551	0.781	2.720	0.251
KBBE	1.410	0.810	2.270	0.409

Table 5 (continued)

FP7 and SUB-PROGRAMS	CLOSED NETWORK		REGIONAL NETWORK	
	Average Geodesic Distance	**Average Clustering Coefficient**	**Average Geodesic Distance**	**Average Clustering Coefficient**
NMP	1.363	0.794	2.201	0.450
PEOPLE	1.314	0.837	2.239	0.414
REGIONS	1.731	0.718	3.016	0.146
REGPOT	2.413	0.364	4.094	0.059
SECURITY	1.475	0.810	2.544	0.270
SIS	1.550	0.730	2.691	0.226
SME	1.399	0.778	2.272	0.430
SPACE	1.585	0.753	2.605	0.235
SSH	1.521	0.829	2.652	0.205
TRANSPORT	1.330	0.822	2.237	0.407

3 Rich Internal Diversity: In accordance with the existing literature on SIs overviewed in Chapter 2, each system of innovation has unique characteristics. Correspondingly, it can be stated that European Research and Innovation Network formed with the database as explained in Chapter 3, has a rich internal diversity. For instance, in FP7, there were 79.167 grant holders with different cultural, regional, social, etc., characteristics; implying that all nodes have their unique peculiarities.

4. Evolution, Adaptation, and Dynamic Characteristics: As detailed in Chapter 2, the aim and characteristics of FPs have changed over years in line with changing conditions (*evolution*). At the same time, some regions (NUTS-2) and countries participated in FPs more than others (*adaptation*). Additionally, in contrast to static systems, we see changes in the number of nodes and links, as well as in the overall structure of networks throughout the course of FPs, as seen in Table 8 and Table 9.

5. Cooperation, Coalition, Competition, and Conflict Behaviors among the Constituents: As explained in Chapter 2, these characteristics form an inherent part of Framework Programs. For instance, according to Fifth FP7 monitoring report (2012), between 2007-2011, 365,983 applicants submitted 79,145 proposals; 14,223 applications were signed with 79,167 grant holders.

6. A Distributed Memory and Learning Ability: As can be seen in Table 24 and Table 25 in Appendix, innovativeness value of each country and region change each year. More or less each has the ability to compete with others, demonstrating each has their own SIs with different capabilities for learning and institutional characteristics for memorizing at system level.

7. Dominance of Local Information without Excluding Global Information: Different centrality values of each country and region, as seen in Table 26, Table 27, Table 28 and Table 29 in Appendix, demonstrate that all give prominence to local information (clustering coefficient) and to reaching global information (betweenness centrality).

8. Lack of Centralized Authority and Distributed Structure in terms of Resources, Relations and Feedbacks, etc.: This measure can be argued to be valid for all FPs networks, except for the "lack of centralized authority" part, as there exists a centralized structure to decide whether a specific proposal is to be supported or not. Since, nodes (countries and regions) are the main source of resources (money, knowledge, etc.), relations are established voluntarily among them, and interactions do exist as per the first item above.

9. Autonomy (Organizational Closure): Implies the existence of common policies and implementations, such as, scientific and or/technological excellence; the quality and efficiency of implementation and management; and the potential impact though the development, dissemination, and use of project results for the evaluation criteria of 'Cooperation' programme in FP7.

In the light of the points above, European Research and Innovation Network can consequently be accepted as mostly complex. One problematic area is item 8, *Lack of Centralized Authority and Distributed Structure*, which can be interpreted disparately, based on the point of view. For instance, not only resources, relations, and feedback used in networks, but also technical—not administrative—experts, who evaluate the proposals, are provided by the EU members. From this aspect, it can be said that European Research and Innovation Network is mostly compliant with item 8. On the other hand, some may insist on the decisive role of Brussels and argue for the existence of a central authority. As a result, with the partial exception of item 8, it can safely be stated that European Research and Innovation Network is a complex system.

In fact, both discussions on item 8 and the networking of different actors that also constructs European Research and Innovation Network are related with the innovativeness of Europe and ERA as well. It has the inherent power to bring the current situation into centralization or decentralization or in between these two positions. Since, bringing together different actors within a network have the potential to increase convergence, or to trigger the realization of difference among the actors. In other words, networking of different actors, which may be accepted as part of different innovation systems with their unique institutional characteristics, play a critical role in determining the future of the EU, as stated earlier. In this regard, three alternatives may be speculated concerning the effects of networking activities. Relationships among the actors may trigger centralization in order to make effective and efficient planning, to prevent duplication in research activities, govern the major shares of public budget, etc. In this scenario, it is not unreasonable to expect a decrease in the power of national authorities and an increase in the power of regional authorities. In the second scenario, networking activities may trigger alienation among nodes due to heterogeneity of actors in terms of cultural, social, and economical differences and may end in decentralization. In this situation, regional, national and sectoral innovation systems as well as global firms compete with each other in order to obtain further benefits. This process may not only decrease the power of European Commission or related organizations; but also trigger an increase in demands for more autonomy from several regions, as well as strategic cooperation among those regions. As a result, this process increases the gap among the rich and poor nodes. Final scenario may be called a mezzo scenario, in which networking activities may trigger cooperation and competition at regional, national and European levels. Here, power and policies are neither centralized like the first case, nor distributed at regional level like the second case. In this case, while the EU level policies are determined and implemented with a focus on EU in its entirety by improving cohesion of different regions and competitiveness of EU to increase the overall welfare (for instance, the creation and development of ERA can be evaluated in the framework of the third alternative); other actors concentrate on their own strategies and implementations to increase competitiveness. Among all three alternatives, the first may be accepted as the worst case from the perspective of complex systems, as discussed above. Realization of both second and third cases is mainly related with policies preferred by policymakers. From the current situation demonstrated by the network analysis in this Chapter, it may be said that the gaps among the nodes are increasing, displaying a tendency towards consistency with the second scenario.

4.2 Network Structure

Since FP1, European Union has been promoting and supporting research and development collaborations via bringing together organizations in related fields to turn ideas into new products, services, and solutions in order to improve competitiveness. In fact, this support is based on the basic reason that knowledge is not only the most valuable resource and the source of competitive advantage (Kogut and Zander, 1992), but also is produced by combining previously unconnected knowledge, generating new knowledge; and/or by exchanging knowledge among actors. In short, it is believed that knowledge production is a social process and it can be produced by interactions of actors rather than as a creative act of a single individual or organization (Håkansson 1989, von Hippel 1988). Such assumptions led the researchers to analyze networks in order to understand the role of network structure for enabling exchange, combination, and the creation of knowledge (Kogut and Zander, 1992; Tsai, 2002; Tsai and Ghoshal, 1998).

A number of studies analyzed the networks established under FPs. Roediger-Schluga and Barber (2006) focused on the structure of R&D collaborations networks in the first five FPs, and found characteristics of complex networks. Breschi and Cusmano (2002) dwell on the R&D network established during FP3 and the first part of FP4. Investigating the network with the help of social network analysis and graph theory, they found the existence of small-world and scale-free characteristics. Protogerou et al. (2010) concentrated on R&D collaboration networks in the field of Information Society Technologies (IST) during FP4, FP5 and FP6. They found the existence of small-world structure as well as preferential attachment. All these studies focus on the projects and participants as nodes to determine the network structure. However, in this thesis, countries and regions (NUTS-2) shall be taken as nodes among which the network will be established, whereas the links will be the projects in the field of RTD. As such, before conducting the analysis, three points, considered important by the author of this thesis, should be brought to the attention of the reader.

One of the issues is concerned with the establishment of relationships between network structure and characteristics, thematic areas, and instruments in FPs, as pointed out by Atlantis (2009). It is assumed that sectoral characteristics shall determine the characteristics of the network. The general problem for this type of studies focusing on network structure established under the FPs is that there is no scale to be used for measuring the quality and importance of RTD studies. For instance, is it possible to say a project on energy or aeronautics, implemented under FP, has more RTD characteristics than such a project on biotechnology, or vice versa? The argument is that projects in energy or aeronautics or biotechnology implemented under FPs have RTD characteristics, implying that all may show the same specifications in terms of their network structure. Another problem in terms of network structure and sectoral characteristics arises with the assumption that network structure shall change in accordance with the codification of knowledge. However, it is not possible to assert that projects implemented 15 years ago in ICTs sector under FP4 have less RTD characteristics than projects currently in progress under FP7. This is due to the fact the projects 15 years ago were implemented as per the conditions of the day, according to the then-current RTD concerns. Put differently, can we say knowledge related with ICTs has already been transferred from tacit to codified? Therefore, every project supported under the FPs possesses RTD characteristics and as such, it is not reasonable or possible to establish relationships between network characteristics and sectoral characteristics due to lack of sufficient knowledge regarding the exact nature of relations.

Second concern is related with 'scratching method' to develop network policy. There is a general tendency to support scale-free and small-world types of networks in the literature, as they are considered to have a positive effect on increasing knowledge transfer or robustness of the networks. Notwithstanding the positive effects of those network types, it is not satisfactory to propose characteristics of scale free or small-world types of networks in each and every network policy analysis without focusing on the network's own characteristics; despite the general tendency in the literature to use them as panacea. As discussed by Kogut (2000), network is an emergent structure and its characteristics are determined mainly by interactions among nodes, rather than exogenous factors. In this framework, policies related with networks should be determined in accordance with the self-possessed characteristics of network, instead of 'scratching method'.

Finally, it is a well-known argument that densely connected networks, *strong tie networks*, are suitable for diffusion and exploitation of existing knowledge; while *weak tie networks* are suitable for exploration of new knowledge. There are different studies for or against this general tendency in the literature. Rowley et al. (2000) argued that while low density and weak ties are appropriate for exploration; high density and strong ties are suitable for exploitation activities. On the contrary, Hagedoorn and Duysters (2002), confront Rowley et al., by arguing that dense network and redundancy in ties are preferable in dynamic environments characterized by rapid technological change. Nooteboom and Gilsing (2004) stay between those views and argue that strong ties are needed for the transfer of highly tacit knowledge; while non-redundant and weak ties may be suitable for identification of knowledge. Furthermore, Nooteboom and Gilsing (2004) also argue in favor of combining both exploration and exploitation notions, as well as transfers from one to another. As illustrated by the examples, each network is unique and there is no on-the-shelf rule to be observed when the network is investigated. Therefore, relationship between sectors and types of ties (strong vs. weak) has not been analyzed in this thesis; since all networks established under the FPs aim to promote and support research and development collaborations.

Based on the commentaries made above and in Chapters 2 and 3, two types of networks[37] shall be derived and analyzed from the European Research and Innovation Network, which itself is an undirected network[38]. These two types of networks are differentiated on the basis of the types of participants of networks. Accordingly, the first one is open network, nodes of which are comprised of all the countries (list of countries is given in Table 30 in Appendix) participated into FPs; and the second one is region network, nodes of which are comprised of NUTS-2 regions (list of NUTS-2 is given in Table 30 in Appendix) participated into FPs.

As detailed in Chapter 3, inconsistencies in the raw data obtained from CORDIS and EC were removed from the database to be able to use it in network analysis. As such, not all information regarding the projects and participants could be obtained from the raw database. For instance, some projects lacked budget information, while names of participants, or project durations were missing in others, etc. After cleaning the missing information, the results shown in Table 6 below were obtained.

To calculate values of each network, number of projects and participants were obtained by deleting incomplete data in the raw database. For instance, according to the raw database, there were 40,097 participants and 12,386 projects in FP4. On the other hand, when start and end dates of projects in FP4 is examined, it is found that there were 41,988 participants and 12,815 projects in FP4. When data was deleted in accordance with two criteria (program name and date), 36,320 participants and 11,108 projects could be obtained as input for FP4 network. Again, relationships among number of participants in projects, average durations, cost and funding are also investigated. Correlation coefficients calculated among those are shown in Table 7. As per the results, the increase in the number of participants have higher positive effects on the number of projects, as well as average durations, cost and funding of the projects. Furthermore, the increase in the number of the partners in

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[37] In fact, three types of network are established. The last one (closed network, consisting of countries participated into FPs and mentioned in IUS 2013) shall be discussed in Section 3 of this Chapter.

[38] Instead of directed networks, undirected networks are established, due to mutual transfer of information, knowledge, etc., among the project participants.

the project is in harmony with the recommendations from evaluation studies of FPs, which point highlights the importance of decreasing administrative procedures.

Table 6 Data Cleaning

FPs	Before Cleaning				After Cleaning					
	# of Participants (FP)	# of Projects (FP)	# of Participants (Date)	# of Projects (Date)	# of Participants	# of Projects	Average Duration of the Projects	Average Cost of the Projects	Average Funding of the Projects	# of Partners (Per Project)
FP1	3009	1299	3786	1038	2742	1210	38.89	499,804.00	499,804.00	3.09
FP2	9810	3243	8037	2956	9811	3243	27.25	1,529,100.26	225,400.39	4.45
FP3	20061	4968	22820	6200	18372	4163	33.48	1,705,682.86	1,695,475.55	5.23
FP4	40097	12386	41988	12815	36320	11108	31.72	2,034,997.44	1,105,486.87	4.03
FP5	52711	9633	59432	13747	47456	8467	46.95	3,243,759.64	1,926,101.74	6.04
FP6	58328	8826	69068	12368	51690	8146	39.96	7,537,105.71	5,783,355.72	6.61
FP7	58761	8386	64380	8909	58122	8243	39.39	6,338,540.60	4,269,276.60	8.67

Table 7 Correlation Coefficient among Number of Participants, Average Durations, Cost, and Funding

	# of Participants	# of Projects	Average Duration of the Projects	Average Cost of the Projects	Average Funding of the Projects
# of Participants	1.00				
# of Projects	0.74	1.00			
Average Duration of the Projects	0.79	0.45	1.00		
Average Cost of the Projects	0.82	0.36	0.55	1.00	
Average Funding of the Projects	0.78	0.33	0.55	0.97	1.00

Region (NUTS-2) Level:

As seen in Table 8, we observe that average clustering coefficient first increases sharply from FP1 to FP2, and then keeps increasing steadily until FP7. At the same time, average path length (average geodesic distance) shows only a little decrease from 2.14 to 1.80 through FP1 to FP7. Except for FP1, power law value ranges between 2.20 and 2.60 in the network (as explained in Chapter 2, power law value usually ranges between 2 and 3 in scale-free networks). In addition, starting from FP1, value of average degree rises; which means that the capacity of regions (NUTS-2) increases in terms of maintaining links with others. Number of unique and duplicated values increase from FP1 to FP7. When their increases are compared, it is observed that the increase ratio of duplicate values is much higher than that of unique values, which means vertices (NUTS-2) primarily prefer to establish a link with the existing ones, instead of new ones.

Table 8 Network Characteristics (Regional Level)

Graph Metric	**FP1**	**FP2**	**FP3**	**FP4**	**FP5**	**FP6**	**FP7**
Graph Type	Undirected						
Vertices	189	223	271	281	298	309	322
Unique Edges	1195	2166	3137	4230	5187	5359	5421
Edges With Duplicates	2487	11751	14472	33291	41352	44510	60877
Total Edges	3682	13917	17609	37521	46539	49869	66298
Self-Loops	218	878	833	1987	3746	2337	3572
Average Geodesic Distance	2.14	1.92	1.94	1.83	1.79	1.82	1.80
Graph Density	0.10	0.17	0.16	0.24	0.26	0.25	0.25
Assortativity (wh)	- 0.011	- 0.017	0.003	0.015	0.035	0.018	0.004
Average Degree	19.429	38.278	44.266	67.480	77.054	77.974	81.814
Average Clustering Coefficient	0.4690	0.6323	0.6322	0.6888	0.6850	0.6761	0.6801
Power Law	3.12	2.60	2.58	2.20	2.40	2.28	2.37
Average Betweenness Centrality	108.45	102.71	127.66	117.53	117.98	127.62	130.01
Average Closeness Centrality	0.0025	0.0024	0.0019	0.0020	0.0019	0.0018	0.0018

Again, from FP1 to FP7, self-loop value increased from 218 to 3,572, implying an increase in the number of project partners participating into projects from same region. In other words, there is not only an increase in integration at region level, which indicates that integration of European Research Area has already been moving toward being closer, but also in the integration of NUTS-2 regions inside. Finally, at NUTS-2 level, disassortative mixing is observed due to correlation coefficients ranging between -0.017 and 0.035, implying nuts are virtually uncorrelated by degree.

Country Level (Open Network)

As seen in Table 9, we observe that average clustering coefficient first decreases sharply from FP1 to FP3, and then increases sharply until FP4; finally stabilizing around 0.75. Similarly, average path length (average geodesic distance) increases from 1.56 to 2.22 followed by a decrease around 2 at FP7. Except for FP1, power law value ranges between 2.39 and 3.02 in the network (as explained in Chapter 2, power law value usually ranges between 2 and 3 in scale-free networks). In addition, except from FP1 to FP2, value of average degree rises from 10 to 18.619; which means that the capacity of countries (countries in IUS are included) increases in terms of maintaining links with others. In fact, it is found that average degree value of closed network, which includes countries stated in IUS 2013, increases from 12.667 to 30.606. When the change ratio is compared, it can be easily realized that capacity of European countries in terms of maintaining links with others increased much more than that of non-European countries, as it is expected. Number of unique and duplicated values increases from FP1 to FP7.

When their increases are compared, it is observed that the increase ratio of duplicate values is much higher than that of unique values; implying vertices (countries) mostly prefer to establish links with the existing ones, instead of new ones. From FP1 to FP7, self-loop value increased from 796 to 11,281; which means there has been an increase in the number of project partners participating into projects from same country. In other words, there is not only an increase in the integration at the region level, which indicates that integration of European Research Area has already been moving toward being closer, but also in the integration of country inside. Finally, disassortative mixing is observed at country level due to correlation coefficients ranging between -0.049 and - 0.009, implying nuts are virtually uncorrelated by degree.

Table 9 Network Characteristics (Open Network)

Graph Metric	FP1	FP2	FP3	FP4	FP5	FP6	FP7
Graph Type	Undirected						
Vertices	21	67	111	139	144	152	168
Unique Edges	21	96	177	339	316	416	437
Edges With Duplicates	3490	12830	20700	45013	51952	57237	74439
Total Edges	3511	12926	20877	45352	52268	57653	74876
Self-Loops	796	2297	3694	6899	7247	8158	11281
Average Geodesic Distance	1.56	2.22	2.17	1.99	2.01	1.98	2.00
Graph Density	0.44	0.10	0.07	0.10	0.10	0.12	0.11
Assortativity (wh)	- 0.011	- 0.037	- 0.009	- 0.049	- 0.023	- 0.022	- 0.016
Average Degree	10.000	7.164	8.234	13.525	14.667	17.842	18.619
Average Clustering Coefficient	0.7862	0.6008	0.5987	0.7744	0.7755	0.7466	0.7616
Power Law	0.94	2.39	2.97	2.93	2.77	2.84	3.02
Average Betweenness Centrality	6.38	41.46	65.50	69.30	73.37	74.61	84.87
Average Closeness Centrality	0.0320	0.0069	0.0042	0.0037	0.0035	0.0034	0.0030

An analysis of the data shows that starting from FP1, the degrees of country or region (NUTS-2) embeddedness and network stability are high, which means that a small number of regions or countries are interconnected with each other and enter into the network much more than the average number of participants (regions or countries). In other words, most regions or countries enter into the network via connecting with central regions or countries.

Additionally, in both types of networks we see an increase in average betweenness centrality and decrease in average closeness centrality values. According to Borgatti et al. (1992), the decrease in closeness and increase in betweenness can be accepted to indicate increase in social capital. In this sense, it can be said that social capital in FPs has been increasing since FP1. This situation can be explained benefiting from the notion of path dependency. That is, successful project management capabilities and experience acquired in the past projects let those actors to become coordinators or participants in the following projects. Acquired experience and project management capabilities may also let them decrease the marginal cost of coordinating or participating into each additional project. Furthermore, visibility or reputation attained makes them attractive partners for the newcomers, demonstrating the notion of preferential attachment. Finally, experience in past projects may also decrease the transaction cost among partners in subsequent partnerships, which process has the potential to augment mutual trust and understanding, as well as collaborations.

The critical question is whether this oligarchic structure brings benefit to European competitiveness and innovativeness or not. In fact, there is no clear and exact answer for this question. For instance, Uzzi (1997) discusses the negative effects of over-embeddedness in fashion industry, stating, "the same processes by which embeddedness creates a requisite fit with the current environment can paradoxically reduce an organization's ability to adapt". Put differently, Uzzi argues that redundancy among actors and their ties prevent the sector to adapt to changes (*lock-in*). This situation is tackled in network literature with the concept of *structural holes* (Burt, 1992) and *social capital* (Coleman, 1988), or *strong ties vs. weak ties* (Granovetter, 1973).

Burt (1992) suggests that a firm gains competitive advantage when it fills in a structural hole existing among the dense group of firms. Contrary to Burt's structural hole argument, Coleman (1988) proposes that staying in a dense network with cohesive ties brings competitive advantage to a firm due to repeated interactions with stable partners. Similar to the structural hole vs. social capital argument, Granovetter (1973) argues that weak ties enable the organization to acquire new information, knowledge, etc. (exploration), while strong ties allow the organization to achieve efficient and effective transfer of tacit knowledge (mutual understanding, trust, etc.) among partners (exploitation). In another study, Rowley et al. (2000) examined the relationship between the performance of the firms and the types of ties (strong and weak), as well as the density of network (close and sparse) in semiconductor and steel industries. They found that strong ties are beneficial for exploitation where uncertainty is high and competitive pressure is high, while weak ties are beneficial for exploration where there is high technological uncertainty. Therefore, there is no one-for-all answer to respond whether repeated interaction with same partners or entrance of new partners in the network is beneficial or not.

It is stated above that the increase in the number of project partners is compatible with the recommendations from evaluation studies (Expert Group, 2010), which underlines the significance of curtailing administrative procedures. On the other hand, this may potentially have a negative effect on project performance, as the increase in the number of partners in a project shall probably decrease the interaction probability among the partners, at the expense of the time required to trust each other. In this sense, as much balance among partners as possible shall be taken into consideration in the evaluation of the proposals. In other words, while previously collaborated partners facilitate the establishment of trust and working practices in a project; newcomers can inject new information, knowledge, etc. Therefore, previously collaborated partners may assist in the solution of problems and initiate the trust-building process; collaboration with newcomers may bring new knowledge and information and help decrease differences at national and regional (NUTS-2) levels in terms of knowledge and experience.

As a visual cue for the network relationships, discussed until now, heat maps at the country and region (NUTS-2) scale are drawn and analyzed. Heat of each country or region is determined in accordance with the number of total projects that the country or region in question participated throughout all FPs (Figure 9and Figure 10). In addition, relationships among the nodes (countries and regions) are drawn for each FP at three scales to provide a visual supplementary for the Thesis, and colored in order to enable reader to follow changes in the relationships among the actors virtually (see Figures in Appendix between 16-36). These two tools of analysis, networks and maps, reveal some interesting findings. According to the analysis, if two nodes, nations, or regions, previously participated into a project, they show an inclination to participate into new projects. Moreover, there is also a tendency to participate into new project with previous coordinator.

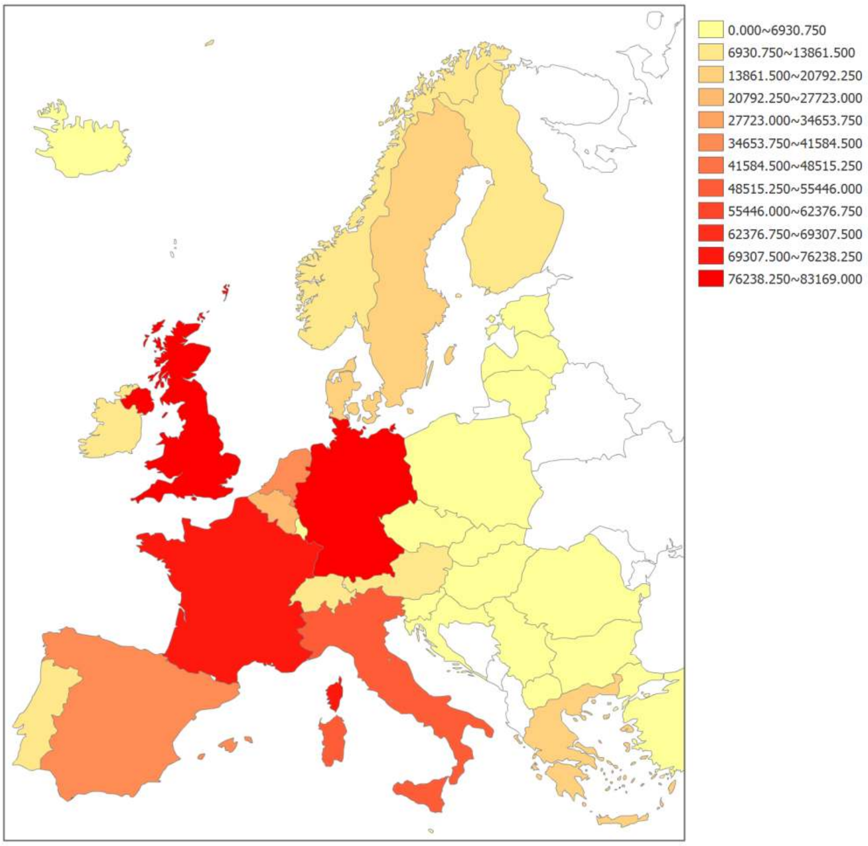

Figure 9 Number of Projects (National)

As illustrated in Table 7, duration and funding of the project are in a positive correlation with the number of participants, implying that interaction probability of potential participants is increasing with the duration and funding of the project.

As a result, shared characteristics of both networks such as scale-free degree distributions, relatively low average path length, high clustering, low assortativity values, etc. throughout the FPs in both networks, may be accepted to indicate not only the existence of complexity but also unchanging characteristics of network formation mechanisms, despite changes in FP rules. All networks show small-world characteristics, they have relatively high clustering coefficients and short path lengths, meaning the structure of network supports knowledge creation and knowledge diffusion (Cowan, 2004). Analysis of participants in FPs demonstrates that same organizations participate repeatedly in FPs and continue to cooperate with each other. Furthermore, increasing clustering coefficients in FPs in both networks says us that creation/integration of ERA has been on the right track.

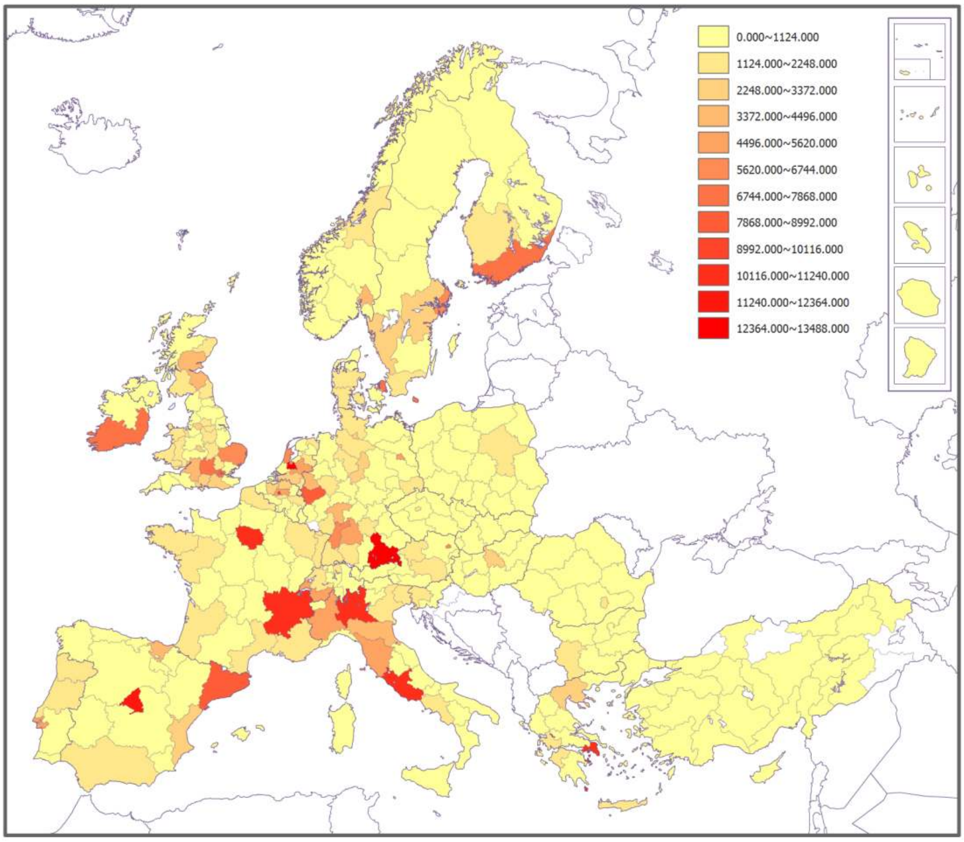

Figure 10 Number of Projects (Regional)

4.3 Network Structure and Innovativeness

Innovation is considered among the essential sources for smart and sustainable economic growth, as stated in Lisbon Agenda (European Communities, 2006) or in the recent discussions Horizon 2020. In this sense, stimulation of innovation is one key concern of policymakers at all levels from local to Union. Correspondingly, development and implementation of network policies may be regarded as a tool to overcome network failures (Nooteboom and Stam, 2008). In other words, connecting actors through links to provide exchange of information, knowledge, etc. can be seen as an appropriate policy within the framework of systems of innovation approach (Carlsson and Jacobsson, 1997). Therefore, in addition to regional network explained in the previous Section 4.2 *Network Structure*, as a third type of European Research and Innovation Network, undirected network (closed network) shall be established as well with the countries listed in IUS 2013 and participated into FPs (for the list of countries, see Table 24 in Appendix). To assess the effect of project participation on innovativeness value; correlation values obtained between number of projects and innovativeness values both at the country and NUTS-2 region levels are provided below in Table 10 and Table 11, respectively. As seen from the correlation results, about half of innovativeness values of nodes (country and region) can be explained by number of projects they participated.

Table 10 Correlation between Number of Projects (Country) and Innovativeness Value

				YEARS			
# of Projects	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
2006	**0.493684**	0.489432	0.486439	0.47624	0.499254	0.478056	0.469629
2007	0.50257	**0.498426**	0.495088	0.485022	0.507844	0.486922	0.478799
2008	0.505421	0.501883	**0.499921**	0.489439	0.511849	0.490776	0.483633
2009	0.50681	0.503824	0.500656	**0.489867**	0.513009	0.491637	0.484962
2010	0.50192	0.499486	0.496992	0.485437	**0.509423**	0.487276	0.480968
2011	0.494195	0.491668	0.489627	0.476886	0.500992	**0.47828**	0.472237
2012	0.487042	0.484222	0.482772	0.468639	0.493042	0.469407	**0.463996**
N	34	34	34	34	34	34	34
t Stat	3.211	3.252	3.265	3.179	3.349	3.081	2.963
P-value	0.003	0.003	0.003	0.003	0.002	0.004	0.006

Table 11 Correlation between Number of Projects (Region) and Innovativeness Value

	YEARS		
# of Projects	2007	2009	2011
2007	**0.270473**	0.265452	0.259666
2009	0.458028	**0.459857**	0.454435
2011	0.479745	0.480143	**0.475126**
N	95	183	182
t Stat	2.709	6.967	7.265
P-value	0.008	0.000	0.000

Among others, clustering is considered an important factor affecting the innovativeness of actors. From the positive side, based on *strong tie* discussion by Coleman (1988) or *embeddedness* argument of Granovetter (1973), it is maintained that clustering increases the exchanges due to mutual trust, etc., as well as enables novel solutions (Brown and Duguid, 1991) owing to shared understanding among partners. Conversely, it is argued that clustering has negative effects on innovation due to redundancy (Burt, 2001). Redundancy in information and knowledge and over shared conventions and norms, as a culprit for reducing creativity (Uzzi and Spiro, 2005), shall make negative effect on innovation. Therefore, it is argued that lower clustering coefficient implies higher number of structural holes to be filled by actors, which enables those actors to combine different resources such as knowledge, information, etc.

Thus, innovativeness and clustering values of countries in three types of networks (open, closed, and regional networks) are correlated in order to analyze the relationships between innovativeness and clustering values of nodes (country or region). The first network is closed network, which only contains the countries ranked in IUS 2013. Second network is open network, established with all participants of FPs. As seen in Table 12, which shows the results related with countries indicated in IUS 2013, there is a negative correlation between innovativeness and clustering values at the country level. Same analysis is repeated at the regional level as well, yielding similar results for regions indicated in RIS 2012.

Table 12 Correlation Coefficients between Innovativeness Values and Clustering Values

Years	**Clustering (Closed Network)**	**Clustering (Open Network)**	**Regional Network**
2007	-0.0308	-0.6783	-0.06172
2008	-0.2151	-0.6573	
2009	-0.273	-0.6328	-0.24239
2010	-0.376	-0.6154	
2011	-0.4266	-0.6226	-0.43965
2012	-0.4755	-0.5905	
	N;t Stat;P-value	**N;t Stat;P-value**	**N;t Stat;P-value**
2007	34;-0.1;0.9207	34;-5.221;0.00001	171;-0.803;0.422
2008	34;-1.074;0.291	34;-4.9342;0.00002	
2009	34;-1.518;0.139	34;-4.623;0.00005	184;-3.37;0.0009
2010	34;-2.111;0.043	34;-4.416;0.0001	
2011	34;-2.499;0.0183	34;-4.5;0.00008	184;-6.603;4.268
2012	34;-2.809;0.008	34;-4.139;0.0002	

Important gatekeepers at country level in FP7 (Germany, France, Italy, and United Kingdom) are determined in order to detect the countries filling the structural hole and playing critical roles in providing connections between closed network and open network (Table 12). Then, the innovativeness values and number of FP7 projects of countries are correlated with the important actors stated in IUS 2013 (Brazil, Canada, China, Israel, India, Japan, South Korea, Russia, United States of America, South Africa) (Table 13). According to the results, average correlation coefficient is 0.4431.

Table 13 Correlation Coefficient between Innovativeness Value and Number of Projects

# of Projects	**YEARS**					
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
Pro-2007	**0.428941**	0.417785	0.411416	0.440944	0.422603	0.421646
Pro-2008	0.452269	**0.441817**	0.434308	0.463342	0.444739	0.444026
Pro-2009	0.45807	0.444814	**0.437611**	0.465471	0.447696	0.447681
Pro-2010	0.447795	0.434635	0.426905	**0.455671**	0.437305	0.436907
Pro-2011	0.458989	0.446227	0.437601	0.465766	**0.447549**	0.447035
Pro-2012	0.4569	0.44342	0.434612	0.462609	0.444052	**0.444339**
N	34	34	34	34	34	34
t Stat	2.686117	2.785954	2.753117	2.895769	2.831081	2.805757
P-value	0.011365	0.008896	0.009647	0.006765	0.007954	0.008471

Based on findings, which show a negative correlation between clustering coefficient and innovativeness, and a positive correlation between the number of projects with important rivals and innovativeness value, it may be articulated that collaboration with important rivals is significant for increasing the innovativeness of Europe. Furthermore, with regards to the role of most important gatekeepers (Germany, France, Italy and United Kingdom), it seems they are the main actors not only in terms of knowledge production, but also for knowledge transaction between the close an open networks (Table 14).

Table 14 Gatekeepers in FP7

Abb.	Brazil	Canada	China	Israel	India	Japan	South Korea	Russia	United States of America	South Africa	Total
	BR	CA	CN	IL	IN	JP	KR	RU	US	ZA	
AT	12	20	93	191	50	4	5	90	57	8	**530**
BE	62	40	152	298	105	14	4	114	93	76	**958**
BG	0	5	4	20	0	0	0	16	0	16	**61**
CH	5	32	36	234	60	5	22	133	101	22	**650**
CY	0	0	0	39	0	0	0	0	10	0	**49**
CZ	12	4	40	61	0	0	0	15	8	0	**140**
DE	171	119	347	1318	99	33	46	618	354	146	**3251**
DK	6	31	91	114	23	3	3	59	42	17	**389**
EE	0	2	4	27	0	0	0	9	0	0	**42**
ES	161	47	123	516	71	8	15	94	154	66	**1255**
FI	14	6	69	143	13	9	3	127	19	9	**412**
FR	141	112	314	930	141	40	44	411	244	114	**2491**
GR	5	18	77	320	20	22	5	108	116	33	**724**
HR	0	0	4	11	0	0	0	0	0	0	**15**
HU	5	3	4	81	8	0	0	34	26	7	**168**
IE	26	18	12	97	0	6	0	49	82	33	**323**
IS	0	0	4	12	0	0	0	4	2	0	**22**
IT	117	56	168	831	204	35	48	307	231	112	**2109**
LT	0	0	0	17	0	0	0	6	0	0	**23**
LU	0	0	0	17	3	0	0	4	4	0	**28**
LV	0	0	0	6	0	0	0	8	0	0	**14**
MK	3	0	1	10	0	0	0	0	0	0	**14**
MT	0	0	16	8	0	0	0	0	0	0	**24**
NL	99	84	150	557	111	12	19	178	135	112	**1457**
NO	25	35	75	70	29	3	3	49	9	25	**323**
PL	5	14	20	122	3	14	0	34	24	9	**245**
PT	24	0	38	85	9	3	0	12	16	16	**203**
RO	0	0	10	36	0	0	0	6	1	8	**61**
RS	0	0	0	22	0	0	0	2	4	0	**28**
SE	29	76	88	257	46	0	7	56	94	37	**690**
SI	0	0	6	32	0	0	0	8	0	0	**46**
SK	0	0	0	18	0	0	0	3	0	4	**25**
TR	0	6	3	33	0	6	0	13	3	0	**64**
UK	173	129	457	1131	226	42	32	398	407	212	**3207**
Total	**1095**	**857**	**2406**	**7664**	**1221**	**259**	**256**	**2965**	**2236**	**1082**	**20041**

As stated in Section 2 of this Chapter, starting from FP1, average degree value of nodes increases; indicating that the capacity of countries is increasing in terms of maintaining links with others. The increase in average degree of nodes does not only provide links between previously disconnected nodes, but may also bring about difficulties for finding appropriate links or ways to reach partner, information, knowledge, etc. For instance, (Choi et al., 2001) in the field of supply networks, and Rycroft (2007) in biotechnology sector found out that increased connectivity was not linearly related with an increase in efficiency, which is measured by delivery time and product development time, respectively. However, as seen in Table 15, there is positive correlation between innovativeness and degree values of nodes in both closed and opened networks. Same analysis is also repeated at regional level and similar results are obtained.

Table 15 Correlation Coefficients between Innovativeness and Degree Values

Years	Average Degree (Closed Network)	Average Degree (Open Network)	Average Degree (Regional Network)
2007	0.47299	0.59676	0.591697
2008	0.32489	0.58737	
2009	0.34297	0.58073	0.644502
2010	0.40699	0.56384	
2011	0.44832	0.56909	0.680136
2012	0.4392	0.54555	
	N;t Stat;P-value	**N;t Stat;P-value**	**N;t Stat;P-value**
2007	32;2.94;0.006	N;t Stat;P-value	171;9.416;0
2008	32;1.881;0.069	34;4.207;0.0001	
2009	32;1.999;0.0546	34;4.105;0.0002	184;11.249;0
2010	32;2.44;0.02	34;4.035;0.0003	
2011	32;2.747;0.01	34;3.861;0.0005	184;12.4118;0
2012	32;2.677;0.011	34;3.915;0.0004	

The discussion presented above is also related with sources and number of project partners. For instance, Lundvall et al. (2002) argue that successful innovation is an outcome of interactive learning processes based on close relationships between actors, implying that it is established on strong ties among the actors. Ruef (2002) and Powell et al. (1996) discuss the importance of number of actors in enabling combination of different information, knowledge, resources, etc. On the other hand, Tatikonda and Rosenthal (2000) assert negative effects of project size on innovation, though they could not provide a strong empirical support for their argument. Furthermore, the role of different source of actors in innovation is widely discussed by authors such as Nooteboom (2000), Ruef (2002), etc., among others. In general, it is presumed that diverse partners bring the newest information, knowledge, and resources into the project, which increases the success of novelty. Therefore, correlations between average project size (number of participants) and innovativeness value between the years 2006-2012, were made to assess their relationships (Table 16). As per the result (-0.649418069), there is an inverse relationship between the project size and innovativeness value.

Table 16 Average Project Size and Innovativeness Correlation Coefficient

	2006	2007	2008	2009	2010	2011	2012
Average Project Size	3.088156	2.923474	3.200642	3.02968	2.891189	2.973018	3.006559
Innovativeness	0.504527	0.517958	0.503871	0.51611	0.531645	0.53093	0.544282

Moreover, the role of different types of actors in innovation is also analyzed. Accordingly, between the years 2006-2012, the number of cooperation of each country with others is calculated in order to analyze the notion of participant diversity in projects. Results obtained are summarized in Table 17. In contrary to the inverse relationship between the project size and innovativeness value, a positive correlation is found between innovativeness and diversity of partners, with an average correlation coefficient of 0.410594174.

Table 17 Correlation Coefficients between Innovativeness and Diversity of Partners

				YEARS			
Diversity	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
2006	**0.25216**	0.41748	0.485448	0.469734	0.474576	0.436136	0.452762
2007	0.24013	**0.408543**	0.502752	0.466889	0.464117	0.439019	0.426181
2008	0.241728	0.406787	**0.492228**	0.46913	0.458239	0.454391	0.431095
2009	0.206755	0.374096	0.471054	**0.446907**	0.443523	0.435912	0.406413
2010	0.234266	0.400848	0.48546	0.472837	**0.459753**	0.442494	0.430819
2011	0.267353	0.428672	0.495791	0.461033	0.446993	**0.428051**	0.424819
2012	0.236293	0.401328	0.479383	0.426251	0.417395	0.39643	**0.386516**
N	34	34	34	34	34	34	34
t Stat	1.242436	2.162436	2.748667	2.422937	2.489626	2.21593	1.9972
P-value	0.226079	0.040771	0.011182	0.023307	0.020113	0.03643	0.057263

4.4 European Research Area

One of the important milestones of Lisbon Agenda was the creation of the ERA. To achieve this objective, the European Council stated that 'research activities at national and Union level must be better integrated and coordinated to make them as efficient and innovative as possible, and to ensure that Europe offers attractive prospects to its best brains" (COM, 2000: 6).

The basic aims of the ERA were stated by European Commission (COM, 2002: 565). According to this:

- ERA is a kind of research market in which knowledge, technology and researchers move freely in order to increase cooperation, to stimulate competition, and to provide better allocation of resources.
- ERA is an attempt to increase coordination research activities at national and/or regional levels.
- ERA does not only focus on research funding but also deals with all issues pertaining to research activities implemented/ planned by other EU, national, and regional bodies.

In accordance with explanations, made in Chapter 2 related with system characteristics, ERA can be understood as integrated nations/ regions, which collaborates within network while competing for markets. Moreover, according to above statements, it can be said that ERA should be designed/ developed/ implemented for creating synergy, competition, and cohesion among actors instead of creating conflicts between those.

Considering the chief Lisbon Strategy objective to achieve "the most competitive and dynamic knowledge-based economy in the world", it is expected from ERA to provide better integration and coordination among research activities done at regional, national, and Union levels to make Europe more efficient and innovative. In this sense, to what extent ERA is complete and how it supports European Research and Innovation Network is discussed.

To respond whether the system is integrated as expected from FPs to achieve, it is assumed, that countries and/or regions can collaborate with other countries and/or regions without concerning geographical distance. While this assumption may seem too strong to capture whether ERA is integrated, it is appropriate when the integration and collaboration expectations from FPs and ERA are taken into consideration. The results show that there are biases among regions and nations when they choose their partner, which means that it is early to talk about an integrated European research system. In brief, it is found that:

1. Regions (NUTS-2) and nations prefer to collaborate with those who are nearby, rather than those that are far away. It means that geographical distance is still an important factor in the selection of partners for research activities. To prove this point, a calculation made for nations and regions is explained below.

2. There are scale free (hierarchical) structures among nodes. It means that nodes prefer to collaborate with nodes that have more links, instead of periphery nodes or lagging nodes. From the other side of the coin, this situation implies that periphery nodes or lagging nodes could not enter the network of excellence and disparities among those shall increase (Clarysse and Muldur, 2001).

To validate these two assumptions, it is assumed that there should be a negative correlation between spatial distance of the project partners and the intensity of the interaction among project partners. In other words, it is assumed that the increase in the distance between two partners shall decrease the probability of those to be partners in a project. To keep calculation uncomplicated, capital city of each country is assumed as the center of that country. Then, the spatial distance between two countries or regions is calculated using ArcGIS software. Number of partnerships of European countries at country (closed network) and region (NUTS-2) levels in FP6 and FP7 and spatial distance of each are calculated and correlated. Results are shown in Table 18 and depicted in Figure 11 at country level; in Table 31 in Appendix and in Figure 12 at regional level.

Table 18 Distance vs. Intensity (Country)

Country (Abb.)	Correlation	Country (Abb.)	Correlation	Country (Abb.)	Correlation
IE	-0.52241	NO	-0.22628	MK	-0.07219
FR	-0.49814	DE	-0.22492	LV	-0.07121
BE	-0.49611	CZ	-0.21117	PL	-0.05965
PT	-0.49267	MT	-0.20006	HU	-0.03943
UK	-0.48347	SK	-0.19712	FI	0.007637
NL	-0.48201	IT	-0.18571	BG	0.067141
ES	-0.47764	SE	-0.166	LT	0.069618
LU	-0.39958	AT	-0.11006	GR	0.111225
CH	-0.382	EE	-0.10021	RO	0.118165
DK	-0.32125	SI	-0.09253	TR	0.212735

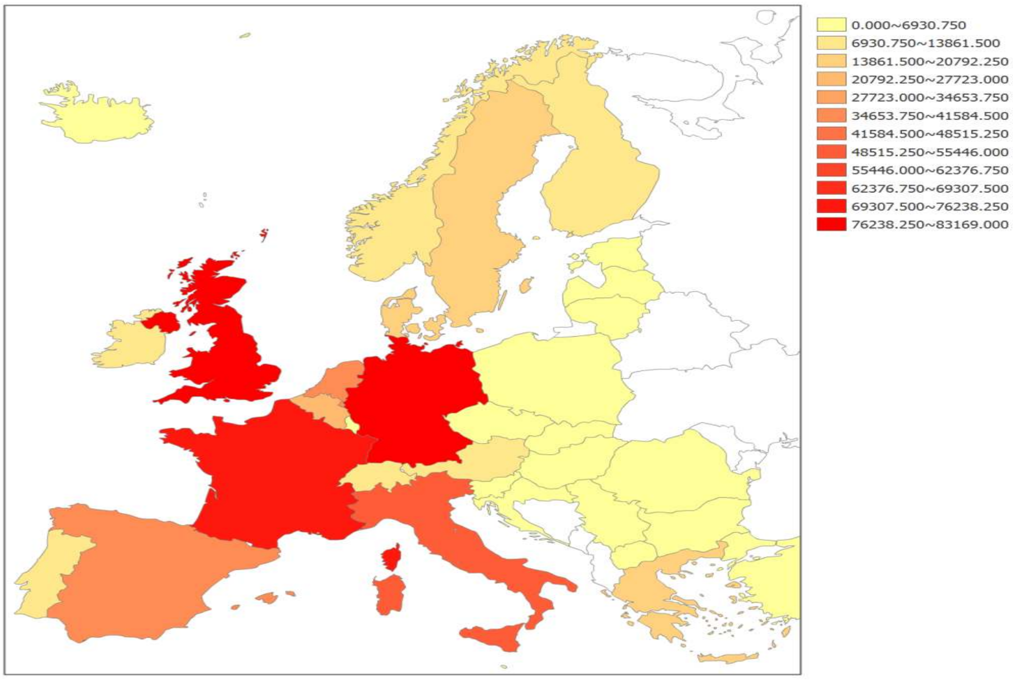

Figure 11 Distance vs. Intensity (Country)

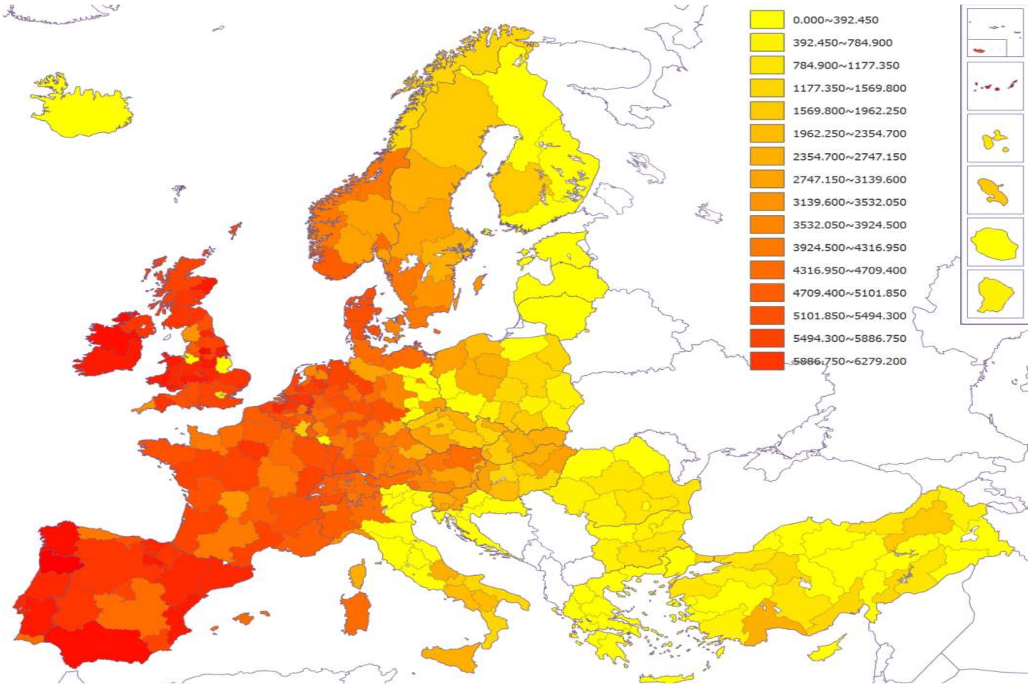

Figure 12 Distance vs. Intensity (Region)

The highest correlation score is -0.52241 (IE) in Table 18 and -0.323 (PT11) in Table 31 in country and region networks respectively. Negative correlation value indicates the importance of distance. For instance, IE or PT11 are among the nodes that prefer to collaborate with those nearby. On the other hand, a positive value indicates the relative unimportance of distance. Therefore, as seen in the results, the importance of distance is increasing from east of Europe to west in both networks. In other words, west of Europe, in addition to some parts in north of Europe give much more importance to the notion of distance. These nodes are also important actors for Europe for its competitiveness and innovativeness. In consequence, results obtained prove that ERA has not completed yet; in other words, proximity is still important factor for nodes in their selection of partners.

3. Regions (NUTS-2) prefer to collaborate with domestic partner(s) instead of those across borders. It means that institutional infrastructure (norms, values, etc.) and national policies such as tax, labor, funding, etc., are still important factors in selecting partner(s) for research activities.

To validate this statement, data shown in network analysis (self-loops in networks of FPs at nuts level) is reused. It is assumed that if the increase in number of nodes value is bigger than the increase in self-loops value, showing the existence of project participant in the same regions more than once, we can say that regions prefer to collaborate with domestic partner(s) instead of those from across borders. According to results shown in Table 19, while the number of partners increases 0.70 folds from FP1 to FP7, the increase in self-loops is 15.38 folds from FP1 to FP7.

Table 19 Increase in Nodes vs. Self-Loops

FPs	**FP1**	**FP2**	**FP3**	**FP4**	**FP5**	**FP6**	**FP7**
Nodes	189	223	271	281	298	309	322
Self-Loops	218	878	833	1987	3746	2337	3572

Therefore, ERA is demonstrated to be a useful tool, as expected, for removing artificial barriers related to geography and borders. Moreover, it helps to establish networks among organizations, excellent regions, countries, which are important ingredients for increasing the competitiveness of Europe on a global scale. However, it also adds up to the increase in discrepancies among organizations, regions and countries, which undermine the social sustainability of the system due to unintended negative consequences of innovation policies. Thus, these dual structures, increasing competitiveness and discrepancies, should be accepted as the result of intended outcomes of ERA. An obvious assumption is that network among the nodes, regions and countries, has positive contribution to the innovativeness of those nodes as shown in Table 10 and Table 11. It is assumed that there should be a positive correlation between number of links and innovativeness value of nodes. In other words, networks enable a node to integrate information, knowledge, etc., generated within the node itself and other nodes. For instance, although financial support is important factor for attracting an organization to participate into a network (exemplified in Table 7), it is not sufficient to encourage that organization to actively participate and involve in network activities. As per the readings of FP related documents, especially private sector participates into FPs to build a network, to obtain knowledge, which may be used in the long run, and to increase its organizational reputation. It should be underlined that the nature of FPs is based on 'pre-competitive' collaboration and cooperation, which means that companies prefer to enter into projects in the areas they do not compete in general. That is, those projects provide them with better networking and overall awareness vis-à-vis new technological opportunities.

Put differently, as stated in the study by Atlantis (2005), aims and objectives of the participants in FP show differences: while almost all participants accept the benefits of FPs in terms of networking, knowledge production, developing human resources and R&D capabilities of Europe, approximately one third of those, who participated in projects to develop products and/or processes, show success in terms of achieving their aims[39]. This situation may be considered positive from the perspective of research policy and ERA; however, from the innovation perspective, it is not a desired situation, at least for Europe, in terms of closing the gap with its rivals, stated in IUS 2013. In this sense, six underlying motives for the establishment of inter-organizational relations are summarized by Oliver (1990), according to which, firms enter into the network: a) in order to meet with necessities resulted from legal or regularity requirements, b) to exercise power or control over another

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[39] "Nevertheless, FP evaluations conclude that more attention should be paid … economic valorisation, in particular since the FP is supposed to support Europe's competitiveness … the FP7 interim evaluation observes a lack of clarity on how the FP incorporates innovation (as opposed to 'pure' research)". (Horizon 2020 Impact Assessment)

organization, c) to establish collaboration and cooperation d) to increase efficiency, which increase internal input-output ratio of the organization, e) to adapt changing conditions, e.g. environmental uncertainties, f) to increase legitimacy such as reputation, image, prestige. Some of these factors are met with participation reasons of firms into the FP networks; but not all, due to the predominantly 'pre-competitive' collaboration and cooperation nature of the FPs.

In terms of ERA, positive correlation between number of projects and innovativeness value of nodes can be regarded as indicators for the existence and/or development of ERA, which targets European integration at regional, national and continental levels, in accordance with Lisbon Agenda, which aims to improve European competitiveness by improving collective innovation and research capacities/capabilities of Europe as a whole. From the view of European Commission, this dual structure shall be eradicated over time. The basic assumption is that those lagging regions shall increase their knowledge base, innovativeness, competitiveness, etc. over time, with the help of funding (i.e. structural funds, devoted to regions with per capita incomes that are less than 75% of the EU average, according to COM, 2011:48. At first glance, the assumption seems reasonable; lagging regions shall utilize support from EC, so that the gap between leader and lagging regions shall be narrowed. In other words, validity of proverbial "rich get richer and poor get poorer" statement will decline, and lagging regions will be able to participate more into collaborative projects.

However, the figures shown in Table 8 and Table 9, point out to the existence of a scale free network with a clear tendency of preferential attachment. That is to say, nodes prefer to collaborate with nodes having more links instead of periphery nodes or lagging nodes. Therefore, as a finding of the Thesis demonstrated by the figures provided, it can be said that improving the knowledge base, innovativeness, competitiveness, etc., is necessary but not sufficient; periphery or lagging regions/ countries are still to pass a threshold to become attractive partners for FP projects or European research network. However, the related literature also underlines the difficulty of entering into scale-free network due to preferential attachment, and into small-world type of networks due to difficulty in attaining access to *cliques*. As exemplified in (Uzzi and Spiro, 205; Fleming et al. 2007; Schilling and Phelps, 2007), cliques have strong ties each other, making it difficult to introduce new information/ knowledge or persuade members of cliques to implement new things. Furthermore, as discussed in the Thesis, it is found that the value of average degree rises (Table 8 and Table 9); which implies the capacity of regions (NUTS-2) and countries increases in terms of maintaining links with others. When the increase in number of unique and duplicated values are analyzed, the increase ratio of duplicate values is observed to be much higher than that of unique values, demonstrating that vertices (regions and nations) primarily prefer to establish links with the existing nodes, instead of new ones.

This situation has positive and negative sides, depending on the point of view, or *vantage point*. While it may be regarded as the establishment of a skeleton of FP programs with the contribution of EU; on the other hand, this may also be seen as a situation in which the same actors doing the same thing with different tools receive the support, or even the research activities of research organizations are financed with few yielding well-known reference companies in the world as an outcome.

High number of persistent participants shows the tendency of constructing the main skeleton of the FPs, and the declining transaction costs among the partners, as well as establishing small-world and scale-free network structures, which are the most common types of networks usually suggested and detected in network studies. In other words, newcomers are tested, verified, and then accepted into the clique. This situation has both head and tail sides, depending again on the viewpoint. While this process increases the sustainability of the structure; at the same time, it has the potential to reduce the opportunities to be provided by the newcomers. As such, it may be speculated that this relatively closed network (or the notion of path dependency), teaming up with previous partners, may not only lead to redundancy but also trigger the risks of lock-in (Leonard-Barton, 1992). That is to say, it is difficult for the latecomers, which may be an organization, region or a country, to form a hub because of the network structure, which may hamper the re-orientation of relations in the network towards more productive research areas.

4.5 Network Structure, Entropy, and Innovativeness

In accordance with the explanation related with Boltzmann's entropy in Chapter 3, if inputs of innovation are concentrated in a single country, organization, or region (Case 3 in Table 4), we have less opportunity to achieve innovation, but if they are distributed among the countries, organizations, or regions (Case 1 or 2 in Table 4), we have a higher possibility to achieve innovation. As seen in Table 33, Table 34, Table 35, Table 36 and Table 37 in Appendix, inputs of innovations (human resources; research systems; finance and support; firm investments; linkages and entrepreneurship; intellectual assets; innovators; and economic effects) with different values are distributed differently among countries. For instance, the value of "firm investments" (composed of business R&D expenditure and non-R&D innovation expenditure) for the year 2012 is 0.287 in Italy and 0.417 in Belgium, which means that the probability of finding a firm investing in R&D and non-R&D for innovation is higher in Belgium than Italy. Furthermore, values of countries do not show drastic changes from one year to another, implying country rankings in terms of their innovativeness inputs does not alter dramatically. As such, it is not logical and meaningful to expect redistribution of innovativeness inputs values of countries from the perspective of IUS sustainability. As it is explained above, distribution cannot be rearranged; in accordance with evenly distribution of probabilities among nodes in Case 1 of Table 4. On the other hand, existence of competition among countries does not permit concentration of probabilities depicted in Case 3 of Table 4. This leaves us with only one alternative which is the real-life like distribution of probabilities, observed in Column 2 of Table 4, upon which we can formulize/develop policies.

The role of networks in innovation was explored in many studies. Ahuja (2000), and Powell, Koput, and Smith-Doerr (1996) analyzed network structure and innovative performance; similarly, Leoncini et al. (1996), and Wal and Boschma, 2007 studied the collaboration among actors in projects. The major idea behind these studies is that links in networks are important means for exchanging information, knowledge, resources, etc., which are important components for novel combinations (Nelson and Winter, 1982),. as well as innovation. In this framework, the position of an actor is also argued to be an important factor in determining its innovativeness (e.g. Schilling and Phelps, 2007). As discussed by Singh (2005), via influencing the structure of network, policymakers may increase not only information, knowledge, capability, etc. of actors, but also the capacity of regions to innovate.

When the relationship between the structure of the network established by FPs and innovativeness values are analyzed, the following correlation results given in Table 20 are obtained for the three types network established in the thesis; i.e. closed network (composed of countries indicated in IUS 2013), open network (consisting of all countries participated into FPs), and regional network (composed of regions indicated in RIS 2012). As seen in Table 20, innovativeness shows the highest correlation with eigenvector, and next, with degree values in country networks either open or closed, in regional network. In line with the discussions above, it is not meaningful to expect the redistribution of links among the countries in order to make positive contributions to the innovativeness of countries. On the other hand, eigenvector value, which shows a node's importance in a network based on the node's connections, may be taken into consideration as a tool for policy intervention.

Table 20 Correlation Coefficients of Average Network Characteristics and Innovativeness

Closed Network	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
Degree	0.47299	0.324893	0.342971	0.406985	0.448324	0.439202
Betweenness Centrality	0.249971	0.02135	0.224012	0.259325	0.391644	0.450729
Closeness Centrality	0.466806	0.336599	0.348279	0.429693	0.460964	0.449777
Eigenvector Centrality	0.476348	0.323803	0.334831	0.391251	0.433681	0.416797
Clustering Coefficient	-0.03078	-0.21511	-0.27303	-0.37595	-0.42659	-0.47553
Open Network	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
Degree	0.596764	0.587369	0.580729	0.563835	0.569093	0.545548
Betweenness Centrality	0.437128	0.405425	0.413817	0.379331	0.389695	0.373925
Closeness Centrality	0.569407	0.551988	0.5476	0.538335	0.545396	0.524671
Eigenvector Centrality	0.581039	0.607821	0.61438	0.604792	0.603746	0.569446
Clustering Coefficient	-0.67828	-0.65733	-0.63282	-0.61541	-0.62263	-0.59051
Regional Network	*2007*		*2009*		*2011*	
Degree	0.591697		0.644502		0.680136	
Betweenness Centrality	0.413133		0.40433		0.426205	
Closeness Centrality	0.647487		0.640923		0.673482	
Eigenvector Centrality	0.613513		0.663702		0.694983	
Clustering Coefficient	-0.06172		-0.24239		-0.43965	

The last statement is also supported by Demetrius and Manke (2005), who suggest "[w]hile robustness is defined as the resilience of the network against changes in the underlying network parameters, network entropy characterizes its pathway diversity". As such, in an unweighted and undirected network (like networks established in this thesis), topological entropy can be calculated using a formula derived from Kolmogorov-Sinai (KS) entropy. According to their findings, topological entropy is positively correlated with the largest eigenvalue of the network. In this framework, the largest entropy value among all nodes in FPs is found and correlated with the innovativeness value of Europe. Correlation coefficient between them is -0.052, meaning that they are almost uncorrelated. Next, the most relevant eigenvector value with Demetrius and Manke's (2005) argument is investigated and it is found that average eigenvector centrality is the most correlated value with innovativeness value, which is -0.8379. This indicates an inverse proportion between average eigenvector centrality and innovativeness value. In other words, if average eigenvector centrality is decreased, we can obtain higher innovativeness value. The emergence of a network structure results not only from the characteristics of nodes and sectors, but also from the interactions among the constituents of the institutional infrastructure, as discussed by Kogut (2000). In this framework, the position and links of the node determine its eigenvector value. In this sense, similar to the approach above, it is not meaningful and possible to demand from nodes (countries or regions) to change the links they have; instead, a policy developed upon eigenvector may be implemented in a manner that allows for the nodes with low eigenvector values to be taken into the networks. In the case of such an implementation, the eigenvector value pertaining to both the countries with previously low and high eigenvector values shall change accordingly.

To decide on the appropriateness of this change, eigenvector distribution of each node in the network is taken into consideration. It is found that eigenvector values of nodes are in accordance with the power law value of the network. That is, correlation coefficient between average eigenvector value and power law value of the network is 0.7888 (p=0.03). That is to say, decrease in power law, which means a more democratic distribution of degree value of nodes, shall result in a decrease in average eigenvector value.

Furthermore, there is an inverse relationship between innovativeness value and power law value, indicated with a correlation coefficient value of -0.5247. Thus, if average eigenvector value decreases, power law value of network shall also decrease due to positive correlation coefficient between those, which is 0.7888. Moreover, when power law value decreases, innovativeness value shall increase due to the negative correlation coefficient between those, which is -0.5247.

As underlined above, network is an emergent structure and it is not meaningful and possible to demand from nodes (countries or regions) to change their links with existing nodes or inflict rules for obtaining smooth eigenvector distribution to increase innovativeness of Europe. Put differently, we cannot trade-off innovativeness of Europe with the characteristics of network. Instead of deciding who shall establish a network, a simple rule may be added to application process, which shall bring about a more democratic distribution (or lower power law value) and more innovativeness.

Another interesting and attractive finding is the relationships between European Research and Innovation Network and entropy of the system, as also discussed in Chapter 3, *Data and Methodology*. Based on discussions by Prigogine and Stengers (1984) and Von Bertalannfy (1968), it can be argued that in a closed system, we cannot see any exchange in any sense through the boundaries of the system due to the lack of gradients, and consequently, it reaches equilibrium (maximum entropy); a process which is irreversible. This means that the ability of a system's energy to perform work is terminated; in other words, entropy of an isolated system never decreases due to the second law of thermodynamics and thus we observe a lock-in or entropic death (Saviotti, 1988). In this sense, average degree value of countries consisting of non-members, candidates and EFTA members is 969.71 between the years 2006-2012.

As such, European Research and Innovation Network clearly maintains its links with outside (Table 14). However, this statement is no more than "stating the obvious", in terms of the relationship between notion of entropy and European Research and Innovation Network. In fact, the critical point here is an analysis of the relationships between European Research and Innovation Network and degree values of *important rivals*, stated in the Innovation Union Scoreboard 2013 (IUS) report. The latest IUS 2013 gives the previous five years' innovativeness values of countries which are member states, candidate states and EFTA countries. On the other hand, degree values of important rivals in (Table 21) listed in IUS 2013 (Brazil, Canada, China, India, Japan, South Korea, Russia, and United States), are calculated in accordance with the methodology in Chapter 3 and analysis in this Chapter.

Table 21 Degree values of Important Rivals

Countries	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Brazil	14	17	17	18	23	22	23
Canada	20	20	19	20	21	19	19
China	25	22	24	24	28	25	23
India	15	16	16	16	17	17	15
Japan	10	10	13	14	15	15	15
South Korea	7	7	12	13	14	14	15
Russia	32	33	33	27	25	25	24
United States	23	22	26	24	24	23	23

Essentially, the changes in the innovativeness value of Europe, stated in IUS 2013, and in degree values of each important rival from successive years (2006-2007, 2007-2008, etc.) are calculated. In this sense, it is assumed that a positive correlation value shall be obtained if the relationships between European Research and Innovation Network and important rivals have positive effect on innovativeness on Europe, or vice versa. Obtained correlation results between innovativeness value of Europe and degree value of important rivals are given in Table 22.

Table 22 Correlation Coefficients between Changes in Average Innovativeness Value of Europe and changes in Degree Values of Important Rivals

Countries	**Brazil**	**Canada**	**China**	**India**	**Japan**	**South Korea**	**Russia**	**United States**
Innovativeness	0.87	0.78	0.02	-	-0.99	-0.99	0.06	-0.89

According to IUS 2013, United States, Korea, and Japan have performance lead over Europe; while Brazil, Canada, China, and Russia have performance gap with Europe. The results obtained and given in Table 22 are consistent with IUS 2013 statements. In other words, Table 22 demonstrates a positive correlation between

Europe, and Brazil, Canada, China, and Russia; and a negative correlation between Europe, and United States, Korea, and Japan. Put differently, when its relations with three of its rivals are considered, the existing policy and implementations have not proved as beneficial as expected in Europe.

4.6 Conclusion

This Chapter makes one of the interesting readings in the Thesis, as theoretical arguments are discussed and proven, where possible. It begins with an analysis of the system labeled as European Research and Innovation Network in this thesis, which emerged as a result of policy and program implementations at the regional, national, and European levels, exploring whether the mentioned system is complex or not, benefiting from the metric developed in Chapter 2, *Theoretical Background*. According to findings, with the exception of a single item in metric, it is found that European Research and Innovation Network, modeled at three scales, fulfills the requirements for being accepted as a complex system. On the other hand, item 8, which is not fully met by the Network, is found very critical for the future of the European Union within the framework of this Thesis. In other words, it is found that existence or lack of central authority pointed at in item 8 is one of the important impediments for increasing the innovativeness of Europe. In this regard, current implementations of EC, i.e. centralizing the existing structure, may be accepted as the worst alternative for increasing the innovativeness of Europe in terms of the arguments developed in this Thesis; though those policies and implementations are advocated by those who argue that implementations are beneficial for certain purposes such as making effective and efficient planning, for preventing duplication in research activities, and for governing the major shares of public budget.

With reference to the discussions on complexity, European Research and Innovation Network was analyzed in relation to basic network characteristics such as path length, clustering coefficient, average betweenness centrality, and average closeness centrality. In order to provide a framework prior to the presentation of the results, various studies on projects implemented under FPs were overviewed. It was shown that studies, which establish relationships between network structure and characteristics/thematic areas/instruments; or between codification of knowledge and network structure, have the inherent potential to produce misleading results. Moreover, due to ambiguity on relationships between strong/weak ties and exploitation/ exploration activities in the literature; relationships between those concepts were not established. Within this framework of arguments made on the literature on network studies, European Research and Innovation Network was analyzed. Subsequently, it is demonstrated that both types of networks, *open* and *regional*, share some characteristics such as scale-free degree distributions, relatively low average path length, high clustering, and low assortativity values. This situation is interpreted to indicate not only the existence of complexity, but also the unchanging characteristics of network formation mechanisms, despite changes in the rules of FPs. Moreover, it is found that both networks show the small-world characteristics, they have relatively high clustering coefficients and short path lengths, meaning the structure of network supports the knowledge creation and knowledge diffusion (Cowan, 2004). Analysis of participants in FPs shows that the same organizations participate repeatedly in FPs and continue to cooperate with each other. Also, increasing clustering coefficients in FPs were interpreted as indication of creation/ integration of ERA.

To develop and enrich analysis on European Research and Innovation Network and explore the relationships between network structure and innovativeness, a third type of European Research and Innovation Network, called *closed network* was modeled. Accordingly, structure and innovativeness relationships were established via benefiting from a number of correlations, many of which were found to be significant. Consequently, innovativeness value was determined to have positive relationships with number of projects, number of projects with important rivals, and diversity of partners, but negative relationship with clustering and average project size. These findings also contribute to the discussions on ERA.

In the analysis of ERA, a discussion was also made on whether ERA has been on the right track in terms of attaining its targets. Specifically, to respond whether the system is as integrated as expected from FPs to achieve, the notion of distance was used with network characteristics obtained in Section 4.2, *Network Structure*. It was demonstrated that **r**egions (NUTS-2) and countries prefer to collaborate with those nearby rather than those far away. This shows that geographical distance is still an important factor in the selection of partners for research activities. In addition, it is demonstrated that there exist scale free (hierarchical) structures among nodes, indicating that nodes prefer to collaborate with nodes with more links instead of periphery nodes or lagging nodes. From the other side, this situation implies that periphery nodes or lagging nodes could not enter the network of excellence and disparities among those shall increase (Clarysse and Muldur, 2001). Finally, it is detected that regions (NUTS-2) prefer to collaborate with domestic partner(s) instead of those across borders. This implies that institutional infrastructure (norms, values, etc.) and national policies such as tax, labor, funding, etc., are still important factors in selecting partner(s) for research activities. As a result, ERA was found to have a dual structure, increasing both competitiveness and discrepancies, which situation is interpreted as an intended outcome of ERA policies.

Blending the previous discussions based on network structure, entropy and innovativeness, a unique approach was developed in Section 4.5 *Network Structure, Entropy, and Innovativeness*, which links Boltzmann's entropy approach to the notion of innovativeness. Contrary to general approaches, which associate the increase in entropy with randomness, this Thesis argued for the importance of entropy increases for innovativeness. From the point of Boltzmann's view, there are many microstates and entropy measures the number of macrostates (or conditions) that can be fulfilled. That is, when entropy is zero, there is only one microstate, implying full predictability, leaving out any possibility for another microstate. On the other hand, when the entropy is higher, there are more possibilities for microstates or less degree of predictability. From the aspect of SIs, the existence of more possibilities for microstates, indicating higher entropy, means each entity is able to innovate; or, the higher the entropy, the higher the capability for innovation.

Furthermore, this Thesis demonstrated a simple and effective rule, which may be employed as a tool by European Commision in order to increase the innovativeness of Europe. As pointed out by Kogut (2000), the emergence of a network structure results not only from the characteristics of nodes and sectors but also from the interactions among the constituents of the institutional infrastructure. In this framework, the position and links of the node determine its eigenvector value. In this sense, similar to the approach above, it is not meaningful and possible to demand from nodes (countries or regions) to change the links they have; instead, a policy to be developed upon eigenvector may be implemented in a manner that allows for the nodes with low eigenvector values to be taken into the networks. Accordingly, it is argued that instead of deciding who shall establish a network, a simple rule may be added to application process, which shall bring about a more democratic distribution (or low power law value) and more innovativeness. In other words, it is advocated that in the project application process, a requisite to be set by the Commission for the inclusion of a node with a low eigenvector value into the project consortium, would both allow the free establishment of the said project consortium, and facilitate the participation of nodes with low innovativeness into the network; thus, benefit from the advantages outlined earlier.

In addition to Boltzmann's entropy, Prigogine's entropy approach was also utilized to develop an argument for relationship between innovativeness of Europe and its important rivals. It is found that there is a positive correlation between Europe, and Brazil, Canada, China, and Russia; and there is a negative correlation between Europe, and United States, Korea, and Japan. Put differently, when its relations with three of its rivals are considered, the existing policy and implementations have not proved as beneficial as expected in Europe.

CHAPTER 5

CONCLUSION, POLICY RECOMMENDATIONS, and FURTHER RESEARCH

A system consisting of actors and interactions of actors can be modeled as a network, which is an increasingly used approach in social sciences (Scott, 1991; Freeman, 2004; Newman, Watts and Strogatz, 2002; Potts, 2000; and Foster, 2005), since, instead of concentrating on a single agent, it enables the researcher to focus on a thorough analysis of the inner structure of network. In view of this, many authors such as Freeman (1991), Lundvall (1992), and Metcalfe (1995), emphasized the role of networks as a tool to produce/transfer information/knowledge. The key reason underlying their insistence on the role of the network is most probably related with the increasing complexity and dynamics of the innovation processes in a globalized economy. Obviously, while no actor is able to learn everything by itself (Foray and Lundvall, 1996); all actors have to cope with the challenges of globalization. In other words, networks among actors have a crucial role in facing the challenges of globalization. As such, the basis of the argument for supporting the networking policy is that the connections among different actors in terms of resources, such as finance, information, knowledge, capabilities, capacities, etc., are more beneficial in improving the innovativeness of systems.

The relationships between network and complex systems are discussed extensively in the literature. Newell and Meek (2000) explored such relationships within the framework of public administration; or Barabási (2002) stated more explicitly "[n]etworks are only the skeleton of complexity". In fact, there are many conceptual similarities between studies focusing on networks and complex systems. As articulated by Powel et al. (1996), unlike complex systems, networks are not ruled by sovereign authorities. That is to say, there may be actors having more influential power than others do; yet, even they cannot completely manage, but only influence networks/complex systems. As discussed in Chapter 2, *Theoretical Background*, similar to complex systems, there are mutual relationships between the members of network and network structure. Thus, the performance of actors and the network structure are dependent on each other, which brings along both stability and dynamic characteristics to the networks. Network is an emergent structure of interactions among its constituents, which means that the structure of the network cannot be predictable if the number of participants and of the links among participants are high. Similarly, studies on complex systems argue that due to the existence of non-linear interaction and emergence notion, complex systems are not entirely knowable or predictable, as also detailed in Chapter 2. Therefore, "[s]ome of the parallels and connections between the network and complexity theories can be summarized in a few sentences. Networks are complex structures. Complexity is the major characteristic of networks" (Morçöl, 2005).

When innovation system is approached from the perspective of complex systems, it may be argued that the strength of links among the actors of innovation has a critical role in determining the capacity and capability of innovation system in terms of dealing with changes. Regarding the order of the entire innovation system, it can be stated that none of the actors of the system can maintain order by itself; or, each actor is affected more or less by the behaviors of the other actors due to the existence of network among those. As stated in Cassi. (2006), "[t]he role of networks in disseminating information and ideas, allowing access to resources, capabilities, and markets and integrating different pieces of knowledge has thus become of critical importance for innovation. And consequently, the viability of network connections has become an important determinant of economic competitiveness". That is to say, in accordance with Prigogine's arguments, the survival of the systems of innovations, as an open system, depends not only on the internal resources but also on the external resources for entropy production and exchange. In this way, with the help of fluctuations that lead to bifurcations of the system, they can keep their existence by dissipation, which phenomenon enables those systems to reduce their state of entropy. As such, the performance of systems of innovation as complex systems is not only determined by the actors, but also by the network structure established among those actors. Again, from the SIs view, production of information, knowledge, etc., nurtures heterogeneity among actors and this heterogeneity is the source of innovation. In other words, systems of innovation can never reach equilibrium due to the nature of economic competition process, which produces innovations. Like heterogeneity, emergence is also a key concept in systems of innovation, despite the scarcity of reference in the literature. Among others, Boschma (2005); Edquist (1997); Edquist, Hommen and McKelvey (2001) state that innovation systems are emergent because of interdependence and non-linear relationships among the actors of the system.

Similar discussions to the above are supported by different authors as well. Lindsay (2005) states that "[i]t appears that complexity theory, and its component concepts of coevolution and self-organisation, can offer some meaningful insights and possible explanations for knowledge phenomena associated with networks and clusters and their evolution". According to Morçöl (2005), "potential theoretical connections between the growing network governance literature and complexity theory (or the sciences of complexity)…can help enhance our understanding of governance networks". Again, Saviotti (2000) argues "networks can be justified in terms of evolutionary theories [which means] networks can be very useful tool to bridge this gap."

The discussion made in Chapter 2 not only discloses the impossibility of exact prediction in policymaking via mathematical methods; but also argues that complex systems may become simpler or more complex during phase transitions. In this sense, the Newtonian view draws upon a deterministic view of the world, which is formulated by a causal relationship among the entities and events, as well as the predictability of the future due to this causality. Reflections of this assumption can be observed in policy development and implementation. In practice, it is presumed that policies and programs not only cause desired effects but also lead to relationships between cause and effect being linear. The injection of appropriate amount of monetary and non-monetary incentives is sufficient to obtain a desired level of economic progress. However, as outlined in theoretical background in Chapter 2, complex system view severely challenges the Newtonian view, where, for instance, Chaos theory models, such as *logistic equation* and *Lorenz attractor*, demonstrate that the deterministic systems can also display behaviors that cannot be exactly predicted. In addition to this break point between predictability and causality in the Newtonian view, Prigogine and Stengers (1984 and 1996) argued for the prevalence of indeterminism instead of determinism in the universe, which implies the impossibility to determine the cause-effect relations exactly as well as to predict the future. Since, the existence of bifurcation points under what Prigogine calls "far-from-equilibrium" conditions may trigger the new conditions in which a higher degree of order exists or vice versa. Furthermore, from the policy development and implementations perspective, the discussion on self-organization, as detailed in Chapter 2 *Theoretical Background*, argues that the internal dynamics of social systems such as values, norms, beliefs, or of economic systems are the critical factors that determine the success or failure of the policy outcomes.

Accordingly, harsh statements are avoided in policy recommendations to be made below based on the results obtained from the analysis in Chapter 4. In this sense, a set of policy recommendations were elaborated, based on the data prepared and used as explained in Chapter 3, while cautiously refraining from any exact mathematical relationships[40]. Instead, policy alternatives shall be recommended in accordance with discussions on the complexity of European Research and Innovation Network, which is demonstrated as complex in Chapter 4. Another reason for caution is the continuously changing structure of the network. As shown in Chapter 4, network characteristics of European Research and Innovation Network have been changing continuously since FP1. When it is considered that with a new Programme (Horizon 2020), the existing links shall disappear and the incoming links shall continuously produce new network structures with the participation of actors, among many of whom will be *old boys* of the FPs, it becomes even more evident that the use of an exact mathematical model and developing a discourse upon thereof is overly non-compliant with the approach developed in the scope of this thesis study.

Besides, this thesis study is thought to provide a valid sort of answer to a concern expressed in the literature as: "Often, network analysts are able to confirm that many FP networks have structural characteristics that should in principle enable

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[40] For instance, in Chapter 2, statements such as 'solution before the bifurcation point does not work and new solutions appear after bifurcation point' or 'sensitivity to initial conditions' can be accepted as reasons for the lack of mathematical formulation.

them to perform certain roles well but are unable to relate these observations to evidence about actual performance" (Arnold et al., 2011); and "[n]etwork evaluations look (still) mainly at the effects at network level, not at the impacts on the research and innovation system" (Weber 2009). In other words, researchers need more than just learning the structural properties of networks to develop policy and implementations (Richardson, 2000). In this sense, network analysis techniques should say more than the obvious results that can be obtained using four operations, such as the changes in network sizes, the determination of the importance of actors by adding the number of projects they participated into, etc. In this context, the methodology developed in this thesis shall also contribute to the elimination of the valid criticisms brought up above. From the classical Newtonian view, it may be said that the structure of the EU is messy and does not look like as a true state to make policy recommendations. On the other hand, from the viewpoint of complex system, it may be argued that the existence of different types and numbers of local, regional, national, etc. interactions and institutions, member states, as well as economic and social actors, all play various roles over time; and that of relatively stable fundamental framework, which is an evolving process (even though it does not follow a clear path), are the very sources of this messiness of the EU that is one of the sources of its strengths, success and progress.

Nodes and links are the most basic ingredients to talk about any system existence. However, regarding the definition of SIs, their existence is necessary but not sufficient to talk about SIs. In this framework, concerning different characteristics of SIs at local and national levels in Europe, it can be articulated that European Research and Innovation Network is an emergent phenomena, instead of exact outcome of any policy purposefully designed for its formation. In this sense, existence of connectivity among the actors of EU can be seen as a critical point for sustaining the capacity of system in terms of promoting and/or tolerating the change resulted from inside and/or outside of the system. In other words, system has to balance entropy increases, resulted from either inside or outside of the system, benefiting from connectivity among the actors. Otherwise, European Research and Innovation Network can be thought of as the sum—or hopefully more than the sum—of its constituents, i.e. national and regional innovation systems.

It is obvious and understandable that while regional and national authorities are trying to increase their own innovativeness and competitiveness at the local level (COM, 2011:48); the European Commission is formally trying to do the same innovativeness and competitiveness in overall Europe. Moreover, SIs perspective is developed taking national systems into consideration. In this sense, any policy formulization and implementation at international level should be carefully designed.

In other words, heterogeneity of national, regional, sectoral actors, expectations, and context should be taken into consideration when the targets and policies are determined. Although the key Lisbon process target, making the European Union "the most competitive and dynamic knowledge-based economy in the world by 2010" (COM, 2001: 114), is widely shared and easily formulated, it still remains an unattained objective. Probably, its most important role key to achieve this target is the formulation and implementation of Research and Technological Development (RTD) policies; in other words, the evaluation of the benefits obtained from policies implemented in EU within the scope of the proverbial "whole is greater is than the sum of parts" is not an easy task.

In a nutshell, a number of factors make the formulations and implementations of systematic policies much harder, including, growing importance of and expectations from innovation; distributed and ubiquitous nature of innovation; blurring boundaries and roles among the actors; uncertainty impact of RTD policies; and last but not the least, the increasing role of networks and collaboration as the loci of innovation where innovation occurs instead of individual organizations.

When dealing with complex system, an essential question is to be asked: why do we measure it; or what would we gain from analyzing it if we could? The fundamental answer to this question is that an attempt at such an analysis would help us better understand the structure, including micro-macro relations, and the characteristics of a system; which would subsequently provide more efficient policy intervention opportunities. In this sense, outcomes of the above discussions shall be taken into consideration when policy recommendations regarding the targets of Innovation Union or ERA are provided. As Smith (1995) clearly states, "[the] overall innovation performance of an economy depends not so much on how specific formal institutions (firms, research institutes, universities, etc.) perform, but on how they interact with each other"; in this sense, Morçöl, (2005) states:

> There is a need for understanding the nature of complexities to improve the policy process" and defines public policy as "an emergent and self-organizational complex system. The relations among the elements (actors) of this complex system are nonlinear and its relations with its elements and with other systems are coevolutionary.

Final point, before stating the policy evaluation and recommendations, is related with the role of Commission, which has a set of tools that can be employed for shaping some specifications of the research and innovation network. Accordingly, the Commission may decide on the duration of support, the amount of project budget, the amount of project funding, and the types of participants. As network is an emergent structure, even if the high clustering or low path length have positive effects on the information/knowledge dissemination/production, the Commission should not decide who will build collaborations in the project. Since, it would be micromanagement and thus, not very possible and logical, an attempt to decide who shall participate and/or in which project and/or with whom, for the manipulation network characteristics such as increasing clustering coefficient, average degree or decreasing the path length, etc. As emphasized repeatedly, network is a prevailing emergent structure, in which, policymakers do not have the opportunity to determine who shall participate in which project. In other words, the policymakers do not have the option to pull an argument wherein they could, for instance, to allow Germany to establish partnerships with France but not Italy because a small-world structure is to be attained. In this context, there is always an opportunity to develop policies, rather via the arguments to be made on the factors that lead to the emergence of the network per se.

5.1 Policy Recommendations

Discussions made on complex system in Chapter 2 reveal some basic characteristics of complex systems. The analysis of European Research and Innovation Network in Chapter 4 discloses that it mostly meets the criteria stated in this metric. In accordance with the first item of the metric, there should be sufficient number of constituents and rich interactions among constituents in the network. As exemplified in related item, there are 79,167 grant holders and 706,888 links established between years 2007-2011 in FP7, which means that European Research and Innovation Network has sufficient number of constituents and rich interactions among constituents.

However, fulfillment of item 1 is not problem-free when the future of the European Research and Innovation Network is taken into consideration, which shall be established with Horizon 2020 (the new EU Framework Programme for Research and Innovation). According to findings derived from the data provided in Chapter 3 and analysis in Chapter 4, as well as the Fifth FP7 Monitoring Report that, although Horizon 2020 undertakes to promote the entrance of new actors into the market and their development, the main actors of Horizon 2020 shall still be the same with those main actors in previous FPs. Put differently, it is found that the value of average degree rises (Table 8and Table 9); which implies the capacity of regions (NUTS-2) and nations increases in terms of maintaining links with others. When the increase in number of unique and duplicated values are analyzed, it is realized that the increase ratio of duplicate values is much higher than that of unique values, which means that vertices (regions and nations) primarily prefer to establish links with the existing nodes, instead of new ones.

This situation has positive and negative sides, depending on the point of view, or *vantage point*. While it may be regarded as the establishment of a skeleton of FP programs with the contribution of EU; on the other hand, this may also be seen as a situation in which the same actors doing the same thing with different tools receive the support, or even the research activities of research organizations are financed with few yielding well-known reference companies in the world as an outcome.

High number of persistent participants shows the tendency of constructing the main skeleton of the FPs, and the declining transaction costs among the partners, as well as establishing small-world and scale-free network structures, which are the most common types of networks usually suggested and detected in network studies. In other words, newcomers are tested, verified, and then accepted into the clique. This situation has both head and tail sides, depending again on the viewpoint. While this process increases the sustainability of the structure; at the same time, it has the potential to reduce the opportunities to be provided by the newcomers. As such, it may be speculated that this relatively closed network (or the notion of path dependency), teaming up with previous partners, may not only lead to redundancy but also trigger the risks of lock-in (Leonard-Barton, 1992). That is to say, it is difficult for the latecomers, which may be an organization, region or a country, to form a hub because of the network structure, which may hamper the re-orientation of relations in the network towards more productive research areas.

Whether they can be newcomers or existing beneficiaries, it is safe to say that time and financial resources play a critical role for the sustainability of networks. In other words, as discussed in Chapter 2, time and resources are important for any networking activity. Establishment of mutual trust and understanding among the actors of network is a time consuming process, as well as insufficient or lacking financial resources are important factors hindering the formation and/or development of networks among the actors. As shown in Chapter 4, number of participants, number of projects, as well as average durations, cost and funding of the projects have positive correlation (Table 7), which means that the interaction probability of potential participants increases, if number of participants is increased in a project. At first glance, this positive correlation between the number of partners and projects seems in harmony with the recommendations from evaluation studies of FPs, a point highlighting the importance of decreasing administrative procedures via increasing the number of participants in a project. However, when other factors, discussed in Chapter 4, are taken into consideration, it is found that this recommendation as it is, needs to be elaborated. As stated in Section 2 of Chapter 4, starting from FP1, the average degree value of nodes has been increasing; which means the same for the capacity of nodes with regards to maintaining links with others. The increase in average degree of nodes does not only provide links between previously disconnected nodes, but may also bring about difficulties for finding appropriate links, or ways to reach partner, information, knowledge, etc. For instance, (Choi et al., 2001) in the field of supply networks, and Rycroft (2007) in biotechnology sector found out that increased connectivity was not linearly related with an increase in efficiency, which is measured by delivery time and product development time, respectively. However, as seen in Table 15, there is positive correlation between innovativeness and degree values of nodes in both closed and open networks. Same analysis is also repeated at regional level and similar results are obtained.

Furthermore, the discussion presented above is also related with sources as well as number of project partners. For instance, Lundvall et al. (2002) argue that successful innovation is an outcome of interactive learning processes based on close relationships between actors, implying that it is established on strong ties among the actors. Ruef (2002) and Powell et al. (1996) discuss the importance of number of actors in enabling a combination of different information, knowledge, resources, etc. On the other hand, Tatikonda and Rosenthal (2000) assert the negative effects of project size on innovation, though they could not provide a strong empirical support for their argument. Moreover, the role of different source of actors in innovation is widely discussed by authors such as Nooteboom (2000), Ruef (2002), etc., among others. In general, it is presumed that diverse partners bring the newest information, knowledge, and resources into the project, which increases the success of novelty. Thus, correlations between average project size (number of participants) and innovativeness value between the years 2006-2012 show that there is an inverse relationship between the project size and innovativeness value (Table 16). In addition to the number of partners, the role of different types of actors in innovation is also analyzed. Between the years 2006-2012, the number of cooperation of each country with others is calculated in order to analyze the notion of participant diversity in projects. Results obtained are summarized in Table 17. In contrary to the inverse relationship between the project size and innovativeness value, a positive correlation is found between innovativeness and diversity of partners. Therefore, it is found that increasing number of degree values of nodes, implying increasing linkages among the nodes (nation or region) and increasing number of different partners come forward as better policy alternatives than the implementations of the Commission on decreasing administrative procedures.

A number of studies on relationships between network structure and sector characteristics/ thematic areas/ instruments in FPs., make efforts as above to provide suggestions as well (e.g. Heller-Schuh et al., 2011), which usually reiterate the well-known statement that ‘policies should be designed in line with the requirements of sub-programmes/instruments to increase innovativeness of EU’. As discussed in Chapter 4, without undervaluing the significance of such analyses, it is possible to reach misguided statements about a sub-programme/ instrument and the network established by projects, which are supported under that sub-programme/instrument. As shown in Chapter 4, for instance, a thematic area of FP6, Information Society Technologies, encapsulates different topics ranging from “micro and nano- systems” and “cognitive systems”, to “cross-media content for leisure and entertainment” and “improving risk management”. Same argument can also be developed for policy analysis based on instruments; for instance, “coordination action”, one of the instruments in FP6, was used to support 19 different types of sub-programmes. Therefore, policy recommendations based on the characteristics of this thematic network and/or instrument would probably prove misleading due to the huge diversity of sectors supported by that thematic area or instrument.

Similar to the criticism against “one size for all” approach of authors, another interesting issue is related with item 8 in Chapter 4, which argues that the existence of a centralized authority is a preventive factor in accepting European Research and Innovation Network as a complex system. Put in practice, in general, shared cost grants are the most preferred approach in supporting the innovation-related activities by the EU. In fact, the type and developmental stage of innovation requires different support mechanisms, such as support services, loan-based financial tools, platforms for obtaining user requirements, or meetings with users, etc. In addition to the differences in type and developmental stage of the innovation, beneficiaries of support also display differences amongst the users, which imply that national, sectoral or regional intermediaries are also available as an option for delivering the financial resources to users. In this way, instead of a "one size for all" approach (many grants are delivered by Commission or its executive agencies), alternative mechanisms such as regional/national authorities, sectoral representatives, etc. can be formed, which would also trigger the competition and reduce the overly centralized focus[41]. Therefore, without leaving the central support mechanism, tailoring the support in accordance with the type, developmental stage, and beneficiaries may not only increase the innovation performance of EU and help to reach wider audiences; but also help to obtain a smartly distributed intelligent system. In this way, the negative outcomes stated in the critique made above, can also be overcome.

Applicability of the last recommendation is mainly related with the statement of European Council related to research and innovation policy: "Research activities at national and Union level must be better integrated and coordinated to make them as efficient and innovative as possible…" (COM, 2000: 6).. In other words, ERA can be accepted as a network in which knowledge, technology and researchers move freely in order to increase cooperation, to stimulate competition, and to provide better allocation of resources.

Honestly, literature on networks actors has boomed, or, the concept of network turned out to be a panacea for most social disciplines ranging from sociology to innovation studies or political science to city planning; such as Castells's (1996) '*Rise of the Network Society*', Bort and Evans (2000) discussion on '*networking Europe*', role of networks for informal governance in the EU (Christiansen and Piattoni, 2004), '*Network Paradigm*' (Cooke and Morgan, 1993). In parallel with literature, establishment of networks or networking among different actors have been particularly fashionable in the EU. Like the perception of mass production, which was seen as best practice four decades ago (Maskell et al. 1998), network formation or participation in network is accepted as the best practice for all.It is also assumed that networks contain all positive notions such as innovation, adaptive, democratic,

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[41] The opposite approach is adopted in the current situation, as the European Commission tends towards a more centralized stance, claiming efficiency purposes.

open, etc. It can be said that networking of different actors has a huge potential in determining the future of the EU, holding the inherent power to bring the current situation into centralization or decentralization, or in between these two positions.. Since, bringing together the different actors within a network have the potential to increase convergence or to trigger realization of difference among the actors. In fact, the above assumption is based on the development of systems of innovation approach as well as globalization. Systems of innovation encapsulate almost all activities related with science, research, technology, labor policies, education and training system, environment, welfare, etc. Put differently, as stated in (COM,2011:48), while regional and national authorities are trying to increase their own innovativeness and competitiveness at the local level via benefiting from SIs approach in one way or other; the European Commission is formally trying to do the same at the European level.

At the same time, increasing globalization, especially starting from 1990s, also brought about a new structure, where industrial actors increased their activities in different countries/ regions and sectors, in order to increase their competiveness; which means that national borders began to be taken less into consideration (Meyer-Krahmer and Reger, 1999). Therefore, the lines demarcating division of work among the innovation systems of regions, nations, sectors, and global firms have blurred. As such, networking of different actors, which may be accepted as part of different innovation systems with their unique institutional characteristics, play a critical role in determining the future of the ERA.

With regards to ERA, answers to three questions are investigated to figure out whether ERA has been completed or not. In this sense, the role of geographical proximity at regional and national network levels; of existing network structure; and of institutional infrastructure (norms, values, etc.) and national policies such as tax, labor, funding, etc., are analyzed. Since, it is thought that one way or another, fulfillment of ERA shall provide harmony among the policymakers in terms of not only their perception and implementations of SIs policies, but also elimination/minimization of critique made above, and in Chapter 2, "*Lack of Centralized Authority and Distributed Structure in terms of Resources, Relations and Feedbacks*".

On the other hand, the discussion on ERA in Chapter 4 based on the obtained results proved that ERA has not been completed yet (COM,2012:392); although the Commission states "European Research Area (ERA) is at the heart of the Europe 2020 strategy and its Innovation Union (IU) policy flagship and why the European Council has called for ERA to be completed by 2014" (COM, 2012: 392).

The findings firmly demonstrate that geographical proximity is still widely considered when the choice of partner is concerned. Researchers do not only prefer to work with those who are located in close proximity; but also with those who are located in country/ region, instead of across borders. Moreover, successful participants of networks, i.e. countries or regions nodes, prefer to collaborate with those which are also successful, rather than the relatively unsuccessful, meaning that it is difficult for unsuccessful participants to join into networks of successful participants. Like successful participants network, it is also demonstrated that there is relatively a closer cooperation among the capital cities, which implies the existence of high rank universities, research institutions, public organizations, etc. in these cities have an impact on the structure of the network.

Policies implemented for the establishment and/or development of a network in Europe bring along important advantages, as stated above, which means that information, knowledge, capability, resource, etc. exchanged through the network, are important factors to achieve targets of ERA and Innovation Union. However, as it is found in Chapter 4, up until now, distribution of benefits is not equal; or they do not bring as much benefit to periphery countries or regions as they do to developed countries or regions. In this sense, uneven distribution of nodes, links; asymmetrical power relations; unequal distribution of network benefits and outcomes are important factors for the establishment/ achievement for ERA targets. Intentionally or unintentionally, ERA gives preferential support to successful participants and their relations, implying that ERA supports the innovativeness and competitiveness of successful participants; though it is expected from ERA to remove barriers among nations and regions, as well as prevent disintegration among those. This dual structure (competition and cohesion) should be taken into consideration when ERA policy is determined and/or developed, if all EU instead of only successful participants are aimed to benefit.

While discussing the characteristics of complex systems in Chapter 2, it is stated that emergence is one of the important notions of complex systems, which is defined as a characteristic that is not shown by the constituents of the system (micro-macro relations). As such, emergence refers to the global level behaviors and properties shown by the system and resulted from the interactions of the constituents of the system (Goldstein, 1999 and Holland, 1998). It cannot be determined via investigating any of the constituents or relations among those. From the point of complex system, general characteristics of networks at regional and national levels, shown in Table 8 and Table 9, are emergent characteristics of European Research and Innovation Network. According to findings, as stated in Chapter 4, integration of European Research Area has already been moving toward being closer, which can be seen from the increase in numbers of links and average clustering coefficient values. On the other hand, the focus on relationships among innovativeness of EU, and number of projects, linkages, average clustering coefficient values reveal another picture.

Starting from the last decade, role of networks in the areas of science, technology, research and innovation policies have been discussed increasingly. The main idea behind this discussion is related with the emphasis on the importance of interactions among different actors, which is accepted as the most important factor for developments in science, technology, research and innovation. That is, instead of focusing on a single actor and its behaviors, policymakers started to focus on the importance of cooperation, collaboration and communication among the actors (Freeman 1991; Lundvall 1992; Metcalfe 1995; Foray and Lundvall, 1996).

Reflection of academic discussion can easily be seen in the discussions related with the future of EU, implying that innovation is considered among the essential sources for smart and sustainable economic growth, as stated in Lisbon Agenda (European Communities, 2006) or in the recent discussions Horizon 2020. Therefore, to increase knowledge production and/or accumulation, among others, participation of projects is supported by policymakers at all levels, ranging from local to EU. To assess the effect of project participation on innovativeness value; correlation values obtained between number of projects and innovativeness values both at the country and NUTS-2 region levels are provided in Table 10 and Table 11, respectively. As seen from the correlation results, about half of innovativeness values of nodes (country and region) can be explained by number of projects they participated.

In addition to participation into projects, clustering is also considered an important factor affecting the innovativeness of actors. From the positive side, based on *strong tie* discussion by Coleman (1988) or *embeddedness* argument of Granovetter (1973), it is maintained that clustering increases the exchanges due to mutual trust, etc., as well as enables novel solutions (Brown and Duguid, 1991) owing to shared understanding among partners. Conversely, it is argued that clustering has negative effects on innovation due to redundancy (Burt, 2001). Redundancy in information and knowledge and over shared conventions and norms, as a culprit for reducing creativity (Uzzi and Spiro, 2005), shall make negative effect on innovation. Therefore, it is argued that lower clustering coefficient implies higher number of structural holes to be filled in by actors, which enables them to combine different resources such as knowledge and information. Innovativeness and clustering values of countries in three types of networks (open, closed, and regional networks) are correlated in order to analyze the relationships between innovativeness and clustering values of nodes (country or region). As seen in Table 12, a negative correlation is found between innovativeness and clustering values of nodes.

Instead of focusing on obtaining high clustering, which may be accepted as a sign for the existence of mass, redundant links among nodes, decrease in differences, etc.; focusing on structural holes may be taken into consideration as an alternative means for increasing innovativeness of EU. Put differently, advantages of existing networks cannot be permanent, which means that there is always potential for entropic death due lack of new information, knowledge, resources, competences, specialization, etc. In this sense, gate keepers have important role for decreasing the entropy of the network (Camagni, 1999). In other words, unless new knowledge is introduced into the system, the actors of the system's "cognitive distance" (Noteboom, 1992 and 2005) start to become similar and the system faces with *inertia* or *lock-in*; a situation that can also be called as *core rigidities* (Leonard-Barton, 1992), *blind spots* (Porter, 1980), and *competency traps* (Cohen and Levinthal, 1990). For production of or access to new knowledge beyond the system, stimulates "symmetry-breaking" (Cilliers, 2001) in system and inhibit it from excessive homogeneity in terms of knowledge, information, capacity, and capabilities. The reason for this, as emphasized by Allen (2001), is that the diversity among the actors of a system increases the effectiveness of the system. Diversity of actors of systems of innovation in terms of their knowledge base helps the system to adapt to the changing conditions, as it enables actors to evaluate and respond requirements of not only market, but also (actors of) system itself. To assess the role of structural hole or gate keepers, the innovativeness value and number of FP7 projects of countries were correlated (Table 13) with the important actors stated in IUS 2013 (Brazil, Canada, China, Israel, India, Japan, South Korea, Russia, United States of America, South Africa).

Moreover, performance of European Research and Innovation Network is also analyzed vis-à-vis its relations with important rivals. In other words, how outside links of the network affect the innovativeness of Europe or vice versa is investigated (Table 22) via focusing on correlation between innovativeness value of Europe and degree value of important rivals in Chapter 4. According to findings, there is a positive correlation between Europe, and Brazil, Canada, China, and Russia; and there is a negative correlation between Europe, and United States, Korea, and Japan.

Based on findings, which show a negative correlation between clustering coefficient and innovativeness, and a partially positive correlation between the number of projects with important rivals and innovativeness value, it may be articulated that collaboration with important rivals is significant for increasing the innovativeness of Europe. Furthermore, with regards to the role of most important gatekeepers (Germany, France, Italy and United Kingdom), it is found that they are the main actors not only in terms of knowledge production and diversity, but also for knowledge transaction between the close an open networks or between EU and outside. However, when its relations with three of its rivals are considered, the existing policy and implementations have not proved as beneficial as expected in Europe. Therefore, from the point of innovation and network relations, above argument can be read as, high clustering may be accepted as a positive sign for innovation if the aim is creation of mass, norms, values, etc. On the other hand, if the aim is to create knowledge diversity and variety, low clustering may be accepted as a positive sign for innovation. In this framework, a tool for supporting the internal knowledge, capability, capacity, etc., diversity of important gatekeepers should be developed in order to increase innovativeness and competitiveness of Europe. The reason, as emphasized by Allen (2001), is that the diversity among the actors of a system increases the effectiveness of the system. Diversity of actors of SIs in terms of their knowledge base helps the system to adapt to the changing conditions. Again, it is diversity, which enables actors to evaluate and respond requirements of not only market, but also (actors of) system itself.

When the discussion above is summarized, stating the need for increasing diversity among the actors in EU in order to increase innovativeness of EU, is easier said than done. Put differently, as discussed in Chapter 4, the basic assumption of EC on ERA is, those lagging regions shall increase their knowledge base, innovativeness, competitiveness, etc. over time, with the help of funds (e.g. structural funds, devoted to regions with per capita incomes less than 75% of the EU average). At first glance, the assumption seems reasonable; lagging regions shall utilize support from EC, so that the gap between leader and lagging regions shall be narrowed. In other words, validity of proverbial "rich get richer and poor get poorer" statement will decline, and lagging regions will be able to participate more into collaborative projects. However, in the analyses on ERA, it is realized that the importance of distance is increasing from the east of Europe to west in both networks. In other words, west of Europe and some part of north of Europe give much more importance to the notion of distance. These nodes are also important actors for Europe for its competitiveness and innovativeness. It is also found that there is not only an increase in integration at nation and region levels, indicating the integration of European Research Area has already been moving toward being closer, but also in the integration of nodes inside, implying nodes (countries and regions) prefer to establish a link with existing ones primarily, instead of new nodes. Starting from FP1, the degrees of country or region (NUTS-2) embeddedness and network stability are found to be high, prevailing that a small number of regions or countries are interconnected with each other and enter into the network much more than the average number of participants (regions or countries). In other words, most regions or countries enter into the network via connecting with central regions or countries.

In view of the current conditions of EU, explained above, and expectations from Innovation Union and Horizon 2020, one of the main assumptions of network studies, which underline the importance of position of a node in network, is taken into consideration in order to offer a simple policy tool for increasing the innovativeness of EU. Put differently, similar to the works by Ahuja (2000), and Powell, Koput, and Smith-Doerr (1996) analyzing network structure and innovative performance, Leoncini et al. (1996), and Wal and Boschma (2007) study the collaboration among actors in projects in which links of networks are seen as means to exchange information, knowledge, resources, etc. The major idea behind these studies is that networks are important means for exchanging information, knowledge, resources, etc., which are important components for novel combinations (Nelson and Winter, 1982) as well as innovation. In this framework, many authors (e.g. Schilling and Phelps, 2007), argued that the position of an actor may be an important factor in determining its innovativeness. As discussed by Singh (2005), via influencing the structure of network, a policymaker may increase not only information, knowledge, capability, etc. of actors, but also the capacity of regions to innovate.

As often stated in this Thesis, Since, as discussed by Kogut (2000), network is an emergent structure and its characteristics are determined mainly by interactions among nodes, rather than exogenous factors. Put in simple terms, it is not meaningful and possible to demand from nodes (countries or regions) to change their links with existing nodes; or, the policymakers do not have the opportunity to determine who shall participate in which project; that is, they can only influence the emergent structure without fully controlling it.. In this framework, policies related with networks should be determined in accordance with the self-possessed characteristics of network, instead of ‘scratching method’.

When the relationship between network structure established by FPs and innovativeness values are analyzed (Table 20), it is found that innovativeness shows the highest correlation with eigenvector and next with degree values in country networks either open or closed, in regional network. Based on the explanations above, it is not meaningful to expect the redistribution of links among the countries in order to make positive contributions to the innovativeness of countries. On the other hand, eigenvector value, which shows a node's importance in a network based on the node's connections, might be taken into consideration as a tool for policy intervention.

Moreover, discussions made on eigenvector revealed an inverse relationship between eigenvector values and innovativeness values. In this framework, without forgetting the emergent structure of European Research and Innovation Network and the importance of current nodes, which can be either country or region, for the innovativeness and competitiveness of Europe, a simple rule which states that in the project application process, a requisite to be set by the Commission for the inclusion of a node with a low eigenvector value into the project consortium, would both allow the free establishment of the said project consortium, and facilitate the participation of nodes with low innovativeness into the network; thus benefit from the advantages mentioned in this Thesis.

All in all, it is found that the dual structure (competition and cohesion) resulted from the different innovativeness of nodes (region and country) is basic impediment for achieving the target of Innovation Union, including ERA. In fact, the current situation is in line with the complex system view; which, like evolutionary approach, underlines both competition and cooperation. Many policy discussions can be made and suggestions can be offered on how this dual structure shall be eliminated and increase innovativeness of EU. Based on the discussions made in the scope of this Thesis, it can be said that increasing variety is one way to increase complexity and innovativeness. In this sense, complex systems need to increase their internal variety as much as they can, even at the expense of lowering performance of the system. However, when the sustainability of EU innovativeness is considered, how to manage increase in diversity is a question to be answered by policymakers of EU to prevent the decrease in performance of the system. This text offers to use of eigenvector calculation as a simple but effective tool for increasing the cohesion of the region or countries for achieving the target of Innovation Union, including ERA. Since participation into FP projects shall increase the knowledge base of the periphery or lagging region or nations in a time. One may ask whether there is a negative side to include periphery or lagging region or nations into project in terms of overall innovation performance of EU, or leader regions or nations. As stated above, this rule does not prevent any partners to establish a project consortium with others. In other words, at least one node, which has a lower eigenvector value, shall be included into project consortium, and rest of project partners shall be selected with free will of the applicants (project leader or coordinator) of the project.

On the other hand, in addition in to cohesion explained above, there is the issue of competitiveness of EU. As shown in Chapter 4, there are enough links among the nodes (regions and countries) to state that nodes are able to collaborate with others. Concerning the competitiveness of EU, with regards to the previously mentioned role of most important gatekeepers (or actors filling structural holes), it is found that they are the main actors not only in terms of knowledge production and diversity, but also for knowledge transaction between closed and open networks, or between EU and outside. However, when relations with three of the important rivals are considered, the existing policy and implementations have not proved as beneficial as expected from European Research and Innovation Network in Europe. Therefore, regarding the ability of important gatekeepers to connect with global networks but low absorptive capacity of the system in terms of benefiting from those rivals, it is logical to propose that policy makers of EU should focus more on the development of diversity and absorptive capacity of nodes in order to benefit more from the European Research and Innovation Network to increase the innovativeness of EU.

Obviously, which tools (or instruments) are preferred to implement the above recommendations is a critical issue. Since, while the selection of policy tools forms a part of the policy formulation; tools turn out to be part of the actual policy implementation. However, no matter which policies and tools related with innovation are selected, their framework and impact are mainly determined by ultimate political objectives, which might be related with various topics ranging from economic issues such as growth, employment, and inflation, to social, environmental, defense concerns. Furthermore, selection and implementation of appropriate innovation policy tools are mainly related with causes behind the problems identified by the researchers, governing authorities, etc. Analysis made in this Thesis reveals two important causes, which initiated two main policy recommendations, stated above. One of the causes is the imbalance among nodes (regions and countries in Europe) in terms of knowledge accumulation, capacities, and capabilities, which prevents cohesion/development of ERA and impedes the innovativeness of EU. Second one is the low level of diversity and absorptive capacity of nodes, especially gatekeepers, which prevents the rise of competitiveness in ERA and adds to the innovation performance gap with the important rivals stated in IUS 2013, specifically USA, Japan and South Korea.

Regulatory, economic and financial instruments, as well as soft tools (Borrás and Edquist, 2013) used for innovation policies, can be considered as important means employed by governing bodies for policy intervention. Within the systems of innovation, complex systems, and network studies scope of the Thesis, two instruments are selected among others to implement suggested policy recommendations. One of them is in the framework of regulatory instrument in accordance with Borrás and Edquist's (2013) categorization. As such, a legal regulation, which stipulates the inclusion of a node with a low eigenvector value, in projects may be used for balancing nodes (regions and countries in Europe) in terms of knowledge accumulation, capacities, and capabilities, to accelerate cohesion/ development of ERA and increase innovativeness of EU.

Second tool falls into the category of soft instruments, mentioned above. It is thought that in order to increase diversity and absorptive capacities of actors, specifically gatekeepers, vis-a-vis important rivals of Europe, stated in IUS 2013, public procurement or public-private partnerships (PPI) may be used for increasing the competitiveness of ERA and decrease innovation performance gap with the important rivals, specifically with USA, Japan and South Korea. Since, specific and challenging projects requested by or implemented with public actors shall increase specific knowledge and capabilities of actors, which increases the diversity as well as absorptive capacity of private actors in the long run.

Final point, related with suggestions, is whether those tools are appropriate to scope of this Thesis or not. Accordingly, as stated in conclusion part of Section 2, intervention policies of governing bodies are not developed within the framework of network approach (Hyötyläinen and Valtion, 2000). Those tools are selected, since, both of them increase networking and interactive learning among the actors of systems of innovation, which enables production/ integration/ transaction of knowledge and capabilities; and the last one may be used for mitigating societal challenges identified in Europe 2020 documents, which are listed in Section 2.4.

As a result, recommendations, suggested above, have the potential to mitigate the coordination and governance problems resulted from the implementations of Horizon 2020 policies. As stated in Barca report (2009), which underlined the importance of combined exogenous and endogenous push for institutional changes in nodes (country and/or region), while innovation policy supports excellence and nourishes inequalities among the nodes; cohesion policy enables measures to decrease inequalities among the nodes. It argues that "an exogenous public intervention (which) can improve things by upsetting the existing balance. But for this intervention to be effective, it needs to be accompanied by increased local involvement." In this sense, recommendations developed in this Thesis related with cohesion and competitiveness of ERA as well as innovativeness of EU could be seen as an appropriate input for developing institutional infrastructures in nodes (country and/or region). Put differently, in accordance with the Prigogine's argument, while European Research and Innovation Network, in a sense, is borrowing some of its order from outside with improving its ability in terms of managing links with non-EU countries, especially important rivals; at the same time, eigenvector approach enables its cohesion, which increases the absorption and diffusion of knowledge of nodes, especially lagging or periphery nodes. In this way, not only political concerns related to 'hollowing out' of globalization on innovation systems in Europe or with network failures arguments (Varblane et al., 2007) can be diminished but also global networks can be used for increasing the performance of systems of innovations at all levels.

Therefotr, this Thesis benefited from the complex systems literature in order to discuss system dimension of SIs, which is rarely discussed aspect. Moreover, review of the CSs literature does not only produce a metric, which was used for deciding whether European Research and Innovation Network is complex or not; but also highlights the importance of entropy concept within the framework of CSs. European Research and Innovation Network, formed at three scales in this Thesis and appeared as a result of policy and programme implementations at the European level, was analyzed benefiting from standard network analysis techniques in order evaluate Research and Technological Development (RTD) policies, implemented by EC. At the same time, discussions on entropy, specifically Boltzmann's and Prigogine's views, were combined with the results, obtained from the analysis of European Research and Innovation Network, and discussions on Systems of Innovation, within the framework of EC implementations related with ERA and innovativeness of EU. In this way, not only network analysis can be used as an ingredient for policy recommendation, but also as one of the unique contributions of the Thesis, is obtained, the innovativeness of EU is discusses and policy recommendations were made benefiting from the discussions and studies on CSs, SIs, and network studies for the first time. This process produced two main policy recommendations. Implementation of a simple rule, inclusion of node which has low eigenvector value into project consortium, by EC shall not only increase the cohesion process of ERA but also the innovativeness of EU. Secondly, without forgetting the emergent structure of European Research and Innovation Network and the importance of current nodes, which can be either country or region, for the innovativeness of Europe, it can be said that when relations with three of the important rivals (United States, Korea, and Japan) are considered, the existing policy and implementations have not proved as beneficial as expected from European Research and Innovation Network in Europe. In this sense, policymakers of EU should focus more on the development of diversity and absorptive capacity of nodes in order to benefit more from the European Research and Innovation Network to increase the innovativeness of EU (Figure 13).

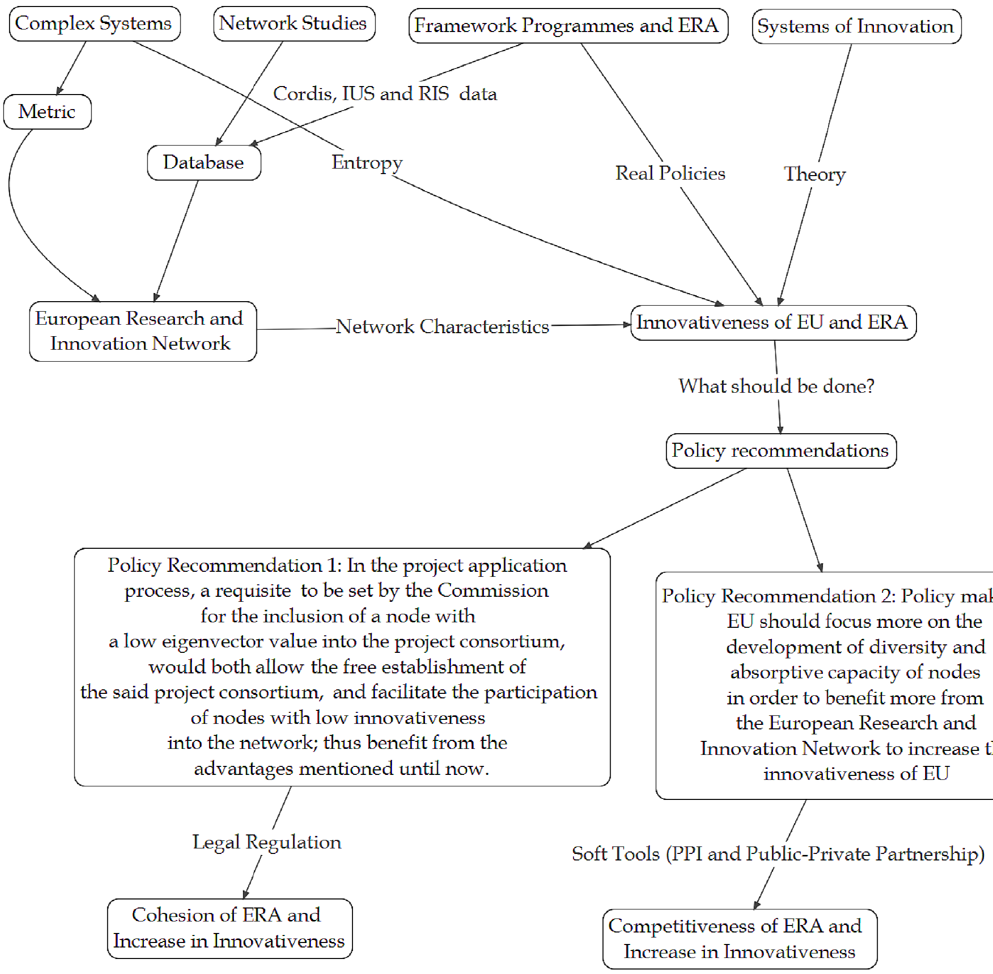

Figure 13 Thesis Process

5.2 Further Research

One of the interesting topics for further research is the establishment of a relationship between European Research and Innovation Network, and national research and innovation networks. Such a network analysis has a huge potential to produce important ingredients for policymakers (Malerba and Nicholas, 2002), such as:

- Network configuration, participants, and links among those, enable policymakers to envisage the future development in technologies, markets, and competitiveness of any field. In other words, network indicators may be used as an early warning system tool to formulize/develop appropriate policies.

- The extensive mapping of relations obtained from different data resources (e.g. regional, sectoral, national, and international projects, patents, publications, etc.) among organizations (e.g. firms, universities, public institutions, etc.), allow policymakers to see the entire network structure in Europe. In this way, policies can be determined more accurately in accordance with local and/or sectoral distributions. Moreover, depiction of existing networks may also be used as an indicator in the establishment of ERA.

- European added value is one of the important criteria for the selection of project applications to be funded. In this sense, depiction of a network can be used as an ingredient for analyzing characteristics and geographical spread of the supported networks. For instance, encouraging establishment of networks from different organizations in different regions can be supported for increasing the European added value.

This study takes topological characteristics of European Research and Innovation Network into consideration; leaving out the function and influence of each one on others. Such an analysis may enable us to understand internal dynamics of network formation and its evolution. In other words, this type of analysis could help us better understand questions concerning the reasons for organizations to enter into the networks, the relationships between organization performance and networks, and underlying reasons for the success/failure of networks.

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APPENDICES

APPENDIX A - TABLES

Table 23 Real Networks

Type of Network(*)	Author (Year)	Number of Nodes (*N*)	Average Degree (*k*)	Exp. cutoff power-law scal.	In-degree Exponent (*y* in)	Out-degree Exponent (*y* out)	Average path length (*L*)	Ave. path length (Random) (*L* ran.)	Clus. Coefficient (*C*)	Clus. Coefficient (Ran.)
Internet, domain *	Yook et al. (2001a)	3015-6209	3.52 -4.11				3.7 -3.76	6.36 - 6.18	0.18 -0.3	0.001
Internet, domain *	Pastor-Satorras and Vespignani (2004)	11 174	4.19		2.38	2.38	3.62		0.24	
Internet, domain *		228 263	2.8		2.18	2.18	9.5		0.03	
Internet, domain *	Faloutsos et al. (1999)	3015 – 4389	3.42- 3.76	30-40	2,1 - 2,2	2,48	4	6.3		
Internet, router *		3888	2.57	30	2,1 - 2,2	2,48	12,15	8.75		
Internet, router *	Govindan and Tangmunarunkit (2000)	15 104	2.66	60	2.4	2.4	11	12.8		
WWW	Barabási et al. (1999)	325 729	4.51	900	2.1	2.45	11.2	8.32		
WWW	Broder (2000)	~2 10^8	7.5		2.1	2.7	16		0.11	
WWW	Kumar et al., 2000	4 107	7		2.1	2.38				

Table 23 (continued)

Type of Network(*)	Author (Year)	Number of Nodes (N)	Average Degree (k)	Exp. cutoff power-law scal.	In-degree Exponent (y in)	Out-degree Exponent (y out)	Average path length (L)	Ave. path length (Random) (L ran.)	Clus. Coefficient (C)	Clus. Coefficient (Ran.)
WWW	Adamic (1999)	153 127	35.21				3.1	3.35	0.1078	$23\ 10^{-3}$
WWW	Broder et al., 2000	2 108	40305	4000	40180	26330	16	8.85		
Scientific, SPIRES (data base) *	Newman (2001b)	56 627	173	1100	1.2	1.2	4	2.12	0.726	0.003
Scientific, Neurosci. (data base) *	Barabási et al. (2001)	209 293	11.5	400	2.1	2.1	6	5.01	0.76	$5.5\ 10^{-5}$
Scientific, Math. (data base) *	Barabási et al. (2001)	70 975	3.9	120	2.5	2.5	9.5	8.2	0.59	$5.4\ 10^{-5}$
Scientific, LANL. (data base)	Watts and Strogatz (1998)	52 909	9.7				5.9	4.79	0.43	$1.83\ 10^{-4}$
Scientific, MEDLINE (data base)	Newman (2001a, 2001b and 2001c)	1 520 251	18.1				4.6	4.91	0.066	$1.1\ 10^{-5}$
Scientific, NCSTRL (data base)	Newman (2001a, 2001b and 2001c)	11 994	3.59				9.7	7.34	0.496	$3\ 10^{-4}$
Scientific, MATH1999 (data base)	Barabási et al. (2001)	57 516	5		2.47	2.47	8.46		0.15	
Movie actors	Watts and Strogatz (1998)	225 226	61				3.65	2.99	0.79	$27\ 10^{-3}$
Movie actors *	Barabási and Albert (1999)	212 250	28.78	900	2.3	2.3	4.54	4.64		
Citation	Render (1998)	783 339	8.57		3					
Cellular (Metabolic, E. coli)	Jeong et al. (2000)	778	7.4	110	2.2	2.2	3.2	3.32		
Cellular (E. coli, substrate graph)	Wagner and Fell (2001)	282	7.35				2.9	3.04	0.32	$26\ 10^{-3}$
Cellular (Protein, S. cerev)*	Jeong, Mason, et al. (2001)	1870	2.39		2.4	2.4				

Table 23 (continued)

Type of Network(*)	Author (Year)	Number of Nodes (*N*)	Average Degree (*k*)	Exp. cutoff power-law scal.	In-degree Exponent (*y* in)	Out-degree Exponent (*y* out)	Average path length (*L*)	Ave. path length (Random) (*L* ran.)	Clus. Coefficient (*C*)	Clus. Coefficient (Ran.)
Cellular (Protein)	Jeong, H. et al., 2001	2115	6.8		2.4	2.4	2.12		0.07	
Ecological (Ythan estuary) *	Montoya and Sole (2002)	134	8.7	35	1.05	1.05	2.43	2.26	0.22	$6\ 10^{-2}$
Ecological (Silwood Park) *		154	4.75	27	1.13	1.13	3.4	3.23	0.15	3 10 -2
Phone call	Aiello et al. (2000)	$53\ 10^{6}$	3.16		2.1	2.1				
e-Mail*	Ebel et al. (2002	59 812	2.88		1.5	2	4.95		0.03	
Words (co-occurrence)*	Ferrer i Cancho and Sole (2001)	460 902	70.13		2.7	2.7	2.67	3.03	0.437	$1\ 10^{-4}$
Words, (synonyms)*	Yook et al. (2001b)	22 311	13.48		2.8	2.8	4.5	3.84	0.7	$6\ 10^{-4}$
Grid (Power)	Watts and Strogatz (1998)	4941	2.67				18.7	12.4	0.08	5 10-3

* Indicates undirected networks

Table 24 Innovativeness Values (Country)

Countries (Abb.)	2006	2007	2008	2009	2010	2011	2012
AT	0.56	0.58	0.58	0.60	0.57	0.58	0.60
BE	0.58	0.61	0.59	0.60	0.61	0.61	0.62
BG	0.16	0.17	0.19	0.20	0.23	0.23	0.19
CY	0.41	0.42	0.49	0.47	0.49	0.51	0.51
CZ	0.38	0.40	0.37	0.37	0.41	0.41	0.40
DE	0.64	0.66	0.68	0.69	0.71	0.70	0.72
DK	0.73	0.73	0.64	0.66	0.70	0.70	0.72
EE	0.39	0.39	0.42	0.46	0.46	0.48	0.50
ES	0.38	0.64	0.66	0.67	0.67	0.68	0.68
FI	0.64	0.51	0.52	0.53	0.56	0.56	0.57
FR	0.49	0.33	0.36	0.34	0.36	0.33	0.34
GR	0.32	0.40	0.39	0.39	0.39	0.39	0.41
HU	0.30	0.31	0.30	0.30	0.33	0.34	0.32
IE	0.55	0.58	0.55	0.57	0.54	0.59	0.60
IT	0.38	0.41	0.40	0.41	0.43	0.43	0.44
LT	0.24	0.26	0.24	0.25	0.25	0.27	0.28
LU	0.58	0.61	0.58	0.61	0.59	0.58	0.63
LV	0.16	0.19	0.19	0.21	0.22	0.23	0.22
MT	0.28	0.29	0.30	0.32	0.34	0.30	0.28
NL	0.55	0.57	0.58	0.59	0.59	0.59	0.65
PL	0.27	0.28	0.27	0.28	0.27	0.28	0.27
PT	0.32	0.34	0.38	0.40	0.43	0.42	0.41
RO	0.19	0.23	0.23	0.25	0.23	0.25	0.22
SE	0.76	0.75	0.73	0.73	0.73	0.74	0.75
SI	0.40	0.43	0.45	0.47	0.49	0.52	0.51
SK	0.27	0.30	0.28	0.30	0.28	0.29	0.34
UK	0.60	0.62	0.58	0.59	0.62	0.62	0.62

Table 25 Innovativeness Value (Region-NUTS-2)

Region (Abb.)	2007	2009	2011	Region (Abb.)	2007	2009	2011	Region (Abb.)	2007	2009	2011
AT1	10	10	10	FI18	12	12	12	NO02	3	3	5
AT2	9	9	9	FI19	11	11	11	NO03	6	6	7
AT3	9	9	8	FI1A	10	11	11	NO04	6	6	7
BE1	10	10	10	FI2	5	4	4	NO05	6	7	7
BE2	11	10	11	FR1	10	11	11	NO06	7	7	8
BE3	8	9	9	FR2	4	5	6	NO07	4	4	3
BG3	1	1	1	FR3	3	5	6	PL11	2	2	2
BG4	3	2	2	FR4	6	8	8	PL12	4	5	6
CH01	11	11	12	FR5	5	6	7	PL21	3	3	3
CH02	10	10	11	FR6	7	9	9	PL22	3	3	2
CH03	12	12	12	FR7	7	9	10	PL31	2	2	1
CH04	12	12	12	FR8	6	7	9	PL32	2	2	1
CH05	9	9	9	FR9	4	4	3	PL33	1	1	1
CH06	10	11	11	GR1	2	3	3	PL34	1	1	1
CH07	9	10	11	GR2	2	2	2	PL41	2	2	2
CZ01	10	11	11	GR3	7	7	8	PL42	1	1	1
CZ02	7	7	9	GR4	2	2	3	PL43	1	1	1
CZ03	5	5	6	HR01	6	6	7	PL51	3	3	3
CZ04	3	2	4	HR02	1	1	1	PL52	2	2	1
CZ05	6	6	8	HR03	3	3	3	PL61	2	1	2
CZ06	7	7	8	HU1	7	6	6	PL62	1	1	1
CZ07	6	7	5	HU21	3	3	3	PL63	3	3	3
CZ08	4	3	4	HU22	2	2	3	PT11	3	4	6
DE1	12	12	12	HU23	2	2	2	PT15	2	4	6
DE2	11	12	12	HU31	2	2	2	PT16	4	5	7
DE3	12	12	12	HU32	2	2	2	PT17	8	9	10
DE4	8	8	8	HU33	2	2	2	PT18	4	5	5
DE5	10	11	11	IE01	6	7	7	PT2	2	2	3
DE6	11	12	12	IE02	8	8	9	PT3	1	1	2
DE7	11	11	12	ITC1	9	8	9	RO11	1	1	1
DE8	7	8	8	ITC2	6	5	6	RO12	1	1	1
DE9	9	10	11	ITC3	7	6	6	RO21	1	2	1
DEA	9	10	10	ITC4	8	8	9	RO22	1	2	2
DEB	9	11	11	ITD1	3	3	4	RO31	1	1	1
DEC	9	10	10	ITD2	7	6	7	RO32	5	5	5
DED	10	10	10	ITD3	6	6	7	RO41	1	1	1
DEE	6	7	7	ITD4	7	7	9	RO42	1	1	1
DEF	8	9	9	ITD5	8	8	9	SE11	12	12	12
DEG	9	9	10	ITE1	6	5	6	SE12	12	12	12
DK01	12	12	12	ITE2	5	5	6	SE21	7	8	8
DK02	9	8	9	ITE3	4	4	6	SE22	12	12	12
DK03	9	8	9	ITE4	8	8	9	SE23	12	11	11
DK04	10	10	10	ITF1	4	4	5	SE31	6	6	6
DK05	9	8	9	ITF2	2	2	2	SE32	7	7	7
ES11	3	4	4	ITF3	4	4	4	SE33	9	10	10
ES12	4	5	5	ITF4	3	3	5	SI01	5	6	6
ES13	3	5	4	ITF5	3	3	4	SI02	8	9	9

Table 25 (continued)

Region (Abb.)	2007	2009	2011	Region (Abb.)	2007	2009	2011	Region (Abb.)	2007	2009	2011
ES21	9	9	9	ITF6	1	2	3	SK01	6	7	6
ES22	8	9	9	ITG1	3	3	4	SK02	3	2	2
ES23	3	5	6	ITG2	2	3	4	SK03	1	2	2
ES24	6	6	7	NL11	9	8	9	SK04	1	2	1
ES3	8	9	9	NL12	4	4	4	UKC	7	7	7
ES41	5	5	6	NL13	5	5	5	UKD	9	8	9
ES42	3	3	3	NL21	7	8	7	UKE	7	6	7
ES43	2	2	3	NL22	9	9	9	UKF	9	8	8
ES51	7	8	8	NL23	9	9	9	UKG	8	7	7
ES52	5	5	4	NL31	11	11	11	UKH	11	10	11
ES53	2	1	2	NL32	10	10	11	UKI	10	8	9
ES61	3	4	3	NL33	10	10	10	UKJ	11	10	11
ES62	5	3	3	NL34	6	6	6	UKK	9	8	8
ES63	1	1	1	NL41	10	11	11	UKL	8	7	7
ES64	1	1	1	NL42	9	9	9	UKM	9	8	8
ES7	2	2	2	NO01	9	9	9	UKN	6	4	5
FI13	10	9	8								

Table 26 Nodes Values (Closed Network) 2007-2012

Country	D2007	B2007	C2007	E2007	CL2007	D2008	B2008	C2008	E2008	CL2008	D2009	B2009	C2009	E2009	CL2009	D2010	B2010	C2010	E2010	CL2010	D2011	B2011	C2011	E2011	CL2011	D2012	B2012	C2012	E2012	CL2012
AT	29.00	9.668	0.029	0.041	0.726	32.00	3.199	0.031	0.036	0.871	32.00	2.073	0.029	0.034	0.906	33.00	3.682	0.030	0.034	0.886	33.00	2.299	0.030	0.033	0.908	34.00	4.752	0.031	0.034	0.861
BE	28.00	9.846	0.028	0.040	0.757	31.00	2.346	0.030	0.035	0.894	33.00	7.273	0.030	0.034	0.856	33.00	6.671	0.030	0.034	0.875	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
BG	16.00	0.604	0.022	0.026	0.925	28.00	13.222	0.028	0.031	0.855	30.00	3.825	0.028	0.032	0.889	30.00	2.601	0.028	0.031	0.913	32.00	1.954	0.029	0.032	0.917	31.00	1.891	0.029	0.032	0.916
CH	19.00	1.307	0.023	0.030	0.901	26.00	0.590	0.026	0.030	0.957	29.00	0.783	0.027	0.032	0.952	31.00	1.194	0.029	0.033	0.936	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
CY	20.00	1.876	0.023	0.029	0.863	25.00	0.458	0.026	0.029	0.960	28.00	1.028	0.026	0.030	0.938	28.00	0.697	0.026	0.030	0.954	26.00	0.351	0.025	0.027	0.971	26.00	0.206	0.025	0.027	0.982
CZ	22.00	1.136	0.024	0.034	0.911	29.00	1.564	0.029	0.033	0.917	29.00	1.010	0.027	0.031	0.943	29.00	0.616	0.027	0.031	0.960	30.00	0.863	0.028	0.031	0.950	29.00	0.608	0.027	0.030	0.960
DE	31.00	12.335	0.030	0.043	0.697	32.00	3.199	0.031	0.036	0.871	34.00	10.660	0.031	0.035	0.817	34.00	9.132	0.031	0.034	0.839	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
DK	26.00	5.025	0.026	0.038	0.790	30.00	1.930	0.029	0.034	0.905	31.00	1.359	0.029	0.033	0.929	32.00	1.471	0.029	0.034	0.926	32.00	1.204	0.029	0.033	0.938	31.00	1.213	0.029	0.032	0.936
EE	22.00	1.713	0.024	0.033	0.879	25.00	0.361	0.026	0.029	0.968	25.00	0.214	0.024	0.027	0.980	28.00	0.583	0.026	0.030	0.960	29.00	0.591	0.027	0.030	0.963	30.00	0.934	0.028	0.031	0.947
ES	31.00	12.335	0.030	0.043	0.697	32.00	3.199	0.031	0.036	0.871	33.00	7.273	0.030	0.034	0.856	34.00	9.132	0.031	0.034	0.839	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
FI	28.00	6.342	0.028	0.040	0.772	32.00	3.199	0.031	0.036	0.871	33.00	5.127	0.030	0.035	0.862	33.00	3.682	0.030	0.034	0.886	33.00	2.299	0.030	0.033	0.908	33.00	2.552	0.030	0.033	0.899
FR	33.00	49.168	0.032	0.043	0.615	33.00	20.199	0.032	0.036	0.817	34.00	10.660	0.031	0.035	0.817	34.00	9.132	0.031	0.034	0.839	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
GR	27.00	4.743	0.027	0.039	0.797	32.00	3.199	0.031	0.036	0.871	34.00	10.660	0.031	0.035	0.817	34.00	9.132	0.031	0.034	0.839	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861
HU	24.00	4.217	0.025	0.035	0.797	29.00	1.294	0.029	0.033	0.926	32.00	2.073	0.029	0.034	0.906	32.00	1.471	0.029	0.034	0.926	33.00	2.299	0.030	0.033	0.908	33.00	2.552	0.030	0.033	0.899
IE	22.00	1.822	0.024	0.033	0.879	27.00	1.103	0.027	0.031	0.933	29.00	0.901	0.027	0.031	0.946	32.00	1.471	0.029	0.034	0.926	33.00	2.299	0.030	0.033	0.908	33.00	2.552	0.030	0.033	0.899
IS	7.00	-	0.018	0.012	1.000	19.00	0.183	0.022	0.022	0.971	24.00	0.462	0.024	0.026	0.957	26.00	0.496	0.025	0.027	0.960	28.00	0.336	0.026	0.029	0.975	26.00	0.776	0.025	0.027	0.953
IT	32.00	19.168	0.031	0.043	0.657	32.00	3.199	0.031	0.036	0.871	33.00	5.127	0.030	0.035	0.862	33.00	3.682	0.030	0.034	0.886	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861

Table 26 (continued)

Country	D2007	B2007	C2007	E2007	CL2007	D2008	B2008	C2008	E2008	CL2008	D2009	B2009	C2009	E2009	CL2009	D2010	B2010	C2010	E2010	CL2010	D2011	B2011	C2011	E2011	CL2011	D2012	B2012	C2012	E2012	CL2012
LT	12.00	-	0.020	0.020	1.000	27.00	1.059	0.027	0.031	0.933	27.00	0.504	0.026	0.029	0.963	27.00	0.298	0.026	0.029	0.977	28.00	0.207	0.026	0.029	0.985	26.00	0.171	0.025	0.027	0.986
LU	13.00	0.056	0.020	0.022	0.987	21.00	-	0.023	0.024	1.000	24.00	2.051	0.024	0.025	0.922	24.00	1.409	0.024	0.025	0.935	28.00	1.145	0.026	0.028	0.938	27.00	0.439	0.026	0.028	0.967
LV	10.00	0.063	0.019	0.017	0.978	25.00	0.922	0.026	0.028	0.933	26.00	0.645	0.025	0.028	0.949	27.00	0.517	0.026	0.029	0.960	27.00	0.342	0.026	0.028	0.973	22.00	-	0.023	0.023	1.000
MK	1.00	-	0.016	0.002	-	2.00	-	0.017	0.002	1.000	8.00	0.050	0.018	0.009	0.964	10.00	0.050	0.019	0.011	0.978	15.00	-	0.020	0.017	1.000	15.00	-	0.020	0.017	1.000
MT	4.00	-	0.017	0.007	1.000	16.00	0.042	0.022	0.020	0.992	20.00	0.082	0.022	0.022	0.987	24.00	0.165	0.024	0.026	0.983	24.00	0.250	0.024	0.025	0.974	26.00	0.204	0.025	0.027	0.982
NL	28.00	5.271	0.028	0.041	0.791	32.00	3.199	0.031	0.036	0.871	32.00	2.073	0.029	0.034	0.906	32.00	1.471	0.029	0.034	0.926	33.00	2.299	0.030	0.033	0.908	34.00	4.752	0.031	0.034	0.861
NO	25.00	3.249	0.026	0.037	0.838	31.00	2.242	0.030	0.035	0.897	31.00	1.359	0.029	0.033	0.929	31.00	1.078	0.029	0.033	0.941	31.00	0.819	0.029	0.032	0.953	32.00	1.442	0.029	0.033	0.929
PL	22.00	1.561	0.024	0.033	0.884	31.00	2.346	0.030	0.035	0.894	32.00	2.073	0.029	0.034	0.906	32.00	1.471	0.029	0.034	0.926	32.00	1.204	0.029	0.033	0.938	31.00	1.112	0.029	0.032	0.941
PT	22.00	2.015	0.024	0.033	0.863	30.00	1.973	0.029	0.034	0.905	30.00	1.379	0.028	0.032	0.929	31.00	1.249	0.029	0.033	0.933	32.00	1.204	0.029	0.033	0.938	32.00	1.442	0.029	0.033	0.929
RO	15.00	0.650	0.021	0.024	0.905	26.00	0.444	0.026	0.030	0.964	28.00	0.430	0.026	0.031	0.969	28.00	0.332	0.026	0.030	0.975	30.00	0.649	0.028	0.031	0.960	31.00	0.923	0.029	0.032	0.948
SE	22.00	1.447	0.024	0.033	0.895	32.00	3.199	0.031	0.036	0.871	32.00	2.073	0.029	0.034	0.906	32.00	1.471	0.029	0.034	0.926	31.00	0.819	0.029	0.032	0.953	31.00	1.165	0.029	0.032	0.938
SI	22.00	3.215	0.024	0.032	0.832	28.00	1.279	0.028	0.032	0.926	28.00	0.646	0.026	0.031	0.957	28.00	0.428	0.026	0.030	0.969	27.00	0.122	0.026	0.028	0.990	28.00	0.296	0.026	0.029	0.978
SK	18.00	0.495	0.022	0.027	0.942	29.00	1.674	0.029	0.033	0.912	30.00	1.131	0.028	0.032	0.937	30.00	0.904	0.028	0.032	0.947	29.00	0.376	0.027	0.030	0.974	27.00	0.162	0.026	0.028	0.987
TR	15.00	0.504	0.021	0.024	0.933	26.00	0.986	0.026	0.030	0.935	27.00	0.868	0.026	0.029	0.943	28.00	0.625	0.026	0.030	0.957	28.00	0.679	0.026	0.029	0.954	30.00	0.840	0.028	0.031	0.950
UK	32.00	19.168	0.031	0.043	0.657	32.00	3.199	0.031	0.036	0.871	33.00	5.127	0.030	0.035	0.862	33.00	3.682	0.030	0.034	0.886	34.00	5.299	0.031	0.034	0.865	34.00	4.752	0.031	0.034	0.861

D: Degree; B: Betweenness Centrality; C: Closeness Centrality; E: Eigenvector Centrality; CL: Clustering Coefficient

Table 27 Nodes Values (Region Network) 2007

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
AT1	84	571.489	0.003	0.014	0.410
AT2	37	75.533	0.003	0.008	0.620
AT3	52	85.215	0.003	0.010	0.561
BE1	84	292.783	0.003	0.015	0.447
BE2	85	606.453	0.003	0.015	0.419
BE3	57	113.565	0.003	0.011	0.575
BG3	1	0.000	0.002	0.000	0.000
BG4	29	22.380	0.003	0.006	0.692
CH01	65	397.875	0.003	0.012	0.470
CH02	30	259.380	0.003	0.006	0.499
CH03	13	2.021	0.003	0.003	0.692
CH04	26	6.975	0.003	0.006	0.775
CH05	6	0.347	0.002	0.001	0.733
CH06	2	0.000	0.002	0.001	1.000
CH07	2	0.000	0.002	0.001	1.000
CZ01	36	23.059	0.003	0.008	0.740
CZ03	5	0.112	0.002	0.001	0.900
CZ04	2	0.000	0.002	0.000	1.000
CZ05	7	3.234	0.002	0.001	0.619
CZ06	13	0.216	0.003	0.003	0.923
CZ08	10	47.392	0.002	0.002	0.400
DE1	105	1336.139	0.004	0.016	0.330
DE2	96	585.177	0.003	0.016	0.391
DE3	55	83.487	0.003	0.011	0.627
DE4	34	28.452	0.003	0.007	0.569
DE5	25	10.594	0.003	0.005	0.667
DE6	26	16.412	0.003	0.005	0.548
DE7	53	128.895	0.003	0.010	0.543
DE8	5	0.302	0.002	0.001	0.600
DE9	57	134.138	0.003	0.011	0.567
DEA	101	524.115	0.004	0.016	0.375
DEB	41	28.433	0.003	0.009	0.678
DEC	15	5.991	0.003	0.003	0.610
DED	30	83.333	0.003	0.005	0.476
DEE	13	0.596	0.003	0.003	0.833
DEF	43	65.954	0.003	0.008	0.540
DEG	27	64.515	0.003	0.005	0.575

Table 27 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
DK00	42	53.902	0.003	0.008	0.597
DK01	68	431.783	0.003	0.012	0.462
DK02	4	0.000	0.002	0.001	1.000
DK03	32	236.510	0.003	0.006	0.569
DK04	27	18.063	0.003	0.006	0.703
DK05	15	1.250	0.003	0.004	0.838
EE001	21	5.023	0.003	0.004	0.684
EE004	1	0.000	0.002	0.000	0.000
EE008	7	0.000	0.002	0.002	1.000
ES11	7	0.279	0.002	0.002	0.762
ES12	6	16.764	0.002	0.001	0.467
ES13	9	1.096	0.002	0.002	0.694
ES21	63	98.422	0.003	0.012	0.531
ES22	9	0.858	0.002	0.002	0.778
ES24	13	6.862	0.003	0.003	0.641
ES3	89	512.651	0.003	0.015	0.389
ES41	8	1.148	0.002	0.002	0.714
ES42	5	0.203	0.002	0.001	0.700
ES43	4	0.093	0.002	0.001	0.833
ES51	75	246.882	0.003	0.014	0.476
ES52	45	50.178	0.003	0.009	0.642
ES53	7	0.577	0.002	0.001	0.667
ES61	28	11.353	0.003	0.006	0.745
ES62	6	0.520	0.002	0.001	0.600
ES7	8	0.346	0.002	0.001	0.733
FI13	10	3.433	0.002	0.002	0.533
FI18	80	502.757	0.003	0.014	0.425
FI19	28	15.823	0.003	0.006	0.643
FI1A	12	4.503	0.003	0.003	0.682
FR1	127	1623.982	0.004	0.018	0.271
FR2	31	27.276	0.003	0.007	0.684
FR3	32	13.732	0.003	0.007	0.674
FR4	47	172.794	0.003	0.009	0.572
FR5	31	51.016	0.003	0.007	0.658
FR6	45	215.976	0.003	0.009	0.671
FR7	85	535.065	0.003	0.014	0.402
FR8	43	303.421	0.003	0.008	0.520
GR1	50	319.854	0.003	0.010	0.572
GR2	47	33.649	0.003	0.010	0.647
GR3	104	890.415	0.004	0.016	0.323

Table 27 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
GR4	40	37.040	0.003	0.008	0.571
HU1	50	289.032	0.003	0.009	0.502
HU21	1	0.000	0.002	0.000	0.000
HU22	3	0.000	0.002	0.001	1.000
HU23	3	0.187	0.002	0.000	0.333
HU31	4	0.160	0.002	0.001	0.667
HU32	2	0.000	0.002	0.000	1.000
HU33	2	0.000	0.002	0.000	1.000
IE01	8	0.532	0.002	0.002	0.821
IE02	62	104.233	0.003	0.012	0.536
IS001	9	1.732	0.002	0.002	0.528
ITC1	50	172.387	0.003	0.009	0.504
ITC3	6	1.782	0.002	0.001	0.467
ITC4	81	600.833	0.003	0.014	0.430
ITD1	15	1.220	0.003	0.004	0.867
ITD2	25	11.853	0.003	0.005	0.687
ITD3	33	49.005	0.003	0.006	0.542
ITD4	15	3.469	0.003	0.003	0.629
ITD5	45	61.274	0.003	0.009	0.568
ITE1	79	536.367	0.003	0.014	0.437
ITE2	10	0.628	0.002	0.002	0.867
ITE3	11	2.357	0.002	0.002	0.582
ITE4	71	169.772	0.003	0.013	0.509
ITF1	7	0.175	0.002	0.002	0.857
ITF2	1	0.000	0.002	0.000	0.000
ITF3	22	3.982	0.003	0.005	0.784
ITF4	17	0.444	0.003	0.004	0.914
ITF6	2	0.000	0.002	0.000	1.000
ITG1	17	29.558	0.003	0.004	0.728
ITG2	20	198.473	0.003	0.004	0.699
LT002	9	0.239	0.002	0.002	0.833
LT003	2	0.000	0.002	0.001	1.000
LT00A	12	2.220	0.003	0.003	0.667
LU00	14	6.502	0.003	0.003	0.692
LV003	1	0.000	0.002	0.000	0.000
LV006	16	4.393	0.003	0.004	0.800
LV008	1	0.000	0.002	0.000	0.000
NL11	21	149.340	0.003	0.005	0.724
NL12	1	0.000	0.002	0.000	0.000
NL13	2	0.000	0.002	0.001	1.000

Table 27 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
NL21	31	38.422	0.003	0.007	0.624
NL22	41	49.821	0.003	0.008	0.587
NL23	6	0.325	0.002	0.001	0.733
NL31	96	823.926	0.004	0.015	0.360
NL32	78	243.443	0.003	0.014	0.468
NL33	11	0.677	0.002	0.002	0.764
NL34	11	1.260	0.003	0.003	0.745
NL41	50	297.979	0.003	0.010	0.576
NL42	17	2.413	0.003	0.004	0.743
NO01	57	105.488	0.003	0.011	0.513
NO02	2	0.042	0.002	0.000	0.000
NO03	3	0.020	0.002	0.001	0.667
NO04	22	16.116	0.003	0.005	0.623
NO05	5	0.801	0.002	0.001	0.400
NO06	27	17.599	0.003	0.006	0.635
NO07	19	2.563	0.003	0.004	0.728
PL11	10	0.159	0.003	0.003	0.911
PL12	36	32.307	0.003	0.007	0.625
PL21	11	2.832	0.003	0.003	0.709
PL22	12	4.762	0.002	0.002	0.545
PL31	2	0.000	0.002	0.001	1.000
PL34	2	0.043	0.002	0.000	0.000
PL41	8	0.171	0.002	0.002	0.929
PL42	1	0.000	0.002	0.000	0.000
PL51	2	0.000	0.002	0.001	1.000
PL52	2	0.333	0.002	0.000	0.000
PL61	1	0.000	0.002	0.000	0.000
PL63	11	0.958	0.003	0.003	0.727
PT11	20	1.122	0.003	0.005	0.850
PT15	2	0.413	0.002	0.000	0.000
PT16	43	83.147	0.003	0.008	0.545
PT17	60	154.627	0.003	0.012	0.569
PT18	5	0.000	0.002	0.001	1.000
PT2	1	0.000	0.002	0.000	0.000
PT3	2	0.000	0.002	0.000	1.000
RO06	1	0.000	0.002	0.000	0.000
RO12	3	0.026	0.002	0.001	0.667
RO21	3	0.000	0.002	0.001	1.000
RO22	1	0.000	0.002	0.000	0.000
RO32	20	8.485	0.003	0.004	0.595

Table 27 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
RO42	2	0.000	0.002	0.001	1.000
SE11	68	210.600	0.003	0.013	0.522
SE12	30	22.583	0.003	0.007	0.731
SE21	16	3.438	0.003	0.004	0.733
SE22	40	50.859	0.003	0.008	0.634
SE23	30	64.319	0.003	0.006	0.701
SE31	8	0.329	0.002	0.002	0.786
SE32	7	0.928	0.002	0.001	0.524
SE33	12	2.037	0.003	0.003	0.712
SI01	7	0.171	0.002	0.002	0.810
SI02	39	48.889	0.003	0.007	0.527
SK01	18	7.486	0.003	0.004	0.750
SK02	2	0.000	0.002	0.001	1.000
SK03	4	0.375	0.002	0.001	0.500
SK04	4	0.099	0.002	0.001	0.667
TR10	7	0.763	0.002	0.002	0.762
TR31	8	1.417	0.002	0.001	0.357
TR42	1	0.000	0.002	0.000	0.000
TR51	7	0.464	0.002	0.002	0.762
TR62	1	0.000	0.002	0.000	0.000
UKC	24	23.352	0.003	0.005	0.663
UKD	49	92.183	0.003	0.010	0.573
UKE	37	14.764	0.003	0.008	0.739
UKF	60	133.006	0.003	0.011	0.497
UKG	47	64.404	0.003	0.009	0.559
UKH	78	539.918	0.003	0.013	0.432
UKI	94	498.078	0.003	0.015	0.387
UKJ	84	458.272	0.003	0.014	0.426
UKK	71	205.244	0.003	0.013	0.468
UKL	24	10.812	0.003	0.005	0.736
UKM	74	357.711	0.003	0.013	0.483
UKN	20	16.005	0.003	0.004	0.579

Table 28 Nodes Values (Region Network) 2009

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
AT1	134	420.558	0.003	0.01	0.509
AT2	87	45.691	0.003	0.008	0.753
AT3	99	189.903	0.003	0.008	0.656
BE1	145	542.844	0.003	0.01	0.468
BE2	143	337.047	0.003	0.01	0.49
BE3	106	78.037	0.003	0.009	0.667
BG3	30	16.26	0.002	0.003	0.757
BG4	83	29.853	0.003	0.007	0.758
CH01	130	272.051	0.003	0.01	0.536
CH02	77	23.028	0.003	0.007	0.768
CH03	56	5.896	0.003	0.005	0.848
CH04	105	169.008	0.003	0.008	0.609
CH05	17	1.587	0.002	0.002	0.816
CH06	30	221.894	0.002	0.003	0.778
CH07	16	0.222	0.002	0.002	0.917
CY00	3	0.015	0.002	0	0.667
CZ01	95	346.922	0.003	0.008	0.662
CZ02	22	0.326	0.002	0.002	0.942
CZ03	21	0.76	0.002	0.002	0.905
CZ04	7	0.157	0.002	0.001	0.667
CZ05	26	4.272	0.002	0.002	0.699
CZ06	51	9.024	0.003	0.005	0.82
CZ07	22	3.564	0.002	0.002	0.736
CZ08	20	6.452	0.002	0.002	0.711
DE1	151	519.863	0.003	0.011	0.453
DE2	155	650.331	0.003	0.011	0.44
DE3	104	83.976	0.003	0.009	0.674
DE4	72	27.316	0.003	0.006	0.734
DE5	98	274.213	0.003	0.008	0.627
DE6	93	309.742	0.003	0.007	0.626
DE7	108	77.08	0.003	0.009	0.667
DE8	41	5.67	0.002	0.004	0.832
DE9	132	232.852	0.003	0.01	0.528
DEA	137	283.135	0.003	0.01	0.507
DEB	83	41.789	0.003	0.007	0.735
DEC	41	1.101	0.002	0.004	0.935
DED	93	64.549	0.003	0.008	0.689
DEE	53	118.886	0.003	0.005	0.695
DEF	76	29.747	0.003	0.007	0.767
DEG	69	42.258	0.003	0.006	0.698
DK00	102	74.116	0.003	0.009	0.677
DK01	102	137.466	0.003	0.008	0.643
DK02	32	2.029	0.002	0.003	0.889
DK03	53	15.318	0.003	0.005	0.802
DK04	76	22.65	0.003	0.007	0.774
DK05	56	10.356	0.003	0.005	0.849
EE001	59	148.765	0.003	0.005	0.807

Table 28 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
EE004	5	0.272	0.002	0	0.4
EE006	1	0	0.002	0	0
EE007	2	0.034	0.002	0	0
EE008	51	9.046	0.003	0.005	0.816
ES11	39	1.329	0.002	0.004	0.91
ES12	26	12.026	0.002	0.003	0.846
ES13	24	0.52	0.002	0.002	0.928
ES21	118	181.296	0.003	0.009	0.578
ES22	37	1.968	0.002	0.003	0.871
ES23	16	0.236	0.002	0.002	0.908
ES24	50	8.353	0.002	0.005	0.799
ES3	153	799.644	0.003	0.011	0.444
ES41	32	2.168	0.002	0.003	0.848
ES42	21	4.441	0.002	0.002	0.79
ES43	25	3.476	0.002	0.002	0.79
ES51	137	345.12	0.003	0.01	0.507
ES52	99	82.361	0.003	0.008	0.672
ES53	15	0.502	0.002	0.001	0.867
ES61	66	44.6	0.003	0.006	0.765
ES62	27	1.418	0.002	0.003	0.84
ES7	28	0.941	0.002	0.003	0.908
FI13	47	18.108	0.002	0.004	0.81
FI18	132	266.786	0.003	0.01	0.538
FI19	55	7.202	0.003	0.005	0.84
FI1A	29	1.696	0.002	0.003	0.889
FR1	179	1693.725	0.004	0.011	0.353
FR2	95	68.973	0.003	0.008	0.673
FR3	44	3.95	0.002	0.004	0.848
FR4	84	69.073	0.003	0.007	0.717
FR5	80	31.626	0.003	0.007	0.721
FR6	89	59.617	0.003	0.008	0.717
FR7	124	180.398	0.003	0.01	0.568
FR8	95	252.153	0.003	0.008	0.62
FR9	1	0	0.002	0	0
GR1	116	370.49	0.003	0.009	0.601
GR2	81	23.085	0.003	0.007	0.784
GR3	150	714.776	0.003	0.01	0.447
GR4	80	48.427	0.003	0.007	0.75
HU1	122	415.342	0.003	0.009	0.551
HU21	12	0.124	0.002	0.001	0.924
HU22	7	0.014	0.002	0.001	0.952
HU23	21	2.12	0.002	0.002	0.781
HU31	8	0.034	0.002	0.001	0.929
HU32	23	1.434	0.002	0.002	0.87
HU33	31	3.95	0.002	0.003	0.798
IE01	32	1.026	0.002	0.003	0.917
IE02	114	177.548	0.003	0.009	0.607
IS001	48	94.33	0.003	0.004	0.731
IS002	6	0.086	0.002	0.001	0.8

Table 28 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
ITC1	112	184.486	0.003	0.009	0.595
ITC2	10	0.096	0.002	0.001	0.933
ITC3	18	0.421	0.002	0.002	0.935
ITC4	147	613.559	0.003	0.01	0.452
ITD1	29	0.285	0.002	0.003	0.956
ITD2	70	20.533	0.003	0.006	0.786
ITD3	78	36.509	0.003	0.007	0.724
ITD4	45	4.793	0.002	0.004	0.866
ITD5	114	207.832	0.003	0.009	0.562
ITE1	124	267.643	0.003	0.009	0.555
ITE2	34	5.335	0.002	0.003	0.854
ITE3	49	11.301	0.002	0.004	0.739
ITE4	159	1315.785	0.004	0.011	0.415
ITF1	28	40.979	0.002	0.002	0.717
ITF2	3	0	0.002	0	1
ITF3	61	19.654	0.003	0.006	0.777
ITF4	47	23.85	0.002	0.004	0.764
ITF5	13	0.445	0.002	0.001	0.859
ITF6	27	0.601	0.002	0.003	0.917
ITG1	35	6.039	0.002	0.003	0.825
ITG2	38	16.452	0.002	0.003	0.83
LT002	38	236.978	0.002	0.003	0.703
LT003	1	0	0.002	0	0
LT005	1	0	0.002	0	0
LT006	2	0	0.002	0	1
LT00A	63	40.192	0.003	0.005	0.722
LU00	44	6.233	0.002	0.004	0.808
LV003	1	0	0.002	0	0
LV005	1	0	0.002	0	0
LV006	57	6.087	0.003	0.005	0.848
LV008	4	0	0.002	0	1
LV009	2	0	0.002	0	1
NL11	54	9.77	0.003	0.005	0.804
NL12	1	0	0.002	0	0
NL13	25	1.702	0.002	0.002	0.874
NL21	65	19.279	0.003	0.006	0.789
NL22	114	182.89	0.003	0.009	0.595
NL23	43	7.077	0.002	0.004	0.822
NL31	135	450.186	0.003	0.01	0.513
NL32	115	115.471	0.003	0.009	0.637
NL33	19	0.426	0.002	0.002	0.906
NL34	24	0.383	0.002	0.002	0.942
NL41	92	70.789	0.003	0.008	0.676
NL42	53	5.316	0.003	0.005	0.88
NO01	116	231.85	0.003	0.009	0.549
NO02	3	0	0.002	0	1
NO03	20	0.852	0.002	0.002	0.921
NO04	42	228.765	0.002	0.004	0.719
NO05	23	2.284	0.002	0.002	0.858

Table 28 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
NO06	74	36.667	0.003	0.006	0.7
NO07	40	20.519	0.002	0.003	0.761
PL11	42	4.553	0.002	0.004	0.853
PL12	124	362.598	0.003	0.009	0.537
PL21	78	22.584	0.003	0.007	0.775
PL22	85	141.547	0.003	0.007	0.627
PL31	20	0.659	0.002	0.002	0.884
PL32	4	0	0.002	0	1
PL33	2	0	0.002	0	1
PL34	14	2.642	0.002	0.001	0.725
PL41	72	32.769	0.003	0.006	0.737
PL42	9	0.438	0.002	0.001	0.833
PL43	3	0.015	0.002	0	0.667
PL51	5	0.049	0.002	0.001	0.8
PL52	7	0.191	0.002	0.001	0.857
PL61	19	3.544	0.002	0.002	0.779
PL62	1	0	0.002	0	0
PL63	53	10.141	0.003	0.005	0.791
PT11	65	24.401	0.003	0.006	0.747
PT15	5	0.125	0.002	0	0.8
PT16	79	60.457	0.003	0.007	0.725
PT17	97	107.58	0.003	0.008	0.676
PT18	12	0.5	0.002	0.001	0.864
PT2	2	0.015	0.002	0	0
PT3	5	0.017	0.002	0	0.9
RO06	1	0	0.002	0	0
RO11	18	1.256	0.002	0.002	0.908
RO12	14	0.851	0.002	0.001	0.868
RO21	17	0.411	0.002	0.002	0.912
RO22	9	0.569	0.002	0.001	0.861
RO31	5	0	0.002	0.001	1
RO32	69	17.384	0.003	0.006	0.809
RO41	2	0.04	0.002	0	0
RO42	7	0	0.002	0.001	1
SE11	121	349.311	0.003	0.01	0.605
SE12	89	119.047	0.003	0.007	0.661
SE21	27	1.905	0.002	0.003	0.846
SE22	75	28.95	0.003	0.007	0.758
SE23	95	157.82	0.003	0.008	0.637
SE31	39	6.692	0.002	0.004	0.854
SE32	7	0	0.002	0.001	1
SE33	63	10.731	0.003	0.006	0.844
SI01	33	2.149	0.002	0.003	0.9
SI02	85	45.946	0.003	0.007	0.757
SK01	70	43.26	0.003	0.006	0.699
SK02	21	5.148	0.002	0.002	0.608
SK03	25	5.538	0.002	0.002	0.707
SK04	27	1.994	0.002	0.003	0.872
TR10	32	0.792	0.002	0.003	0.929

Table 28 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
TR31	17	1.207	0.002	0.002	0.757
TR32	3	0	0.002	0	1
TR41	3	0	0.002	0	1
TR42	4	0	0.002	0	1
TR51	48	3.745	0.002	0.005	0.878
TR52	1	0	0.002	0	0
TR61	10	0.076	0.002	0.001	0.933
TR62	5	0.169	0.002	0	0.7
TR71	1	0	0.002	0	0
TR72	1	0	0.002	0	0
TR90	1	0	0.002	0	0
TRB1	1	0	0.002	0	0
TRC1	2	0	0.002	0	1
TRC2	1	0	0.002	0	0
UKC	94	67.606	0.003	0.008	0.681
UKD	102	101.666	0.003	0.008	0.62
UKE	110	87.091	0.003	0.009	0.642
UKF	103	116.8	0.003	0.008	0.647
UKG	98	121.817	0.003	0.008	0.677
UKH	130	565.141	0.003	0.01	0.532
UKI	152	527.194	0.003	0.011	0.451
UKJ	140	500.35	0.003	0.01	0.497
UKK	119	185.746	0.003	0.009	0.581
UKL	88	91.235	0.003	0.007	0.663
UKM	126	405.077	0.003	0.01	0.545
UKN	74	37.721	0.003	0.007	0.751

Table 29 Nodes Values (Region Network) 2011

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
AT1	157	506.267	0.003	0.009	0.512
AT2	105	62.889	0.003	0.007	0.728
AT3	119	162.069	0.003	0.008	0.670
BE1	162	506.616	0.003	0.009	0.492
BE2	152	422.995	0.003	0.009	0.550
BE3	119	89.216	0.003	0.008	0.665
BG3	35	3.212	0.002	0.002	0.814
BG4	100	44.439	0.003	0.007	0.741
CH01	145	221.627	0.003	0.009	0.575
CH02	97	44.328	0.003	0.007	0.754
CH03	74	37.243	0.003	0.006	0.847
CH04	114	124.045	0.003	0.008	0.672
CH05	28	4.271	0.002	0.002	0.868
CH06	38	224.946	0.002	0.003	0.878
CH07	46	5.847	0.002	0.003	0.859
CY00	4	0.000	0.002	0.000	1.000
CZ01	111	97.100	0.003	0.007	0.680
CZ02	29	0.375	0.002	0.002	0.957
CZ03	32	2.029	0.002	0.003	0.895
CZ04	8	0.000	0.002	0.001	1.000
CZ05	31	3.622	0.002	0.002	0.805
CZ06	71	7.797	0.003	0.005	0.868
CZ07	34	4.047	0.002	0.002	0.784
CZ08	17	3.878	0.002	0.001	0.699
DE1	159	372.356	0.003	0.009	0.513
DE2	171	673.854	0.004	0.010	0.463
DE3	120	169.296	0.003	0.008	0.669
DE4	88	25.610	0.003	0.006	0.779
DE5	126	245.875	0.003	0.008	0.629
DE6	110	89.254	0.003	0.007	0.687
DE7	133	194.030	0.003	0.008	0.612
DE8	81	41.842	0.003	0.006	0.732
DE9	146	221.295	0.003	0.009	0.561
DEA	161	481.095	0.003	0.009	0.494
DEB	101	58.226	0.003	0.007	0.727
DEC	64	8.346	0.003	0.005	0.869
DED	113	62.339	0.003	0.008	0.705
DEE	70	125.055	0.003	0.005	0.747
DEF	90	18.488	0.003	0.007	0.813
DEG	82	27.276	0.003	0.006	0.762
DK00	120	110.163	0.003	0.008	0.655
DK01	125	125.312	0.003	0.008	0.634
DK02	52	2.338	0.002	0.004	0.922
DK03	83	54.390	0.003	0.006	0.720
DK04	91	44.777	0.003	0.006	0.786
DK05	77	17.484	0.003	0.006	0.835

Table 29 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
EE001	81	143.849	0.003	0.006	0.811
EE004	9	0.095	0.002	0.001	0.833
EE006	3	0.026	0.002	0.000	0.667
EE007	2	0.022	0.002	0.000	0.000
EE008	71	12.632	0.003	0.005	0.815
ES11	56	7.351	0.002	0.004	0.848
ES12	33	1.933	0.002	0.003	0.875
ES13	31	0.701	0.002	0.003	0.938
ES21	122	63.967	0.003	0.008	0.695
ES22	58	3.102	0.002	0.004	0.901
ES23	25	0.898	0.002	0.002	0.900
ES24	62	7.843	0.003	0.005	0.845
ES3	159	636.417	0.003	0.009	0.504
ES41	69	22.308	0.003	0.005	0.748
ES42	33	5.028	0.002	0.002	0.804
ES43	37	5.822	0.002	0.003	0.788
ES51	152	331.826	0.003	0.009	0.543
ES52	107	58.995	0.003	0.007	0.715
ES53	31	3.841	0.002	0.002	0.796
ES61	83	58.878	0.003	0.006	0.754
ES62	38	1.122	0.002	0.003	0.910
ES7	45	5.787	0.002	0.003	0.848
FI13	47	3.755	0.002	0.004	0.892
FI18	144	224.045	0.003	0.009	0.572
FI19	83	19.109	0.003	0.006	0.792
FI1A	58	5.809	0.002	0.004	0.875
FR1	187	1506.950	0.004	0.010	0.402
FR2	111	62.433	0.003	0.007	0.704
FR3	56	4.867	0.002	0.004	0.850
FR4	99	54.632	0.003	0.007	0.737
FR5	107	72.558	0.003	0.007	0.683
FR6	96	30.331	0.003	0.007	0.774
FR7	141	207.294	0.003	0.009	0.583
FR8	110	110.539	0.003	0.007	0.695
FR9	2	0.000	0.002	0.000	1.000
GR1	129	284.576	0.003	0.008	0.632
GR2	88	32.362	0.003	0.006	0.746
GR3	155	304.801	0.003	0.009	0.517
GR4	107	69.864	0.003	0.007	0.695
HU1	148	330.124	0.003	0.009	0.552
HU21	16	0.131	0.002	0.001	0.958
HU22	17	0.034	0.002	0.001	0.985
HU23	23	0.377	0.002	0.002	0.937
HU31	13	0.565	0.002	0.001	0.782
HU32	40	6.979	0.002	0.003	0.735
HU33	57	7.321	0.003	0.004	0.864
IE01	64	5.166	0.003	0.005	0.888
IE02	130	157.173	0.003	0.008	0.629

Table 29 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
IS001	69	76.587	0.003	0.005	0.740
IS002	25	3.142	0.002	0.002	0.720
ITC1	135	177.334	0.003	0.008	0.603
ITC2	10	0.026	0.002	0.001	0.978
ITC3	37	3.973	0.002	0.003	0.863
ITC4	162	390.459	0.003	0.009	0.493
ITD1	22	0.176	0.002	0.002	0.952
ITD2	85	32.188	0.003	0.006	0.778
ITD3	96	40.249	0.003	0.007	0.749
ITD4	70	9.902	0.003	0.005	0.836
ITD5	132	156.619	0.003	0.008	0.597
ITE1	134	209.196	0.003	0.008	0.608
ITE2	46	10.049	0.002	0.003	0.801
ITE3	57	9.807	0.003	0.004	0.824
ITE4	178	1182.321	0.004	0.010	0.428
ITF1	53	53.837	0.002	0.004	0.747
ITF2	3	0.000	0.002	0.000	1.000
ITF3	78	21.626	0.003	0.005	0.769
ITF4	58	24.365	0.003	0.004	0.788
ITF5	30	29.187	0.002	0.002	0.810
ITF6	33	0.403	0.002	0.003	0.948
ITG1	50	4.996	0.002	0.004	0.845
ITG2	45	9.951	0.002	0.003	0.829
LT002	56	121.056	0.003	0.004	0.705
LT003	11	0.081	0.002	0.001	0.909
LT005	1	0.000	0.002	0.000	0.000
LT006	5	0.000	0.002	0.000	1.000
LT009	1	0.000	0.002	0.000	0.000
LT00A	81	37.009	0.003	0.006	0.799
LU00	49	4.058	0.002	0.004	0.871
LV003	5	0.000	0.002	0.000	1.000
LV005	2	0.026	0.002	0.000	0.000
LV006	76	165.556	0.003	0.006	0.823
LV008	4	0.015	0.002	0.000	0.833
LV009	4	0.033	0.002	0.000	0.833
NL11	81	27.671	0.003	0.006	0.798
NL12	6	0.027	0.002	0.000	0.867
NL13	40	2.474	0.002	0.003	0.909
NL21	95	129.676	0.003	0.007	0.744
NL22	129	126.669	0.003	0.008	0.640
NL23	50	4.314	0.002	0.004	0.859
NL31	161	423.061	0.003	0.009	0.497
NL32	138	170.564	0.003	0.009	0.609
NL33	35	2.474	0.002	0.003	0.882
NL34	30	0.381	0.002	0.002	0.945
NL41	119	114.268	0.003	0.008	0.684
NL42	76	11.858	0.003	0.006	0.832
NO01	138	517.514	0.003	0.009	0.585

Table 29 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
NO02	7	0.000	0.002	0.001	1.000
NO03	29	1.146	0.002	0.002	0.929
NO04	44	32.352	0.002	0.003	0.800
NO05	34	49.284	0.002	0.002	0.712
NO06	101	65.829	0.003	0.007	0.699
NO07	53	289.074	0.002	0.003	0.634
PL11	55	3.550	0.002	0.004	0.904
PL12	133	173.587	0.003	0.008	0.616
PL21	97	57.230	0.003	0.007	0.729
PL22	80	37.997	0.003	0.006	0.789
PL31	25	0.448	0.002	0.002	0.937
PL32	8	0.043	0.002	0.001	0.929
PL33	4	0.000	0.002	0.000	1.000
PL34	16	1.640	0.002	0.001	0.792
PL41	90	47.520	0.003	0.006	0.755
PL42	17	0.812	0.002	0.001	0.816
PL43	7	0.016	0.002	0.001	0.952
PL51	5	0.051	0.002	0.000	0.800
PL52	8	0.493	0.002	0.001	0.821
PL61	19	0.516	0.002	0.001	0.871
PL62	2	0.036	0.002	0.000	0.000
PL63	73	37.288	0.003	0.005	0.725
PT11	90	268.039	0.003	0.006	0.713
PT15	24	1.544	0.002	0.002	0.841
PT16	82	24.703	0.003	0.006	0.808
PT17	122	427.549	0.003	0.008	0.620
PT18	16	0.653	0.002	0.001	0.883
PT2	2	0.000	0.002	0.000	1.000
PT3	19	0.864	0.002	0.001	0.846
RO06	2	0.000	0.002	0.000	1.000
RO11	32	4.600	0.002	0.002	0.786
RO12	26	0.808	0.002	0.002	0.917
RO21	28	0.458	0.002	0.002	0.944
RO22	20	1.773	0.002	0.001	0.789
RO31	8	0.000	0.002	0.001	1.000
RO32	89	34.762	0.003	0.006	0.760
RO41	3	0.026	0.002	0.000	0.667
RO42	25	0.521	0.002	0.002	0.913
SE11	144	429.390	0.003	0.009	0.576
SE12	122	118.609	0.003	0.008	0.654
SE21	32	4.056	0.002	0.002	0.848
SE22	97	39.701	0.003	0.007	0.763
SE23	123	180.243	0.003	0.008	0.621
SE31	48	6.066	0.002	0.004	0.921
SE32	14	0.111	0.002	0.001	0.956
SE33	73	13.810	0.003	0.005	0.823
SI01	50	2.930	0.002	0.004	0.902
SI02	101	44.021	0.003	0.007	0.750

Table 29 (continued)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Clustering Coefficient
SK01	81	28.987	0.003	0.006	0.769
SK02	33	4.201	0.002	0.002	0.778
SK03	33	2.772	0.002	0.002	0.831
SK04	35	2.876	0.002	0.003	0.840
TR10	62	5.272	0.003	0.005	0.892
TR21	1	0.000	0.002	0.000	0.000
TR22	1	0.000	0.002	0.000	0.000
TR31	22	1.007	0.002	0.002	0.835
TR32	4	0.089	0.002	0.000	0.667
TR41	7	0.040	0.002	0.001	0.952
TR42	8	0.000	0.002	0.001	1.000
TR51	71	6.307	0.003	0.005	0.882
TR52	2	0.000	0.002	0.000	1.000
TR61	12	0.036	0.002	0.001	0.970
TR62	10	0.740	0.002	0.001	0.644
TR63	1	0.000	0.002	0.000	0.000
TR71	1	0.000	0.002	0.000	0.000
TR82	1	0.000	0.002	0.000	0.000
TR90	3	0.095	0.002	0.000	0.667
TRA1	1	0.000	0.002	0.000	0.000
TRA2	1	0.000	0.002	0.000	0.000
TRB1	1	0.000	0.002	0.000	0.000
TRC1	3	0.000	0.002	0.000	1.000
TRC2	1	0.000	0.002	0.000	0.000
UKC	106	62.451	0.003	0.007	0.729
UKD	124	108.662	0.003	0.008	0.634
UKE	128	123.470	0.003	0.008	0.644
UKF	123	106.657	0.003	0.008	0.656
UKG	123	192.194	0.003	0.008	0.651
UKH	143	580.243	0.003	0.009	0.571
UKI	166	496.967	0.003	0.009	0.483
UKJ	149	370.678	0.003	0.009	0.549
UKK	142	236.501	0.003	0.009	0.570
UKL	104	61.532	0.003	0.007	0.726
UKM	135	157.176	0.003	0.008	0.603
UKN	82	20.923	0.003	0.006	0.812

Table 30 Abbreviation of Countries and NUTS-2 Participated in FPs

Abb. of Countries Participated in FP			Abb. of NUTS-2 Participated in FP				
AE	GN	NI	BE10	DEA4	FR41	MT00	SI02
AF	GR	NL	BE21	DEA5	FR42	MTZZ	SIZZ
AL	GT	NO	BE22	DEB1	FR43	NL11	SK01
AM	GW	NP	BE23	DEB2	FR51	NL12	SK02
AN	GY	NZ	BE24	DEB3	FR52	NL13	SK03
AO	HK	OM	BE25	DEC0	FR53	NL21	SK04
AR	HN	PA	BE31	DED2	FR61	NL22	SKZZ
AT	HR	PE	BE32	DED4	FR62	NL23	FI19
AU	HT	PG	BE33	DED5	FR63	NL31	FI1B
AZ	HU	PH	BE34	DEE0	FR71	NL32	FI1C
BA	ID	PK	BE35	DEF0	FR72	NL33	FI1D
BD	IE	PL	BEZZ	DEG0	FR81	NL34	FI20
BE	IL	PS	BG31	DEZZ	FR82	NL41	FIZZ
BF	IN	PT	BG32	EE00	FR83	NL42	SE11
BG	IQ	PY	BG33	EEZZ	FR91	NLZZ	SE12
BH	IR	QA	BG34	IE01	FR92	AT11	SE21
BI	IS	RO	BG41	IE02	FR93	AT12	SE22
BJ	IT	RS	BG42	IEZZ	FR94	AT13	SE23
BN	JM	RU	BGZZ	EL11	FRZZ	AT21	SE31
BO	JO	RW	CZ01	EL12	HR03	AT22	SE32
BR	JP	SA	CZ02	EL13	HR04	AT31	SE33
BT	KE	SC	CZ03	EL14	HRZZ	AT32	SEZZ
BW	KG	SD	CZ04	EL21	ITC1	AT33	UKC1
BY	KH	SE	CZ05	EL22	ITC2	AT34	UKC2
CA	KO	SG	CZ06	EL23	ITC3	ATZZ	UKD1
CD	KR	SI	CZ07	EL24	ITC4	PL11	UKD3
CF	KW	SK	CZ08	EL25	ITF1	PL12	UKD4
CG	KY	SM	CZZZ	EL30	ITF2	PL21	UKD6
CH	KZ	SN	DK01	EL41	ITF3	PL22	UKD7
CI	LA	SO	DK02	EL42	ITF4	PL31	UKE1
CL	LB	SR	DK03	EL43	ITF5	PL32	UKE2
CM	LI	SV	DK04	ELZZ	ITF6	PL33	UKE3
CN	LK	SY	DK05	ES11	ITG1	PL34	UKE4
CO	LS	SZ	DKZZ	ES12	ITG2	PL41	UKF1
CR	LT	TG	DE11	ES13	ITH1	PL42	UKF2
CU	LU	TH	DE12	ES21	ITH2	PL43	UKF3
CV	LV	TJ	DE13	ES22	ITH3	PL51	UKG1
CY	LY	TM	DE14	ES23	ITH4	PL52	UKG2
CZ	MA	TN	DE21	ES24	ITH5	PL61	UKG3
DE	MC	TR	DE22	ES30	ITI1	PL62	UKH1
DK	MD	TT	DE23	ES41	ITI2	PL63	UKH2
DO	ME	TW	DE24	ES42	ITI3	PLZZ	UKH3
DZ	MG	TZ	DE25	ES43	ITI4	PT11	UKI1
EC	MH	UA	DE26	ES51	ITZZ	PT15	UKI2
EE	MK	UG	DE27	ES52	CY00	PT16	UKJ1
EG	ML	US	DE30	ES53	CYZZ	PT17	UKJ2
ES	MM	UY	DE40	ES61	LV00	PT18	UKJ3
ET	MO	UZ	DE50	ES62	LVZZ	PT20	UKJ4

Table 30 (continued)

Abb. of Countries Participated in FP			Abb. of NUTS-2 Participated in FP				
EU	MR	VA	DE60	ES63	LT00	PT30	UKK1
FI	MT	VE	DE71	ES64	LTZZ	PTZZ	UKK2
FJ	MU	VN	DE72	ES70	LU00	RO11	UKK3
FO	MV	XK	DE73	ESZZ	LUZZ	RO12	UKK4
FR	MW	YE	DE80	FR10	HU10	RO21	UKL1
GA	MX	YU	DE91	FR21	HU21	RO22	UKL2
GB	MY	ZA	DE92	FR22	HU22	RO31	UKM2
GE	MZ	ZM	DE93	FR23	HU23	RO32	UKM3
GF	NA	ZW	DE94	FR24	HU31	RO41	UKM5
GH	NC	ZZ	DEA1	FR25	HU32	RO42	UKM6
GL	NE		DEA2	FR26	HU33	ROZZ	UKN0
GM	NG		DEA3	FR30	HUZZ	SI01	UKZZ

Table 31 Distance vs. Intensity (Region)

Region	Corr.	Region	Corr.	Region	Corr.	Region	Corr.	Region	Corr.	Region	Corr.
PT11	- 0.323	UKH3	- 0.237	ITC1	- 0.204	FR62	- 0.167	ITG1	- 0.101	RO42	- 0.024
ES70	- 0.317	FR51	- 0.237	LU00	- 0.204	NO06	- 0.167	SK03	- 0.101	BG33	- 0.023
IS001	- 0.313	ES30	- 0.234	FR72	- 0.204	FR25	- 0.166	PL41	- 0.100	PL33	- 0.021
ES61	- 0.302	UKJ2	- 0.234	CH04	- 0.204	SE22	- 0.165	SE32	- 0.099	TR32	- 0.021
UKE4	- 0.296	UKJ3	- 0.234	FR22	- 0.203	DE27	- 0.165	DE22	- 0.098	LT004	- 0.021
ES11	- 0.293	UKE3	- 0.234	FR30	- 0.203	CH07	- 0.165	CZ08	- 0.098	BG41	- 0.018
IE01	- 0.291	NL11	- 0.234	BE33	- 0.201	DE21	- 0.162	HU23	- 0.093	LT00A	- 0.015
UKL1	- 0.288	UKD6	- 0.233	FR82	- 0.200	DE60	- 0.162	SE11	- 0.093	BG31	- 0.011
IE02	- 0.287	DE94	- 0.231	AT34	- 0.200	DEB2	- 0.158	EE001	- 0.092	LV008	- 0.010
ES52	- 0.286	UKJ1	- 0.231	DEA1	- 0.199	NL13	- 0.158	ITF3	- 0.091	TR71	- 0.007
ES23	- 0.285	FR61	- 0.231	NO04	- 0.198	NL12	- 0.154	EE004	- 0.087	LT003	- 0.007
UKM5	- 0.279	NL32	- 0.230	DEB1	- 0.198	DEE0	- 0.153	ITF5	- 0.086	LT002	- 0.006
UKF1	- 0.278	UKE2	- 0.229	DE14	- 0.196	AT32	- 0.153	PL63	- 0.082	LT005	- 0.004
PT18	- 0.276	DE92	- 0.229	UKD4	- 0.196	AT21	- 0.151	CZ06	- 0.080	RO32	- 0.003
UKE1	- 0.275	FR43	- 0.227	DEA2	- 0.193	DK02	- 0.147	CZ02	- 0.078	PL43	- 0.002
UKG1	- 0.274	UKJ4	- 0.227	DE50	- 0.193	UKD7	- 0.146	HU10	- 0.073	FI20	0.000
ES24	- 0.270	FR81	- 0.227	ITG2	- 0.192	ITC3	- 0.141	FR92	- 0.073	PL51	0.003
PT16	- 0.270	FR24	- 0.227	NL23	- 0.191	SE21	- 0.141	PL22	- 0.071	PL62	0.005
ES51	- 0.268	ES62	- 0.227	CH05	- 0.190	UKD1	- 0.137	SE33	- 0.071	FR94	0.005
UKG2	- 0.264	UKD3	- 0.226	ES53	- 0.190	FR63	- 0.136	ITF2	- 0.071	TR82	0.007
NL42	- 0.264	FR41	- 0.226	DK01	- 0.189	AT13	- 0.132	BE34	- 0.070	RO21	0.007
UKL2	- 0.262	DK03	- 0.224	DEF0	- 0.187	DE30	- 0.132	FI19	- 0.070	UKF3	0.007
PT17	- 0.262	FR53	- 0.223	NO01	- 0.187	ITC2	- 0.131	EE007	- 0.069	TR31	0.007
BE23	- 0.262	FR52	- 0.223	DEA4	- 0.185	UKK3	- 0.129	SK02	- 0.069	LV009	0.009
UKC1	- 0.262	DE71	- 0.223	AT33	- 0.184	AT22	- 0.126	PL21	- 0.068	TR63	0.009
UKF2	- 0.259	DEA5	- 0.222	DE72	- 0.183	HU22	- 0.125	CZ04	- 0.066	RO11	0.010
ES21	- 0.258	UKC2	- 0.220	CH06	- 0.182	CZ03	- 0.125	NO07	- 0.063	CY00	0.014
UKN0	- 0.258	DE13	- 0.218	ES42	- 0.182	SI01	- 0.125	CZ07	- 0.062	TR21	0.015
UKG3	- 0.258	BE32	- 0.217	FR23	- 0.182	PL42	- 0.124	LV006	- 0.062	PL32	0.017
FR10	- 0.258	DE73	- 0.216	PT15	- 0.182	NO02	- 0.121	PL34	- 0.061	PL31	0.017
ES22	- 0.256	NL33	- 0.215	FR21	- 0.181	NO03	- 0.121	PL11	- 0.058	TR41	0.018
NL21	- 0.255	FR42	- 0.214	DE26	- 0.181	DED2	- 0.120	ITF6	- 0.057	LV007	0.025
UKK4	- 0.255	DK04	- 0.214	DE91	- 0.181	HU32	- 0.120	HU33	- 0.057	TRA2	0.027
ES41	- 0.254	FR71	- 0.214	ITC4	- 0.180	DE93	- 0.117	HU21	- 0.053	RO41	0.029
UKM2	- 0.253	BE35	- 0.213	DE80	- 0.178	SE31	- 0.116	EE008	- 0.053	BG42	0.032
UKM3	- 0.252	UKK2	- 0.213	AT12	- 0.178	CZ01	- 0.114	PL12	- 0.053	TRC2	0.033
UKH1	- 0.250	ES13	- 0.213	DE12	- 0.177	AT11	- 0.112	LV003	- 0.051	RO31	0.033
BE21	- 0.248	DEG0	- 0.212	DEB3	- 0.177	SK01	- 0.112	ITF4	- 0.051	TR22	0.039
NL41	- 0.245	DK05	- 0.211	DE25	- 0.176	HU31	- 0.111	BG34	- 0.048	TR90	0.041
ES43	- 0.245	DEA3	- 0.211	DE23	- 0.174	ITF1	- 0.108	RO12	- 0.047	TR42	0.042
NL31	- 0.243	CH01	- 0.210	SE23	- 0.174	DE24	- 0.108	TR52	- 0.046	RO22	0.045
UKM6	- 0.242	UKK1	- 0.210	IS002	- 0.173	FR83	- 0.108	PT20	- 0.042	TR51	0.052
BE25	- 0.242	CH03	- 0.209	BE31	- 0.173	LV005	- 0.107	FR91	- 0.033	TRC1	0.060
PT30	- 0.241	DE11	- 0.207	BE22	- 0.172	SE12	- 0.105	FR93	- 0.032	LT009	0.061
BE24	- 0.241	BE10	- 0.206	NO05	- 0.171	CZ05	- 0.105	PL52	- 0.031	TR10	0.063
UKH2	- 0.240	DEC0	- 0.206	AT31	- 0.171	SK04	- 0.104	LT006	- 0.026	TR62	0.064
NL22	- 0.239	CH02	- 0.205	ES12	- 0.170	SI02	- 0.103	BG32	- 0.026	TRA1	0.066
UKI	- 0.239	NL34	- 0.205	FR26	- 0.168	PL61	- 0.102	EE006	- 0.025	TR61	0.105

Table 32 NUTS-2

NUTS-2 Code	NUTS Label	Country Code	NUTS-2 Code	NUTS Label	Country Code
BE10	Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest	BE	DE72	Gießen	DE
BE21	Prov. Antwerpen	BE	DE73	Kassel	DE
BE22	Prov. Limburg (BE)	BE	DE80	Mecklenburg-Vorpommern	DE
BE23	Prov. Oost-Vlaanderen	BE	DE91	Braunschweig	DE
BE24	Prov. Vlaams-Brabant	BE	DE92	Hannover	DE
BE25	Prov. West-Vlaanderen	BE	DE93	Lüneburg	DE
BE31	Prov. Brabant Wallon	BE	DE94	Weser-Ems	DE
BE32	Prov. Hainaut	BE	DEA1	Düsseldorf	DE
BE33	Prov. Liège	BE	DEA2	Köln	DE
BE34	Prov. Luxembourg (BE)	BE	DEA3	Münster	DE
BE35	Prov. Namur	BE	DEA4	Detmold	DE
BEZZ	Extra-Regio NUTS 2	BE	DEA5	Arnsberg	DE
BG31	Северозападен (Severozapaden)	BG	DEB1	Koblenz	DE
BG32	Северен централен (Severen tsentralen)	BG	DEB2	Trier	DE
BG33	Североизточен (Severoiztochen)	BG	DEB3	Rheinhessen-Pfalz	DE
BG34	Югоизточен (Yugoiztochen)	BG	DEC0	Saarland	DE
BG41	Югозападен (Yugozapaden)	BG	DED2	Dresden	DE
BG42	Южен централен (Yuzhen tsentralen)	BG	DED4	Chemnitz	DE
BGZZ	Extra-Regio NUTS 2	BG	DED5	Leipzig	DE
CZ01	Praha	CZ	DEE0	Sachsen-Anhalt	DE
CZ02	Střední Čechy	CZ	DEF0	Schleswig-Holstein	DE
CZ03	Jihozápad	CZ	DEG0	Thüringen	DE
CZ04	Severozápad	CZ	DEZZ	Extra-Regio NUTS 2	DE
CZ05	Severovýchod	CZ	EE00	Eesti	EE
CZ06	Jihovýchod	CZ	EEZZ	Extra-Regio NUTS 2	EE
CZ07	Střední Morava	CZ	IE01	Border, Midland and Western	IE
CZ08	Moravskoslezsko	CZ	IE02	Southern and Eastern	IE
CZZZ	Extra-Regio NUTS 2	CZ	IEZZ	Extra-Regio NUTS 2	IE

Table 32(continued)

NUTS-2 Code	NUTS Label	Country Code	NUTS-2 Code	NUTS Label	Country Code
DK01	Hovedstaden	DK	EL11	Ανατολική Μακεδονία, Θράκη (Anatoliki Makedonia, Thraki)	EL
DK02	Sjælland	DK	EL12	Κεντρική Μακεδονία (Kentriki Makedonia)	EL
DK03	Syddanmark	DK	EL13	Δυτική Μακεδονία (Dytiki Makedonia)	EL
DK04	Midtjylland	DK	EL14	Θεσσαλία (Thessalia)	EL
DK05	Nordjylland	DK	EL21	Ήπειρος (Ipeiros)	EL
DKZZ	Extra-Regio NUTS 2	DK	EL22	Ιόνια Νησιά (Ionia Nisia)	EL
DE11	Stuttgart	DE	EL23	Δυτική Ελλάδα (Dytiki Ellada)	EL
DE12	Karlsruhe	DE	EL24	Στερεά Ελλάδα (Sterea Ellada)	EL
DE13	Freiburg	DE	EL25	Πελοπόννησος (Peloponnisos)	EL
DE14	Tübingen	DE	EL30	Αττική (Attiki)	EL
DE21	Oberbayern	DE	EL41	Βόρειο Αιγαίο (Voreio Aigaio)	EL
DE22	Niederbayern	DE	EL42	Νότιο Αιγαίο (Notio Aigaio)	EL
DE23	Oberpfalz	DE	EL43	Κρήτη (Kriti)	EL
DE24	Oberfranken	DE	ELZZ	Extra-Regio NUTS 2	EL
DE25	Mittelfranken	DE	ES11	Galicia	ES
DE26	Unterfranken	DE	ES12	Principado de Asturias	ES
DE27	Schwaben	DE	ES13	Cantabria	ES
DE30	Berlin	DE	ES21	País Vasco	ES
DE40	Brandenburg	DE	ES22	Comunidad Foral de Navarra	ES
DE50	Bremen	DE	ES23	La Rioja	ES
DE60	Hamburg	DE	ES24	Aragón	ES
DE71	Darmstadt	DE	ES30	Comunidad de Madrid	ES
ES41	Castilla y León	ES	ITF5	Basilicata	IT
ES42	Castilla-La Mancha	ES	ITF6	Calabria	IT
ES43	Extremadura	ES	ITG1	Sicilia	IT
ES51	Cataluña	ES	ITG2	Sardegna	IT
ES52	Comunidad Valenciana	ES	ITH1	Provincia Autonoma di Bolzano/Bozen	IT
ES53	Illes Balears	ES	ITH2	Provincia Autonoma di Trento	IT
ES61	Andalucía	ES	ITH3	Veneto	IT
ES62	Región de Murcia	ES	ITH4	Friuli-Venezia Giulia	IT
ES63	Ciudad Autónoma de Ceuta	ES	ITH5	Emilia-Romagna	IT

Table 32 (continued)

NUTS-2 Code	NUTS Label	Country Code	NUTS-2 Code	NUTS Label	Country Code
ES64	Ciudad Autónoma de Melilla	ES	ITI1	Toscana	IT
ES70	Canarias	ES	ITI2	Umbria	IT
ESZZ	Extra-Regio NUTS 2	ES	ITI3	Marche	IT
FR10	Île de France	FR	ITI4	Lazio	IT
FR21	Champagne-Ardenne	FR	ITZZ	Extra-Regio NUTS 2	IT
FR22	Picardie	FR	CY00	Κύπρος (Kýpros)	CY
FR23	Haute-Normandie	FR	CYZZ	Extra-Regio NUTS 2	CY
FR24	Centre	FR	LV00	Latvija	LV
FR25	Basse-Normandie	FR	LVZZ	Extra-Regio NUTS 2	LV
FR26	Bourgogne	FR	LT00	Lietuva	LT
FR30	Nord - Pas-de-Calais	FR	LTZZ	Extra-Regio NUTS 2	LT
FR41	Lorraine	FR	LU00	Luxembourg	LU
FR42	Alsace	FR	LUZZ	Extra-Regio NUTS 2	LU
FR43	Franche-Comté	FR	HU10	Közép-Magyarország	HU
FR51	Pays de la Loire	FR	HU21	Közép-Dunántúl	HU
FR52	Bretagne	FR	HU22	Nyugat-Dunántúl	HU
FR53	Poitou-Charentes	FR	HU23	Dél-Dunántúl	HU
FR61	Aquitaine	FR	HU31	Észak-Magyarország	HU
FR62	Midi-Pyrénées	FR	HU32	Észak-Alföld	HU
FR63	Limousin	FR	HU33	Dél-Alföld	HU
FR71	Rhône-Alpes	FR	HUZZ	Extra-Regio NUTS 2	HU
FR72	Auvergne	FR	MT00	Malta	MT
FR81	Languedoc-Roussillon	FR	MTZZ	Extra-Regio NUTS 2	MT
FR82	Provence-Alpes-Côte d'Azur	FR	NL11	Groningen	NL
FR83	Corse	FR	NL12	Friesland (NL)	NL
FR91	Guadeloupe	FR	NL13	Drenthe	NL
FR92	Martinique	FR	NL21	Overijssel	NL
FR93	Guyane	FR	NL22	Gelderland	NL
FR94	Réunion	FR	NL23	Flevoland	NL
FRZZ	Extra-Regio NUTS 2	FR	NL31	Utrecht	NL
HR03	Jadranska Hrvatska	HR	NL32	Noord-Holland	NL
HR04	Kontinentalna Hrvatska	HR	NL33	Zuid-Holland	NL
HRZZ	Extra-Regio NUTS 2	HR	NL34	Zeeland	NL
ITC1	Piemonte	IT	NL41	Noord-Brabant	NL
ITC2	Valle d'Aosta/Vallée d'Aoste	IT	NL42	Limburg (NL)	NL
ITC3	Liguria	IT	NLZZ	Extra-Regio NUTS 2	NL
ITC4	Lombardia	IT	AT11	Burgenland (AT)	AT
ITF1	Abruzzo	IT	AT12	Niederösterreich	AT
ITF2	Molise	IT	AT13	Wien	AT
ITF3	Campania	IT	AT21	Kärnten	AT
ITF4	Puglia	IT	AT22	Steiermark	AT

Table 32 (continued)

NUTS-2 Code	NUTS Label	Country Code	NUTS-2 Code	NUTS Label	Country Code
AT31	Oberösterreich	AT	FI1D	Pohjois- ja Itä-Suomi	FI
AT32	Salzburg	AT	FI20	Åland	FI
AT33	Tirol	AT	FIZZ	Extra-Regio NUTS 2	FI
AT34	Vorarlberg	AT	SE11	Stockholm	SE
ATZZ	Extra-Regio NUTS 2	AT	SE12	Östra Mellansverige	SE
PL11	Łódzkie	PL	SE21	Småland med öarna	SE
PL12	Mazowieckie	PL	SE22	Sydsverige	SE
PL21	Małopolskie	PL	SE23	Västsverige	SE
PL22	Śląskie	PL	SE31	Norra Mellansverige	SE
PL31	Lubelskie	PL	SE32	Mellersta Norrland	SE
PL32	Podkarpackie	PL	SE33	Övre Norrland	SE
PL33	Świętokrzyskie	PL	SEZZ	Extra-Regio NUTS 2	SE
PL34	Podlaskie	PL	UKC1	Tees Valley and Durham	UK
PL41	Wielkopolskie	PL	UKC2	Northumberland and Tyne and Wear	UK
PL42	Zachodniopomorskie	PL	UKD1	Cumbria	UK
PL43	Lubuskie	PL	UKD3	Greater Manchester	UK
PL51	Dolnośląskie	PL	UKD4	Lancashire	UK
PL52	Opolskie	PL	UKD6	Cheshire	UK
PL61	Kujawsko-Pomorskie	PL	UKD7	Merseyside	UK
PL62	Warmińsko-Mazurskie	PL	UKE1	East Yorkshire and Northern Lincolnshire	UK
PL63	Pomorskie	PL	UKE2	North Yorkshire	UK
PLZZ	Extra-Regio NUTS 2	PL	UKE3	South Yorkshire	UK
PT11	Norte	PT	UKE4	West Yorkshire	UK
PT15	Algarve	PT	UKF1	Derbyshire and Nottinghamshire	UK
PT16	Centro (PT)	PT	UKF2	Leicestershire, Rutland and Northamptonshire	UK
PT17	Lisboa	PT	UKF3	Lincolnshire	UK
PT18	Alentejo	PT	UKG1	Herefordshire, Worcestershire and Warwickshire	UK
PT20	Região Autónoma dos Açores	PT	UKG2	Shropshire and Staffordshire	UK
PT30	Região Autónoma da Madeira	PT	UKG3	West Midlands	UK
PTZZ	Extra-Regio NUTS 2	PT	UKH1	East Anglia	UK
RO11	Nord-Vest	RO	UKH2	Bedfordshire and Hertfordshire	UK
RO12	Centru	RO	UKH3	Essex	UK
RO21	Nord-Est	RO	UKI1	Inner London	UK
RO22	Sud-Est	RO	UKI2	Outer London	UK

Table 32 (continued)

NUTS-2 Code	NUTS Label	Country Code	NUTS-2 Code	NUTS Label	Country Code
RO31	Sud - Muntenia	RO	UKJ1	Berkshire, Buckinghamshire and Oxfordshire	UK
RO32	Bucureşti - Ilfov	RO	UKJ2	Surrey, East and West Sussex	UK
RO41	Sud-Vest Oltenia	RO	UKJ3	Hampshire and Isle of Wight	UK
RO42	Vest	RO	UKJ4	Kent	UK
ROZZ	Extra-Regio NUTS 2	RO	UKK1	Gloucestershire, Wiltshire and Bristol/Bath area	UK
SI01	Vzhodna Slovenija	SI	UKK2	Dorset and Somerset	UK
SI02	Zahodna Slovenija	SI	UKK3	Cornwall and Isles of Scilly	UK
SIZZ	Extra-Regio NUTS 2	SI	UKK4	Devon	UK
SK01	Bratislavský kraj	SK	UKL1	West Wales and The Valleys	UK
SK02	Západné Slovensko	SK	UKL2	East Wales	UK
SK03	Stredné Slovensko	SK	UKM2	Eastern Scotland	UK
SK04	Východné Slovensko	SK	UKM3	South Western Scotland	UK
SKZZ	Extra-Regio NUTS 2	SK	UKM5	North Eastern Scotland	UK
FI19	Länsi-Suomi	FI	UKM6	Highlands and Islands	UK
FI1B	Helsinki-Uusimaa	FI	UKN0	Northern Ireland	UK
FI1C	Etelä-Suomi	FI	UKZZ	Extra-Regio NUTS 2	UK

Table 33 Summary Innovation Index 2012

Countries*	**II**	**HR**	**RS**	**FS**	**FI**	**L&E**	**IA**	**I**	**EE**
	"2012"	"2012"	"2012"	"2012"	"2012"	"2012"	"2012"	"2012"	"2012"
EU	**0.544**	0.557	0.478	0.585	0.406	0.532	0.555	0.571	0.603
Belgium	**0.624**	0.644	0.737	0.527	0.417	0.809	0.534	0.722	0.585
Bulgaria	**0.188**	0.429	0.094	0.085	0.111	0.088	0.231	0.064	0.245
Czech Republic	**0.402**	0.537	0.227	0.343	0.409	0.429	0.275	0.518	0.486
Denmark	**0.718**	0.605	0.800	0.729	0.569	0.831	0.828	0.632	0.671
Germany	**0.720**	0.626	0.553	0.610	0.637	0.731	0.814	1.000	0.728
Estonia	**0.500**	0.565	0.289	0.760	0.594	0.604	0.483	0.606	0.409
Ireland	**0.597**	0.758	0.682	0.320	0.305	0.566	0.425	0.702	0.791
Greece	**0.340**	0.506	0.294	0.151	0.220	0.485	0.122	0.676	0.347
Spain	**0.407**	0.433	0.493	0.436	0.223	0.297	0.399	0.318	0.507
France	**0.568**	0.669	0.664	0.631	0.347	0.498	0.516	0.532	0.611
Italy	**0.445**	0.420	0.354	0.289	0.287	0.404	0.519	0.616	0.535
Cyprus	**0.505**	0.577	0.378	0.198	0.479	0.731	0.427	0.494	0.543
Latvia	**0.225**	0.451	0.083	0.375	0.111	0.103	0.330	0.123	0.220
Lithuania	**0.280**	0.645	0.144	0.563	0.396	0.229	0.128	0.227	0.214
Luxembourg	**0.626**	0.549	0.692	0.636	0.231	0.630	0.666	0.876	0.652
Hungary	**0.323**	0.452	0.169	0.271	0.244	0.217	0.250	0.131	0.590
Malta	**0.284**	0.129	0.224	0.104	0.356	0.220	0.293	0.363	0.419
Netherlands	**0.648**	0.648	0.864	0.720	0.339	0.753	0.649	0.621	0.603
Austria	**0.602**	0.597	0.538	0.474	0.473	0.769	0.796	0.636	0.476
Poland	**0.270**	0.550	0.094	0.383	0.319	0.094	0.271	0.078	0.324
Portugal	**0.406**	0.404	0.435	0.414	0.279	0.416	0.312	0.728	0.378
Romania	**0.221**	0.421	0.087	0.218	0.137	0.083	0.101	0.124	0.433
Slovenia	**0.508**	0.671	0.385	0.521	0.437	0.623	0.506	0.476	0.479
Slovakia	**0.337**	0.746	0.116	0.302	0.210	0.301	0.155	0.289	0.470
Finland	**0.681**	0.827	0.550	0.788	0.621	0.689	0.690	0.628	0.663
Sweden	**0.747**	0.900	0.775	0.829	0.659	0.802	0.767	0.693	0.612
United Kingdom	**0.622**	0.749	0.795	0.730	0.459	0.832	0.452	0.271	0.626
Croatia	**0.302**	0.586	0.125	0.292	0.218	0.379	0.107	0.389	0.350
Turkey	**0.214**	0.070	0.147	0.365	0.089	0.245	0.121	0.577	0.272
Iceland	**0.622**	0.385	0.776	1.000	0.697	0.871	0.436	0.821	0.552
Norway	**0.485**	0.660	0.864	0.585	0.189	0.503	0.339	0.387	0.377
Switzerland	**0.835**	0.846	1.000	0.606	0.767	0.613	0.963	1.000	0.848
Serbia	**0.365**	0.367	0.223	0.563	0.302	0.336	0.017	0.530	0.494
Former Yugoslav Republic of Macedonia	**0.238**	0.367	0.121	0.000	0.241	0.125	0.012	0.478	0.385

* SII:Summary Innovation Index; HR:Human Resources; RS: Research Systems; FS: Finance and Support; FI: Firm Investments; L&E: Linkages & Entrepreneurship; IA: Intellectual Assets; I: Innovators; EE: Economic Effects

Table 34 Summary Innovation Index 2011

Countries*	**II**	**HR**	**RS**	**FS**	**FI**	**L&E**	**IA**	**I**	**EE**
	"2011"	"2011"	"2011"	"2011"	"2011"	"2011"	"2011"	"2011"	"2011"
EU	**0.531**	0.543	0.480	0.593	0.444	0.504	0.542	0.509	0.580
Belgium	**0.612**	0.656	0.712	0.589	0.421	0.839	0.503	0.675	0.538
Bulgaria	**0.234**	0.435	0.117	0.144	0.313	0.126	0.211	0.123	0.314
Czech Republic	**0.413**	0.520	0.204	0.270	0.481	0.467	0.258	0.590	0.526
Denmark	**0.696**	0.549	0.725	0.741	0.568	0.949	0.822	0.559	0.604
Germany	**0.705**	0.595	0.533	0.587	0.632	0.698	0.798	0.961	0.742
Estonia	**0.484**	0.556	0.294	0.677	0.671	0.677	0.388	0.567	0.368
Ireland	**0.587**	0.748	0.676	0.311	0.519	0.519	0.442	0.458	0.782
Greece	**0.334**	0.455	0.285	0.170	0.220	0.481	0.112	0.676	0.354
Spain	**0.393**	0.407	0.465	0.469	0.255	0.284	0.385	0.339	0.461
France	**0.560**	0.665	0.653	0.632	0.407	0.531	0.500	0.479	0.572
Italy	**0.432**	0.411	0.344	0.341	0.293	0.421	0.510	0.557	0.485
Cyprus	**0.513**	0.560	0.379	0.219	0.501	0.728	0.364	0.690	0.550
Latvia	**0.225**	0.428	0.031	0.250	0.369	0.093	0.273	0.046	0.271
Lithuania	**0.271**	0.631	0.133	0.438	0.240	0.246	0.163	0.180	0.256
Luxembourg	**0.581**	0.531	0.632	0.558	0.254	0.557	0.594	0.742	0.658
Hungary	**0.335**	0.447	0.180	0.233	0.336	0.235	0.244	0.112	0.625
Malta	**0.300**	0.104	0.175	0.115	0.371	0.210	0.338	0.271	0.537
Netherlands	**0.594**	0.624	0.840	0.706	0.311	0.589	0.660	0.367	0.588
Austria	**0.584**	0.574	0.557	0.504	0.514	0.653	0.765	0.610	0.468
Poland	**0.283**	0.578	0.094	0.337	0.380	0.147	0.253	0.100	0.339
Portugal	**0.425**	0.424	0.395	0.524	0.324	0.493	0.336	0.715	0.359
Romania	**0.252**	0.378	0.097	0.231	0.409	0.124	0.068	0.183	0.464
Slovenia	**0.517**	0.636	0.372	0.552	0.507	0.606	0.474	0.476	0.543
Slovakia	**0.291**	0.623	0.123	0.229	0.236	0.192	0.122	0.221	0.450
Finland	**0.681**	0.848	0.537	0.853	0.639	0.724	0.681	0.515	0.658
Sweden	**0.735**	0.885	0.737	0.917	0.688	0.777	0.744	0.557	0.630
United Kingdom	**0.621**	0.716	0.778	0.737	0.463	0.824	0.441	0.341	0.631
Croatia	**0.317**	0.529	0.116	0.292	0.293	0.426	0.111	0.408	0.387
Turkey	**0.209**	0.051	0.146	0.365	0.089	0.248	0.110	0.577	0.268
Iceland	**0.612**	0.320	0.812	1.000	0.697	0.871	0.400	0.821	0.554
Norway	**0.470**	0.623	0.805	0.644	0.182	0.584	0.306	0.360	0.331
Switzerland	**0.827**	0.842	0.989	0.607	0.767	0.613	0.917	1.000	0.853
Serbia	**0.279**	0.369	0.130	0.563	0.224	0.244	0.017	0.103	0.453
Former Yugoslav Republic of Macedonia	**0.220**	0.306	0.027	0.000	0.241	0.125	0.017	0.478	0.395

* SII:Summary Innovation Index; HR:Human Resources; RS: Research Systems; FS: Finance and Support; FI: Firm Investments; L&E: Linkages & Entrepreneurship; IA: Intellectual Assets; I: Innovators; EE: Economic Effects

Table 35 Summary Innovation Index 2010

Countries*	**II**	**HR**	**RS**	**FS**	**FI**	**L&E**	**IA**	**I**	**EE**
	"2010"	"2010"	"2010"	"2010"	"2010"	"2010"	"2010"	"2010"	"2010"
EU	**0.532**	0.539	0.468	0.616	0.446	0.497	0.543	0.509	0.586
Belgium	**0.606**	0.641	0.685	0.604	0.423	0.835	0.495	0.675	0.534
Bulgaria	**0.231**	0.420	0.142	0.236	0.282	0.127	0.177	0.123	0.298
Czech Republic	**0.408**	0.494	0.208	0.270	0.464	0.463	0.261	0.590	0.522
Denmark	**0.698**	0.544	0.673	0.681	0.594	0.932	0.857	0.559	0.643
Germany	**0.710**	0.586	0.526	0.600	0.639	0.688	0.811	0.961	0.760
Estonia	**0.460**	0.513	0.261	0.646	0.632	0.671	0.308	0.567	0.395
Ireland	**0.544**	0.727	0.643	0.359	0.517	0.504	0.408	0.458	0.626
Greece	**0.362**	0.429	0.255	0.194	0.220	0.481	0.138	0.676	0.493
Spain	**0.390**	0.374	0.473	0.506	0.255	0.278	0.378	0.339	0.453
France	**0.558**	0.654	0.647	0.676	0.405	0.525	0.483	0.479	0.573
Italy	**0.432**	0.404	0.319	0.380	0.291	0.413	0.508	0.557	0.493
Cyprus	**0.494**	0.565	0.320	0.198	0.503	0.700	0.313	0.690	0.556
Latvia	**0.216**	0.403	0.063	0.156	0.358	0.088	0.238	0.046	0.278
Lithuania	**0.255**	0.591	0.131	0.521	0.233	0.239	0.122	0.180	0.229
Luxembourg	**0.595**	0.563	0.564	0.646	0.321	0.550	0.640	0.742	0.654
Hungary	**0.329**	0.409	0.179	0.250	0.330	0.222	0.264	0.112	0.608
Malta	**0.338**	0.089	0.231	0.063	0.353	0.188	0.444	0.271	0.633
Netherlands	**0.588**	0.612	0.794	0.721	0.302	0.577	0.654	0.367	0.595
Austria	**0.571**	0.566	0.519	0.486	0.502	0.642	0.754	0.610	0.464
Poland	**0.273**	0.569	0.095	0.322	0.378	0.142	0.234	0.100	0.321
Portugal	**0.427**	0.411	0.361	0.558	0.334	0.486	0.335	0.715	0.385
Romania	**0.233**	0.323	0.085	0.235	0.411	0.116	0.055	0.183	0.428
Slovenia	**0.489**	0.587	0.330	0.531	0.457	0.585	0.445	0.476	0.533
Slovakia	**0.281**	0.551	0.110	0.146	0.221	0.183	0.158	0.221	0.456
Finland	**0.675**	0.868	0.505	0.850	0.639	0.730	0.660	0.515	0.648
Sweden	**0.733**	0.872	0.705	0.938	0.691	0.773	0.764	0.557	0.621
United Kingdom	**0.623**	0.683	0.765	0.786	0.468	0.813	0.442	0.341	0.651
Croatia	**0.308**	0.481	0.103	0.375	0.295	0.415	0.125	0.408	0.359
Turkey	**0.201**	0.044	0.118	0.385	0.084	0.247	0.103	0.577	0.257
Iceland	**0.588**	0.305	0.747	1.000	0.697	0.871	0.443	0.821	0.466
Norway	**0.478**	0.643	0.754	0.740	0.193	0.579	0.321	0.360	0.337
Switzerland	**0.826**	0.808	0.999	0.591	0.767	0.613	0.920	1.000	0.868
Serbia	**0.290**	0.352	0.268	0.667	0.231	0.238	0.013	0.103	0.455
Former Yugoslav Republic of Macedonia	**0.219**	0.263	0.079	0.000	0.241	0.125	0.001	0.478	0.394

* SII:Summary Innovation Index; HR:Human Resources; RS: Research Systems; FS: Finance and Support; FI: Firm Investments; L&E: Linkages & Entrepreneurship; IA: Intellectual Assets; I: Innovators; EE: Economic Effects

Table 36 Summary Innovation Index 2009

Countries*	**II**	**HR**	**RS**	**FS**	**FI**	**L&E**	**IA**	**I**	**EE**
	"2009"	"2009"	"2009"	"2009"	"2009"	"2009"	"2009"	"2009"	"2009"
EU	**0.516**	0.527	0.446	0.594	0.435	0.462	0.541	0.515	0.565
Belgium	**0.596**	0.629	0.659	0.554	0.472	0.746	0.486	0.704	0.559
Bulgaria	**0.198**	0.413	0.127	0.184	0.233	0.107	0.181	0.258	0.224
Czech Republic	**0.371**	0.462	0.189	0.287	0.415	0.446	0.252	0.431	0.461
Denmark	**0.660**	0.501	0.703	0.623	0.546	0.808	0.845	0.462	0.577
Germany	**0.694**	0.563	0.506	0.563	0.686	0.640	0.794	0.952	0.755
Estonia	**0.458**	0.496	0.241	0.583	0.613	0.621	0.281	0.649	0.411
Ireland	**0.567**	0.713	0.620	0.366	0.455	0.543	0.382	0.638	0.708
Greece	**0.338**	0.487	0.257	0.189	0.220	0.485	0.125	0.676	0.348
Spain	**0.394**	0.379	0.434	0.531	0.269	0.293	0.386	0.336	0.458
France	**0.531**	0.627	0.629	0.620	0.350	0.475	0.479	0.484	0.543
Italy	**0.410**	0.374	0.302	0.347	0.434	0.322	0.513	0.383	0.457
Cyprus	**0.465**	0.557	0.270	0.156	0.515	0.673	0.306	0.678	0.487
Latvia	**0.206**	0.382	0.103	0.333	0.354	0.119	0.208	0.164	0.202
Lithuania	**0.248**	0.603	0.072	0.479	0.195	0.250	0.087	0.381	0.251
Luxembourg	**0.615**	0.471	0.508	0.615	0.513	0.584	0.690	0.668	0.668
Hungary	**0.301**	0.393	0.161	0.253	0.295	0.212	0.220	0.225	0.522
Malta	**0.322**	0.088	0.173	0.052	0.372	0.184	0.350	0.206	0.695
Netherlands	**0.585**	0.601	0.760	0.687	0.242	0.572	0.650	0.340	0.637
Austria	**0.596**	0.532	0.481	0.450	0.504	0.750	0.736	0.835	0.501
Poland	**0.278**	0.553	0.094	0.294	0.314	0.220	0.200	0.245	0.315
Portugal	**0.400**	0.416	0.348	0.491	0.411	0.372	0.293	0.715	0.358
Romania	**0.250**	0.316	0.086	0.302	0.324	0.133	0.075	0.210	0.447
Slovenia	**0.473**	0.599	0.309	0.458	0.530	0.591	0.436	0.484	0.456
Slovakia	**0.295**	0.493	0.081	0.135	0.460	0.232	0.141	0.175	0.481
Finland	**0.673**	0.886	0.493	0.732	0.639	0.872	0.642	0.425	0.598
Sweden	**0.731**	0.849	0.660	0.896	0.666	0.818	0.763	0.435	0.656
United Kingdom	**0.588**	0.669	0.748	0.755	0.463	0.520	0.466	0.312	0.637
Croatia	**0.286**	0.464	0.090	0.375	0.084	0.354	0.168	0.431	0.357
Turkey	**0.195**	0.018	0.105	0.281	0.080	0.246	0.094	0.577	0.281
Iceland	**0.609**	0.242	0.687	1.000	0.610	0.788	0.615	0.821	0.543
Norway	**0.458**	0.594	0.702	0.694	0.194	0.515	0.324	0.338	0.333
Switzerland	**0.816**	0.818	0.991	0.664	0.695	0.716	0.930	0.906	0.771
Serbia	**0.248**	0.302	0.268	0.250	0.224	0.234	0.016	0.103	0.414
Former Yugoslav Republic of Macedonia	**0.216**	0.228	0.106	0.000	0.241	0.137	0.023	0.478	0.366

* SII:Summary Innovation Index; HR:Human Resources; RS: Research Systems; FS: Finance and Support; FI: Firm Investments; L&E: Linkages & Entrepreneurship; IA: Intellectual Assets; I: Innovators; EE: Economic Effects

Table 37 Summary Innovation Index 2009

Countries*	**II**	**HR**	**RS**	**FS**	**FI**	**L&E**	**IA**	**I**	**EE**
	"2008"	"2008"	"2008"	"2008"	"2008"	"2008"	"2008"	"2008"	"2008"
EU	**0.504**	0.505	0.420	0.583	0.427	0.463	0.536	0.515	0.548
Belgium	**0.594**	0.620	0.639	0.523	0.467	0.741	0.489	0.704	0.582
Bulgaria	**0.187**	0.400	0.118	0.179	0.231	0.101	0.154	0.071	0.209
Czech Republic	**0.365**	0.434	0.177	0.303	0.426	0.442	0.241	0.453	0.457
Denmark	**0.643**	0.484	0.665	0.581	0.505	0.813	0.850	0.595	0.557
Germany	**0.677**	0.543	0.480	0.527	0.666	0.643	0.774	0.952	0.734
Estonia	**0.415**	0.479	0.218	0.417	0.604	0.614	0.171	0.742	0.366
Ireland	**0.549**	0.681	0.580	0.324	0.435	0.550	0.396	0.638	0.671
Greece	**0.364**	0.492	0.239	0.189	0.220	0.489	0.127	0.676	0.481
Spain	**0.388**	0.396	0.393	0.500	0.269	0.292	0.396	0.353	0.449
France	**0.519**	0.607	0.586	0.610	0.346	0.475	0.478	0.484	0.531
Italy	**0.397**	0.356	0.280	0.347	0.426	0.321	0.512	0.479	0.420
Cyprus	**0.493**	0.565	0.304	0.177	0.515	0.678	0.419	0.678	0.489
Latvia	**0.188**	0.349	0.021	0.271	0.363	0.121	0.232	0.014	0.178
Lithuania	**0.244**	0.574	0.104	0.458	0.204	0.243	0.103	0.230	0.220
Luxembourg	**0.585**	0.416	0.419	0.563	0.519	0.568	0.632	0.856	0.684
Hungary	**0.301**	0.365	0.175	0.264	0.286	0.211	0.232	0.174	0.518
Malta	**0.301**	0.092	0.083	0.052	0.374	0.196	0.286	0.206	0.691
Netherlands	**0.577**	0.590	0.733	0.672	0.257	0.567	0.625	0.387	0.642
Austria	**0.582**	0.530	0.463	0.408	0.486	0.745	0.711	0.835	0.488
Poland	**0.268**	0.531	0.093	0.284	0.309	0.216	0.179	0.245	0.303
Portugal	**0.378**	0.401	0.287	0.402	0.379	0.370	0.282	0.715	0.353
Romania	**0.234**	0.290	0.097	0.250	0.335	0.131	0.069	0.301	0.401
Slovenia	**0.448**	0.599	0.269	0.458	0.487	0.582	0.383	0.484	0.431
Slovakia	**0.285**	0.465	0.075	0.146	0.456	0.232	0.120	0.175	0.468
Finland	**0.657**	0.892	0.473	0.732	0.639	0.872	0.614	0.548	0.553
Sweden	**0.725**	0.839	0.645	0.881	0.666	0.820	0.750	0.558	0.657
United Kingdom	**0.579**	0.646	0.712	0.750	0.468	0.525	0.468	0.312	0.629
Croatia	**0.275**	0.437	0.074	0.344	0.069	0.348	0.181	0.431	0.337
Turkey	**0.188**	0.012	0.096	0.302	0.076	0.246	0.086	0.577	0.261
Iceland	**0.593**	0.235	0.651	1.000	0.619	0.788	0.556	0.821	0.547
Norway	**0.449**	0.532	0.668	0.704	0.194	0.511	0.319	0.413	0.348
Switzerland	**0.805**	0.765	0.981	0.664	0.695	0.716	0.923	0.906	0.761
Serbia	**0.255**	0.303	0.268	0.219	0.235	0.234	0.010	0.103	0.451
Former Yugoslav Republic of Macedonia	**0.191**	0.223	0.080	0.000	0.239	0.142	0.020	0.478	0.276

* SII:Summary Innovation Index; HR:Human Resources; RS: Research Systems; FS: Finance and Support; FI: Firm Investments; L&E: Linkages & Entrepreneurship; IA: Intellectual Assets; I: Innovators; EE: Economic Effects

APPENDIX B - FIGURES

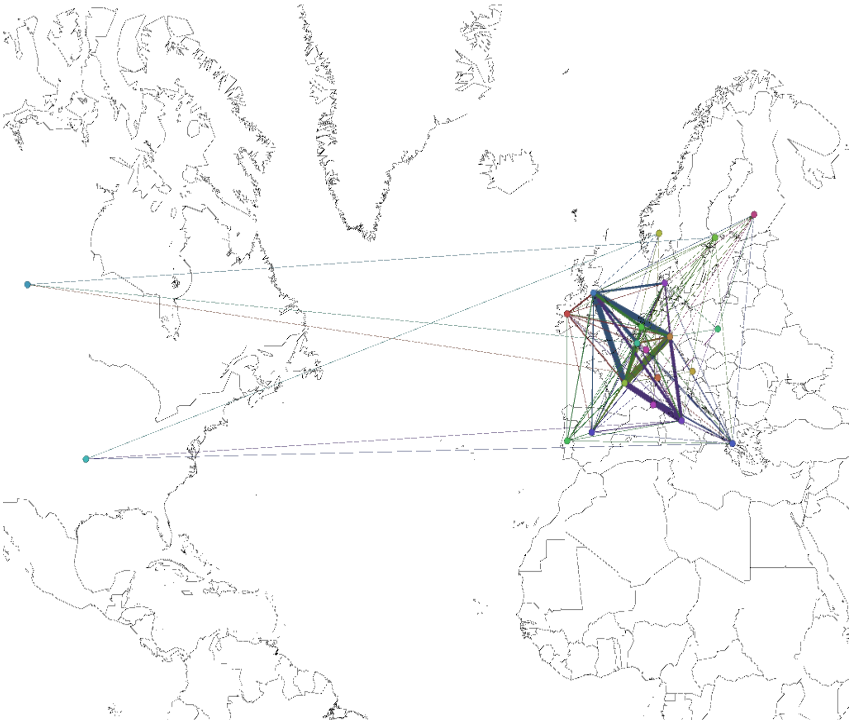

Figure 14 Open Network (Country)

Figure 15 Open Network (Country)

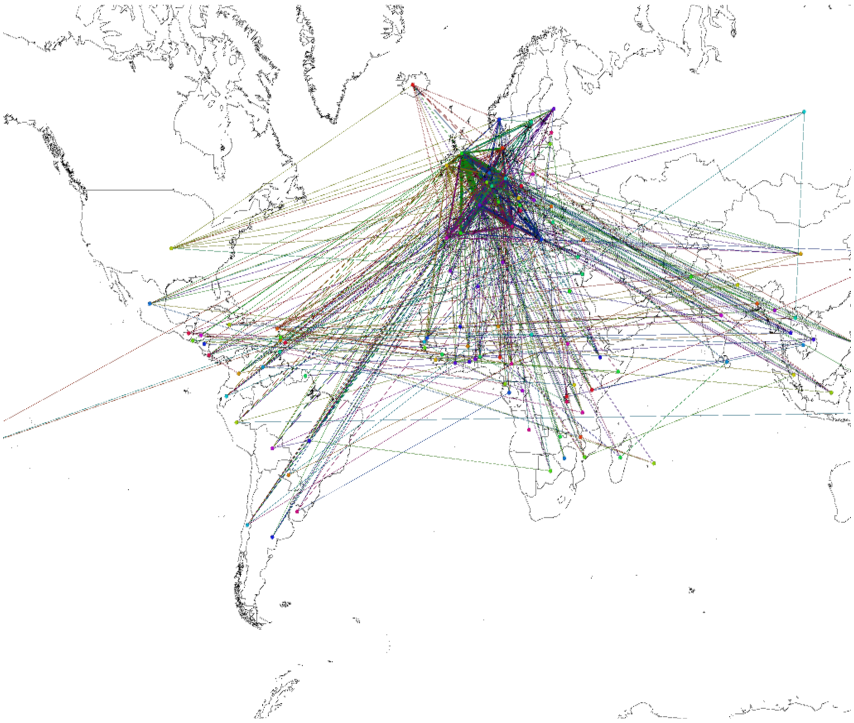

Figure 16 FP3 Open Network (Country)

Figure 17 FP4 Open Network (Country)

Figure 18 FP5 Open Network (Country)

Figure 19 FP6 Open Network (Country)

Figure 20 FP7 Open Network (Country)

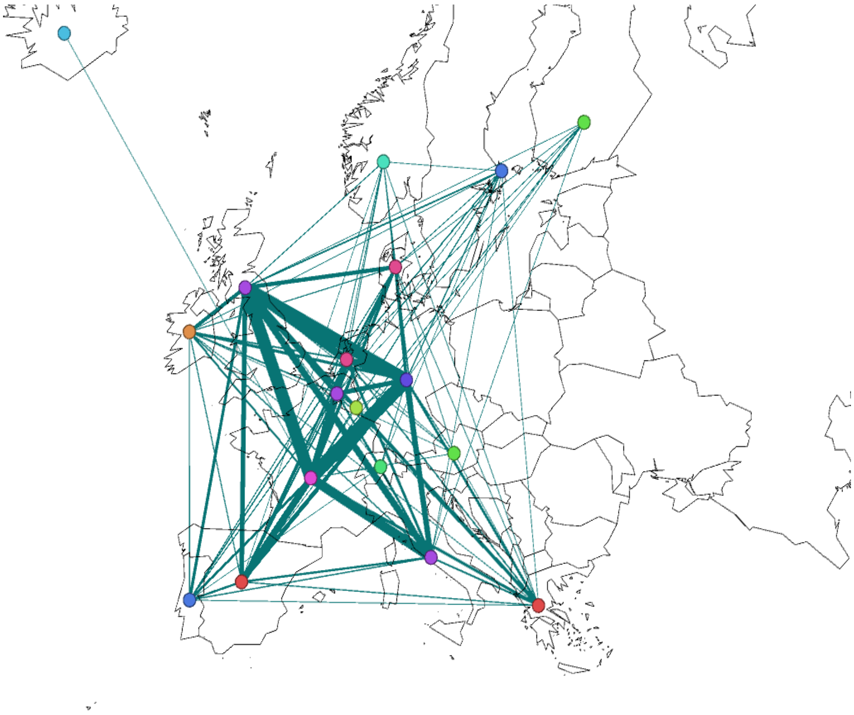

Figure 21 FP1 Closed Network (Country)

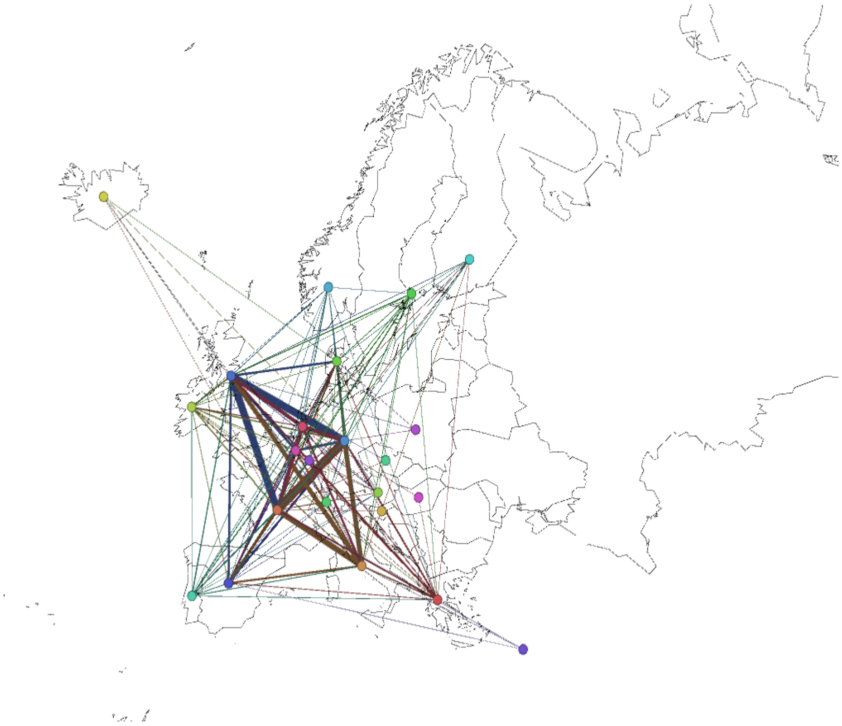

Figure 22 FP2 Closed Network (Country)

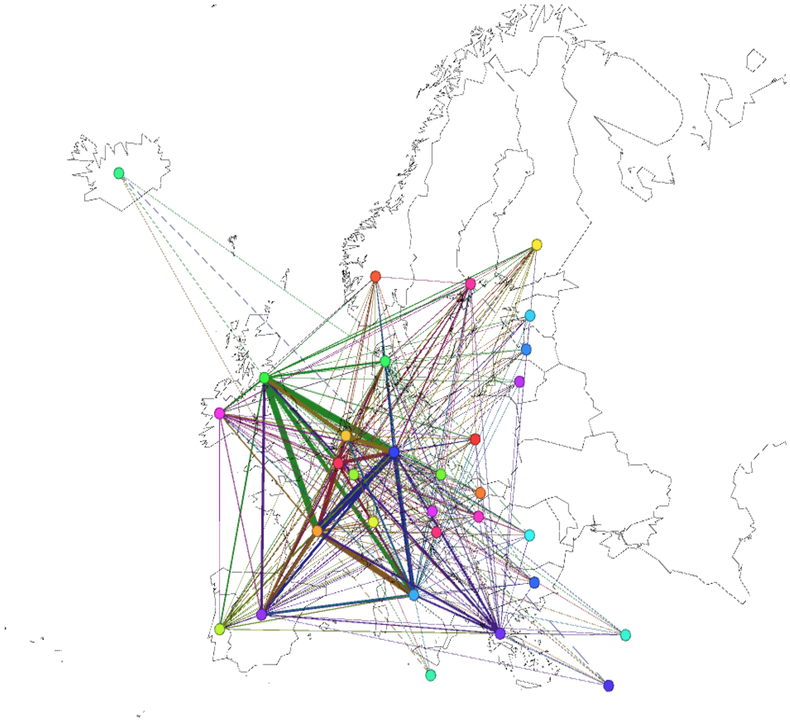

Figure 23 FP3 Closed Network (Country)

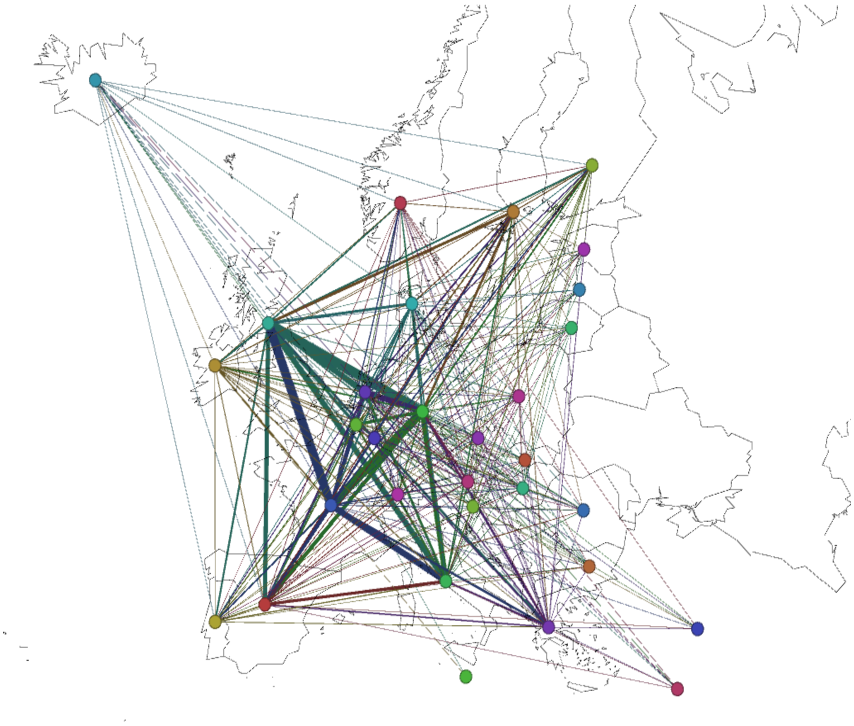

Figure 24 FP4 Closed Network (Country)

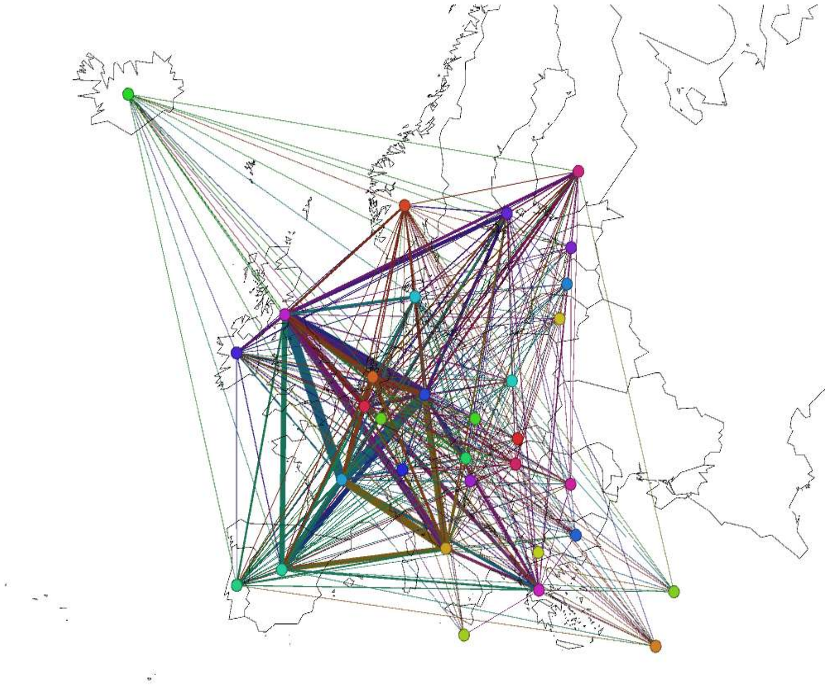

Figure 25 FP5 Closed Network (Country)

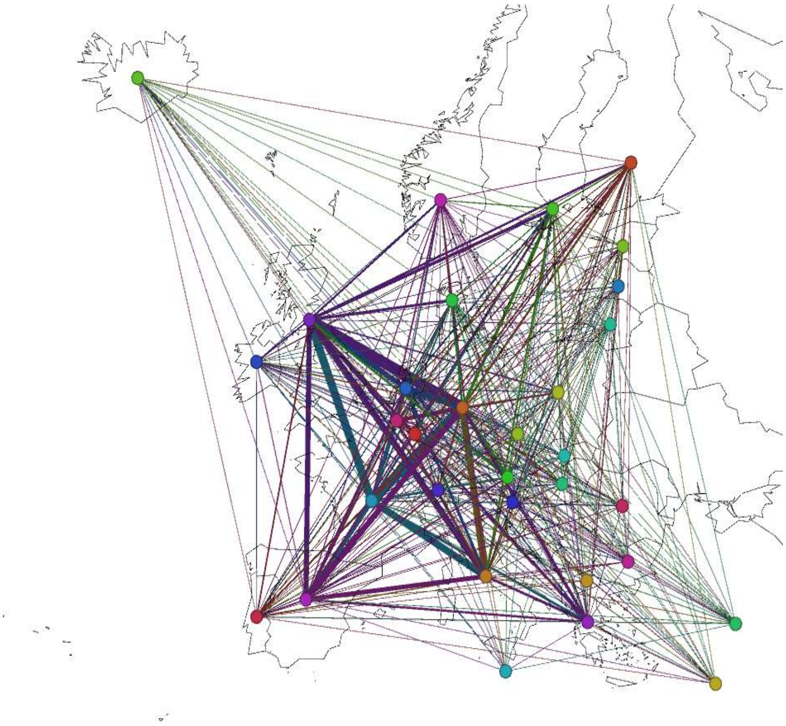

Figure 26 FP6 Closed Network (Country)

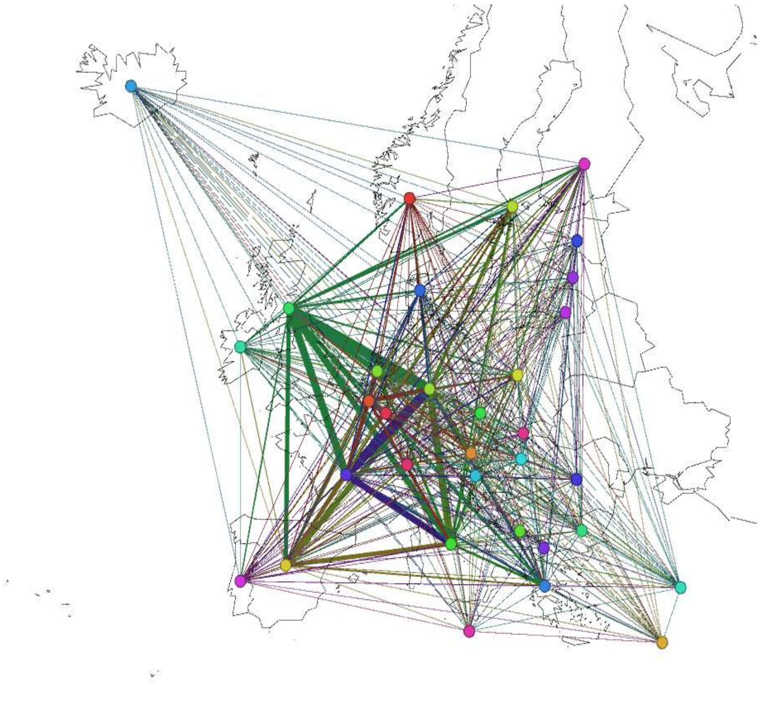

Figure 27 FP7 Closed Network (Country)

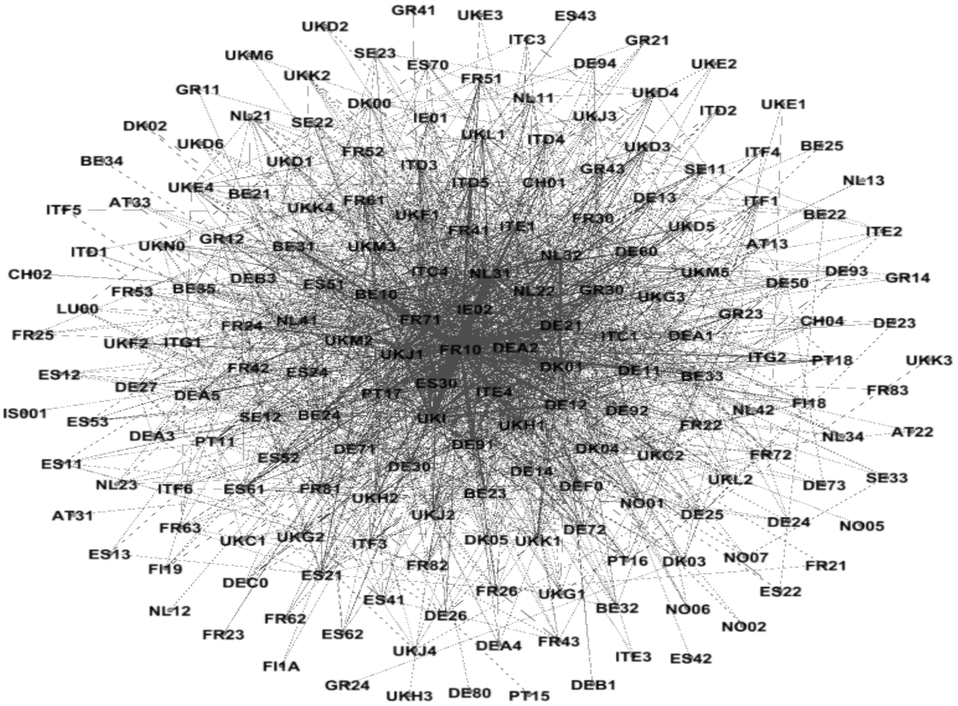

Figure 28 FP1 Network (Region)

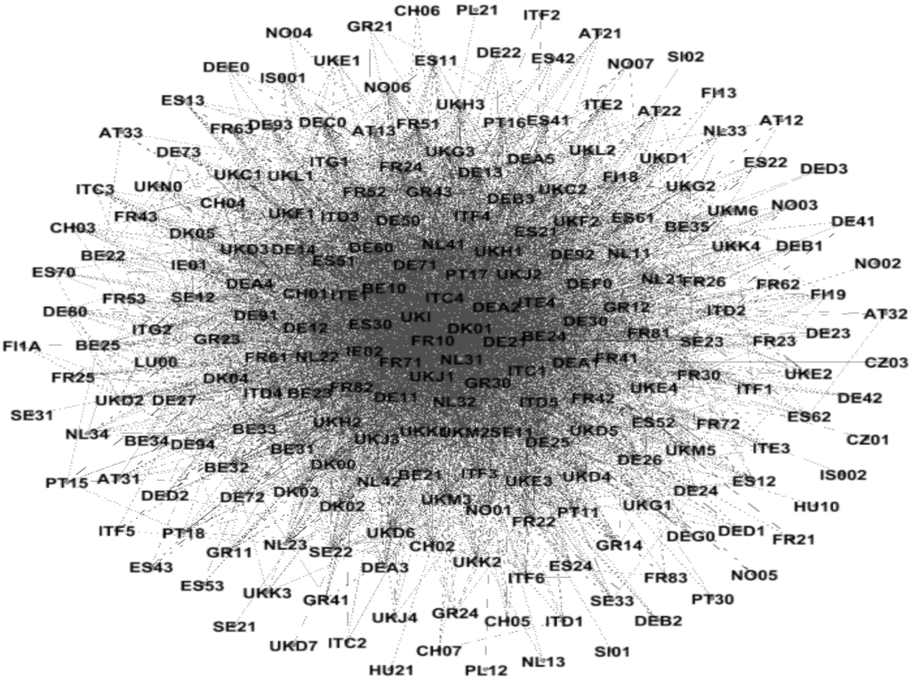

Figure 29 FP2 Network (Region)

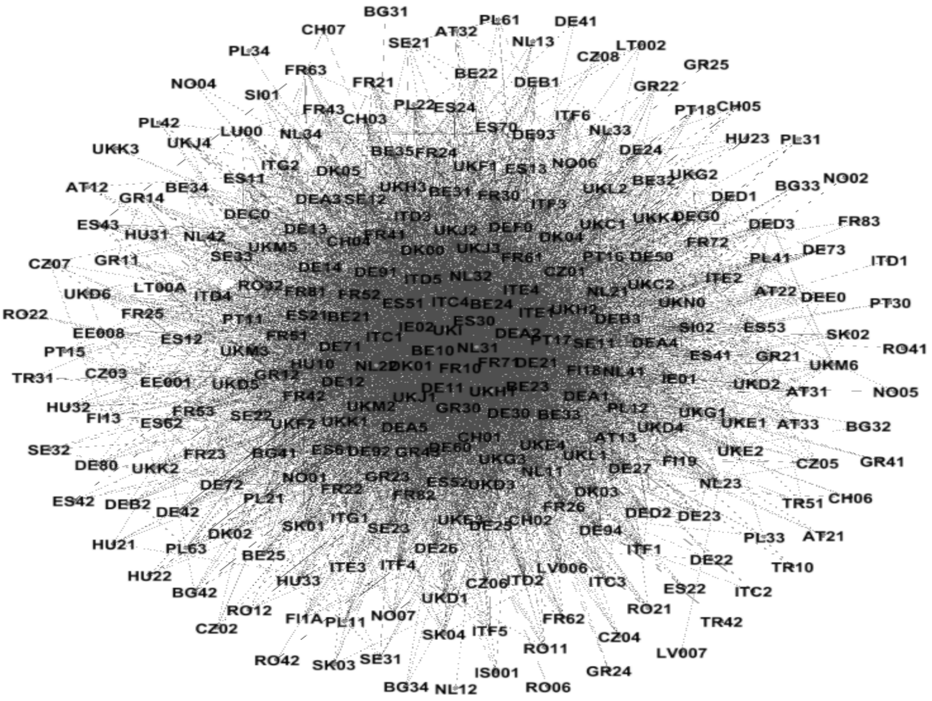

Figure 30 FP3 Network (Region)

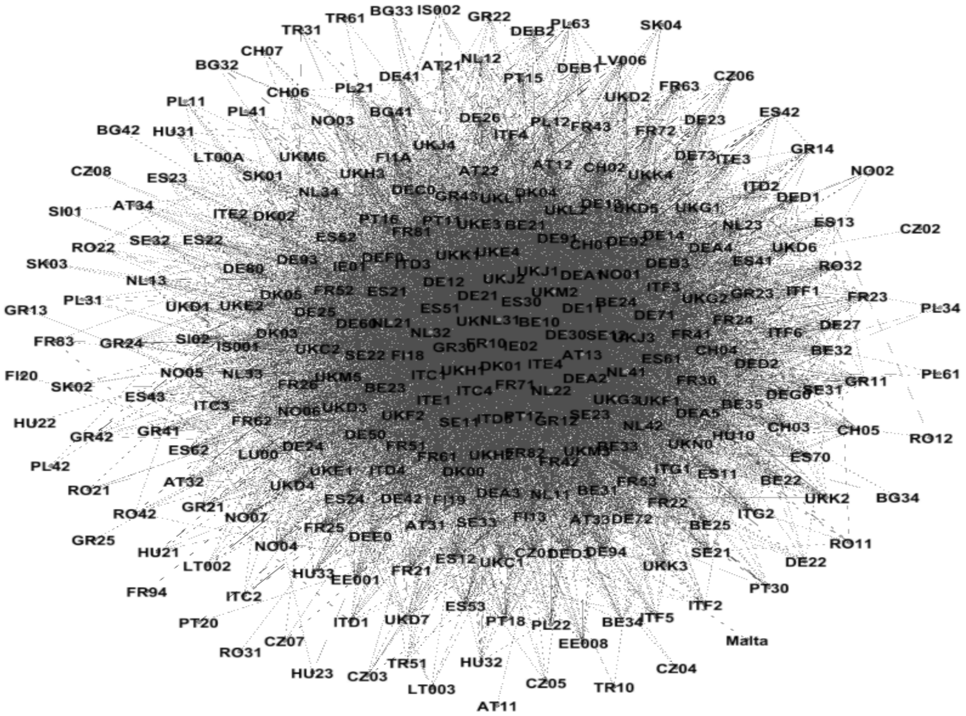

Figure 31 FP4 Network (Region)

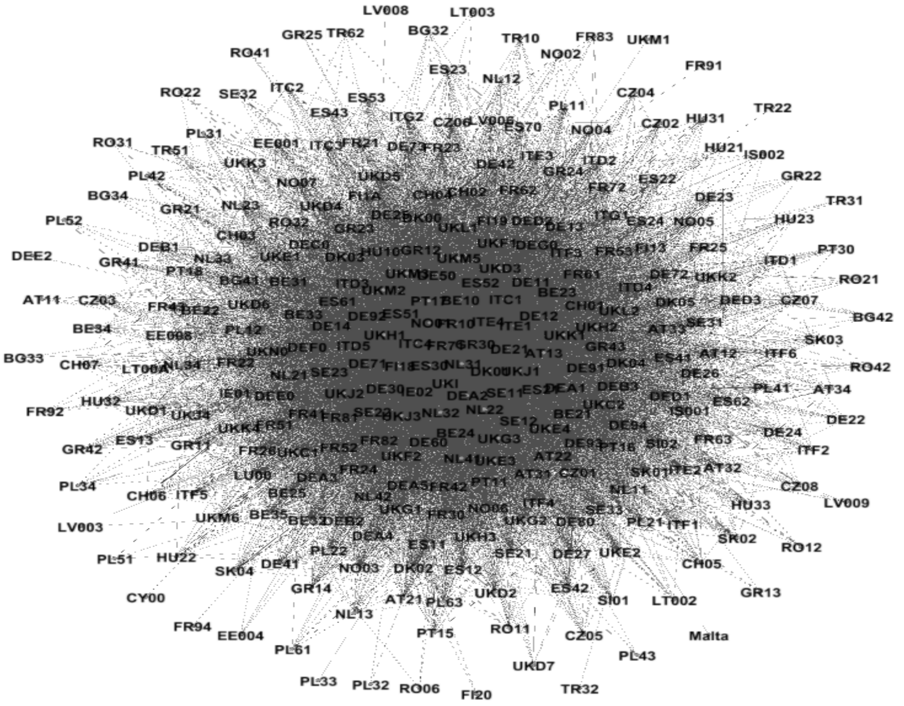

Figure 32 FP5 Network (Region)

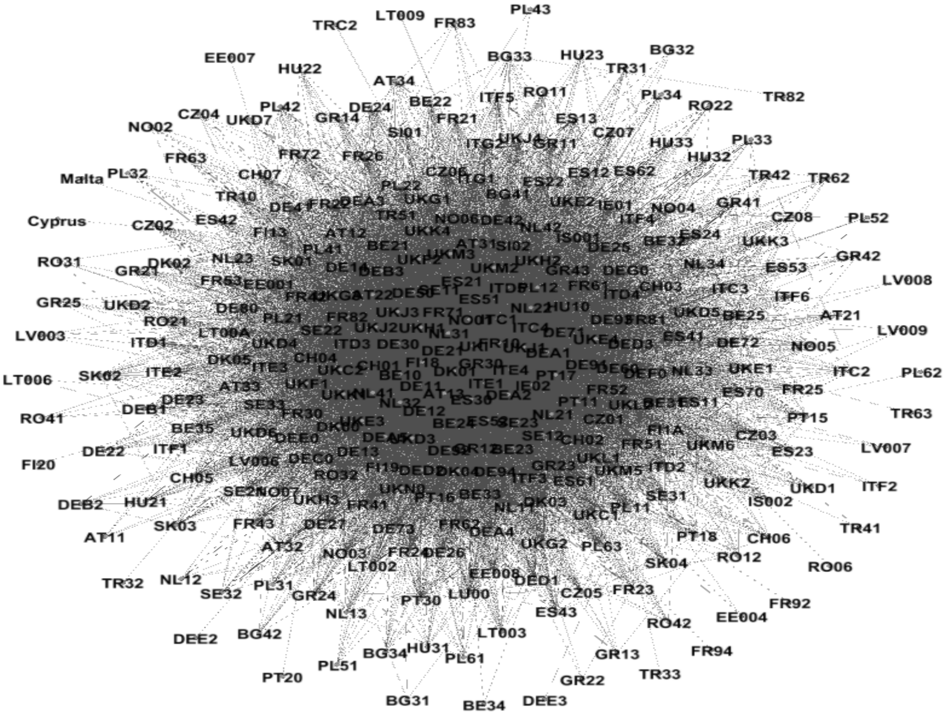

Figure 33 FP6 Network (Region)

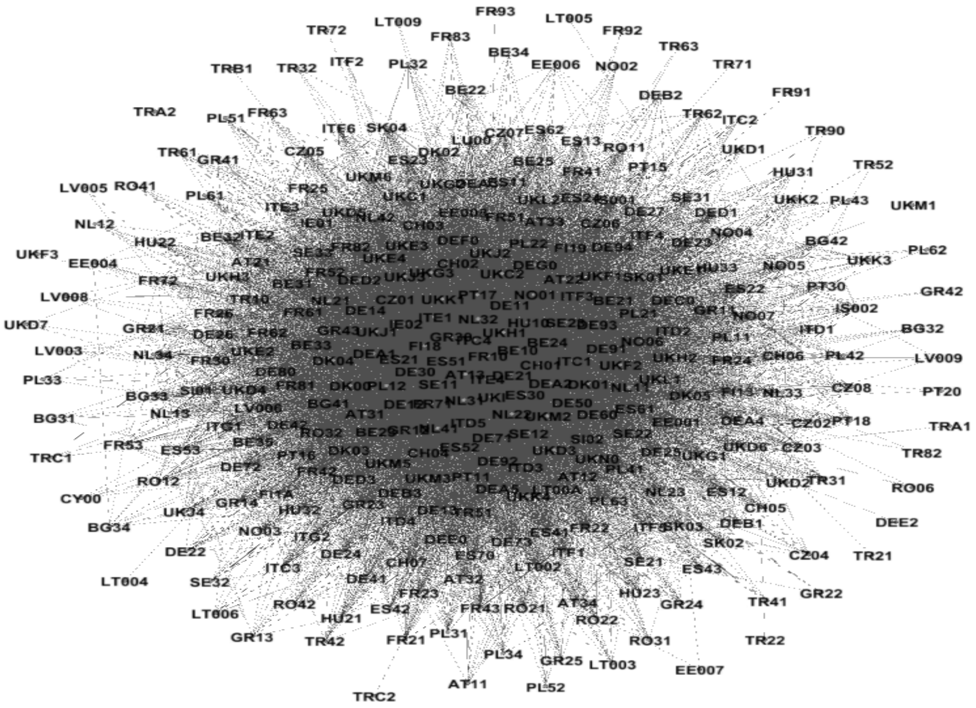

Figure 34 FP7 Network (Region)

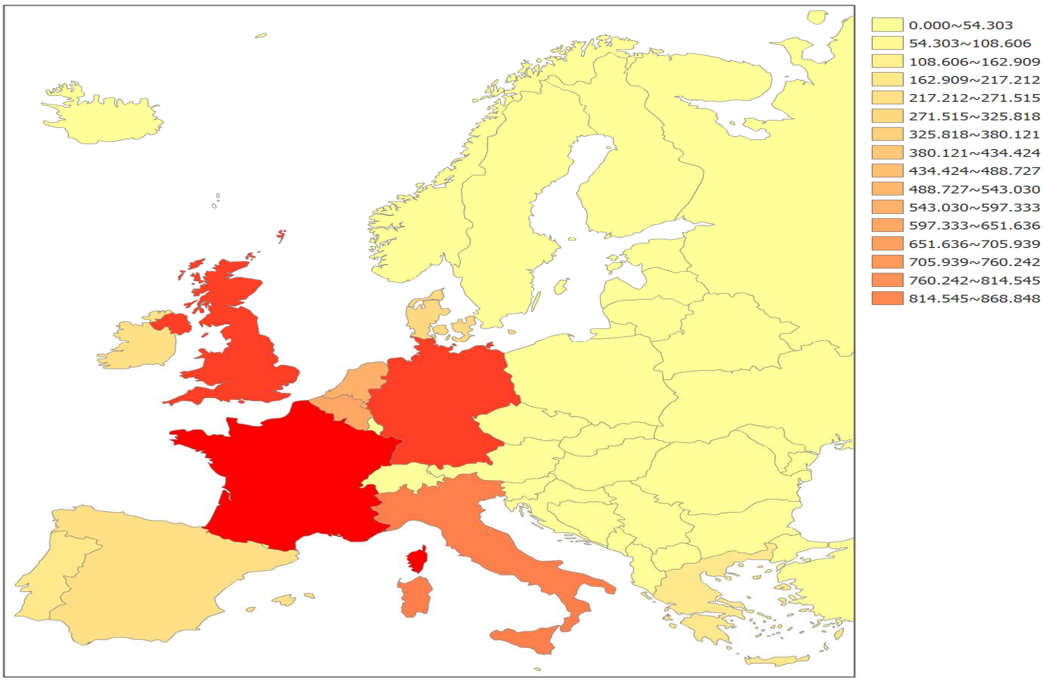

Figure 35 FP1 Network (Country)

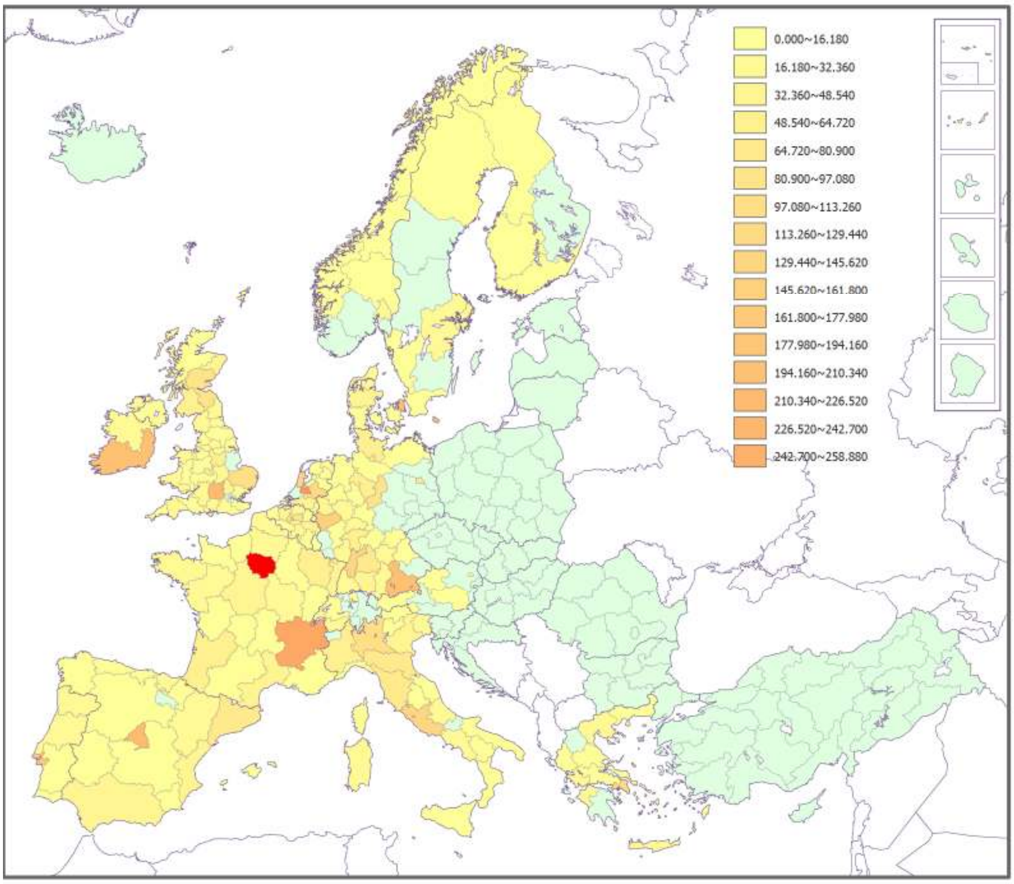

Figure 36 FP1 Network (Region)

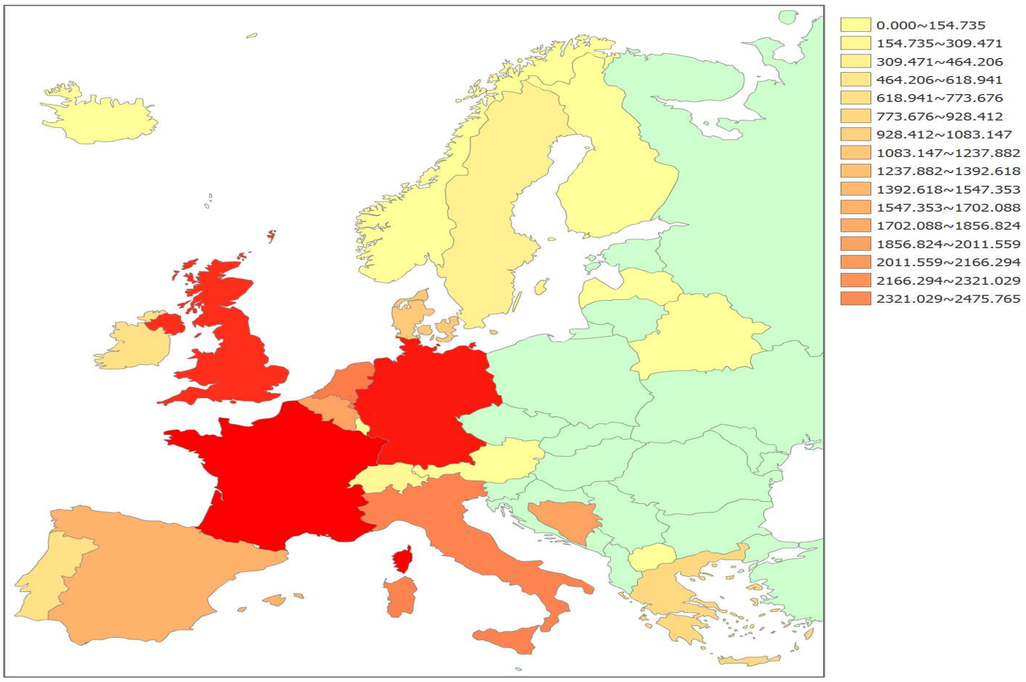

Figure 37 FP2 Network (Country)

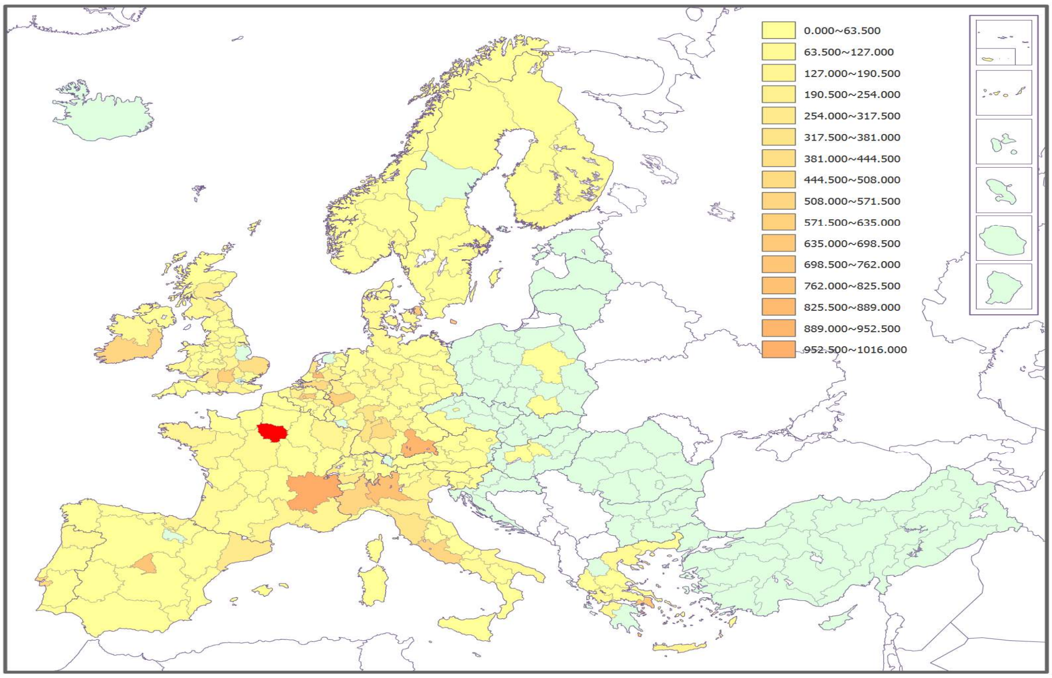

Figure 38 FP2 Network (Region)

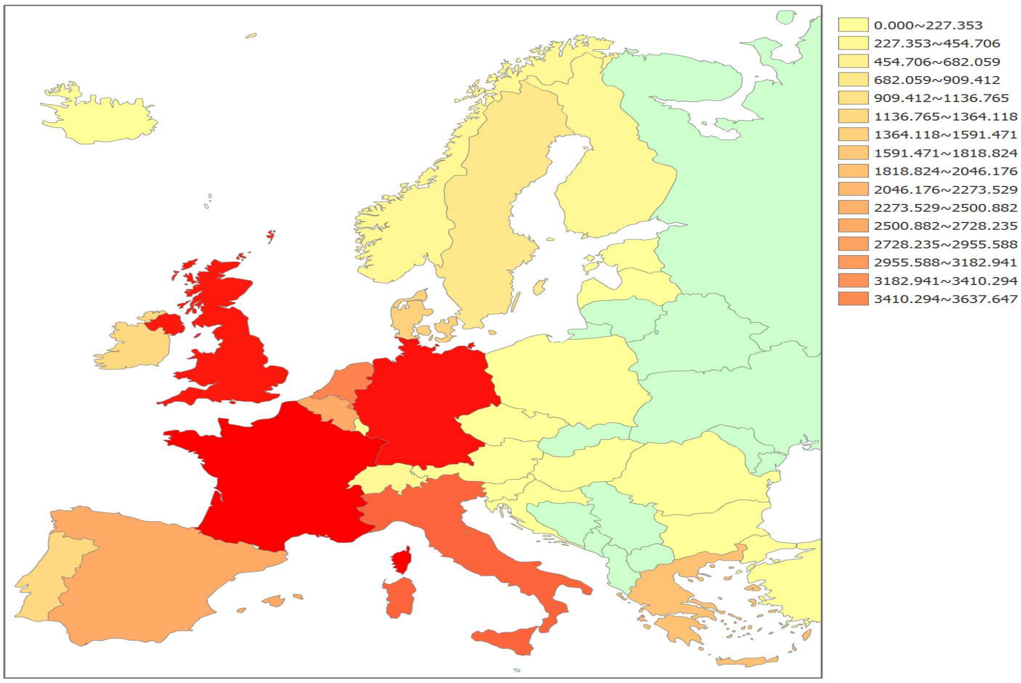

Figure 39 FP3 Network (Country)

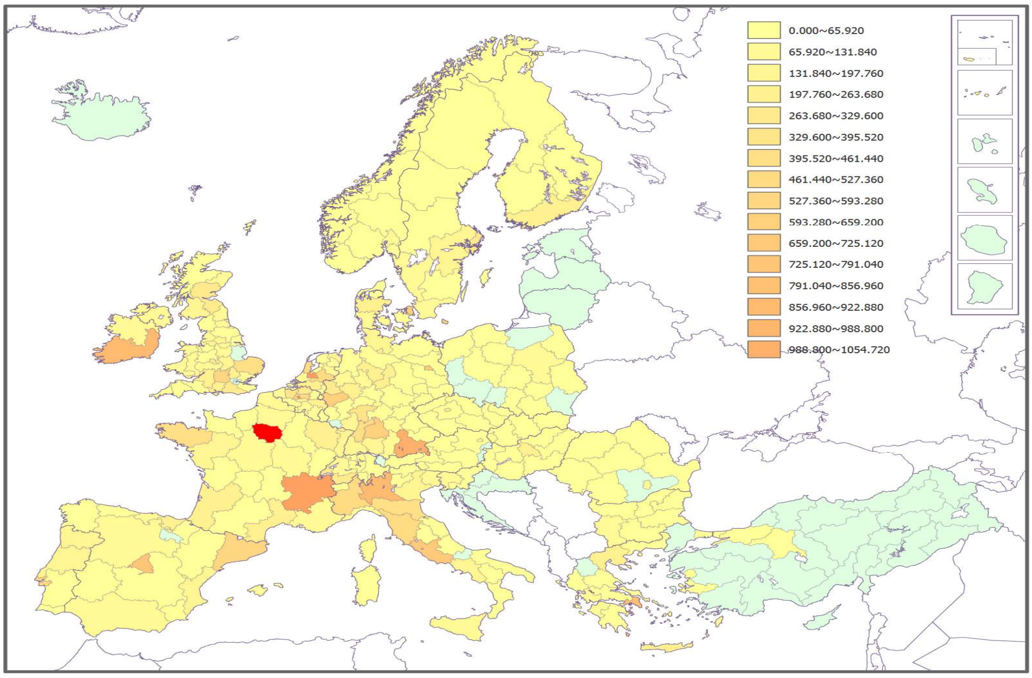

Figure 40 FP4 Network (Country)

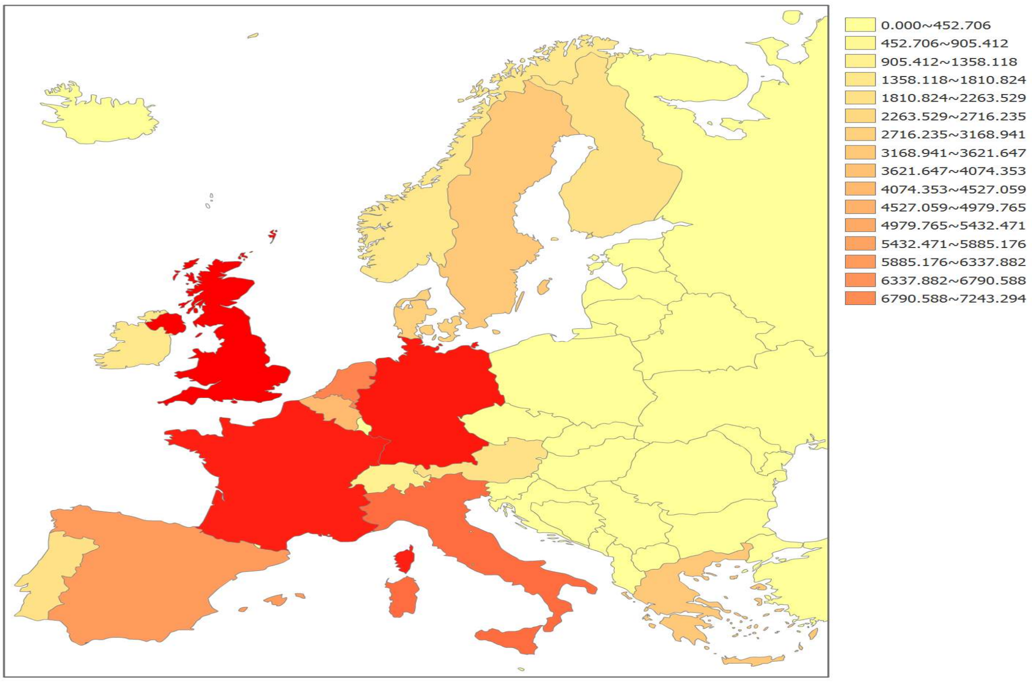

Figure 41 FP4 Network (Region)

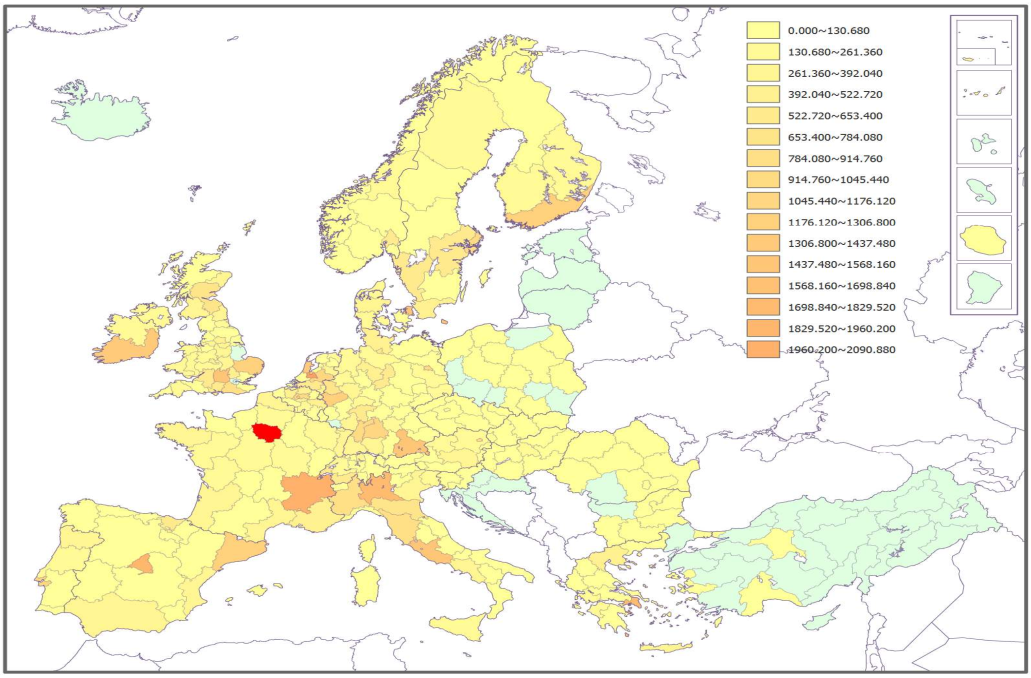

Figure 42 FP4 Network (Region)

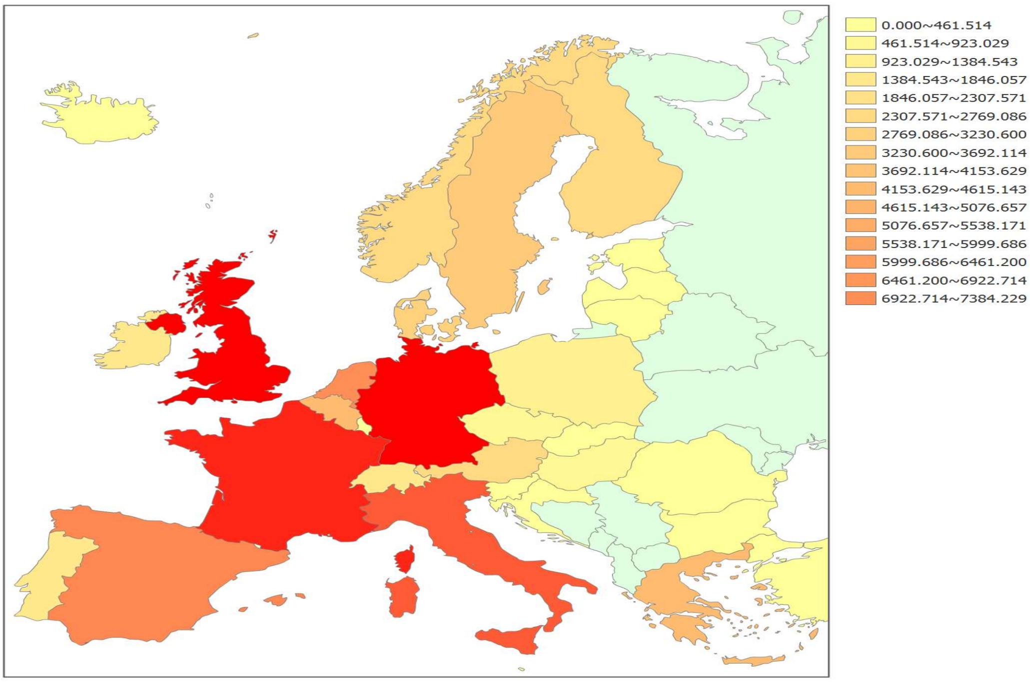

Figure 43 FP5 Network (Country)

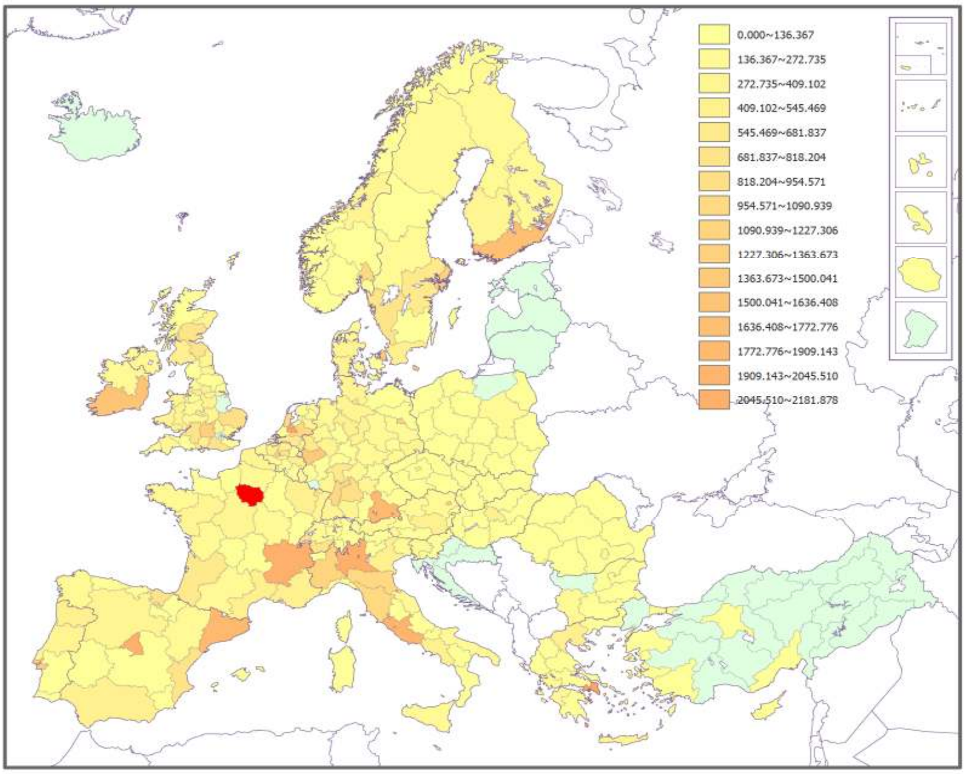

Figure 44 FP5 Network (Region)

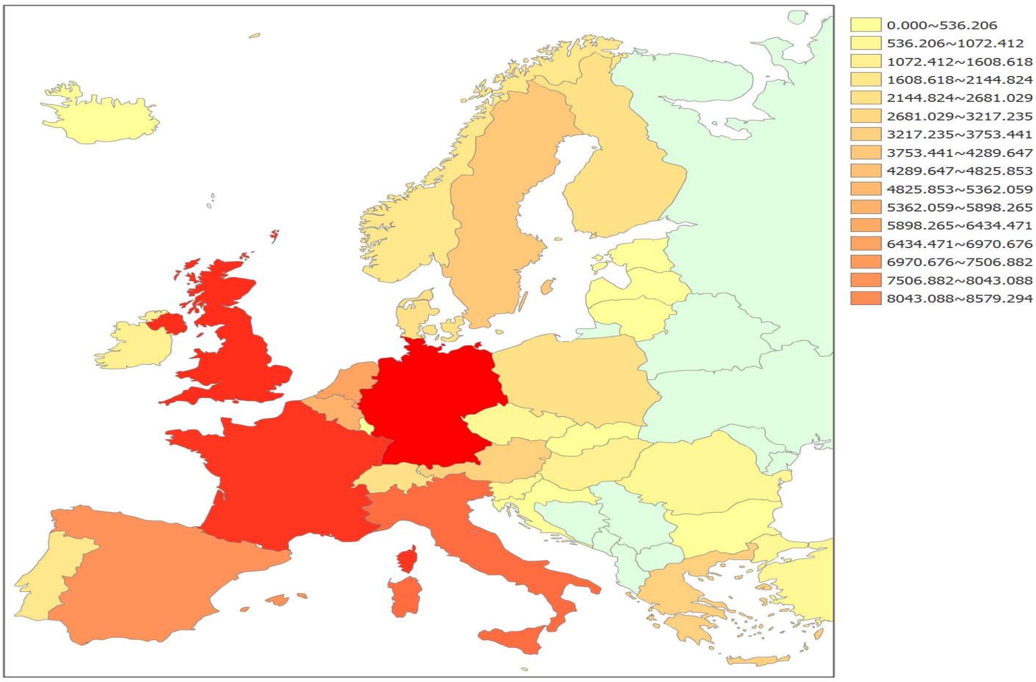

Figure 45 FP6 Network (Country)

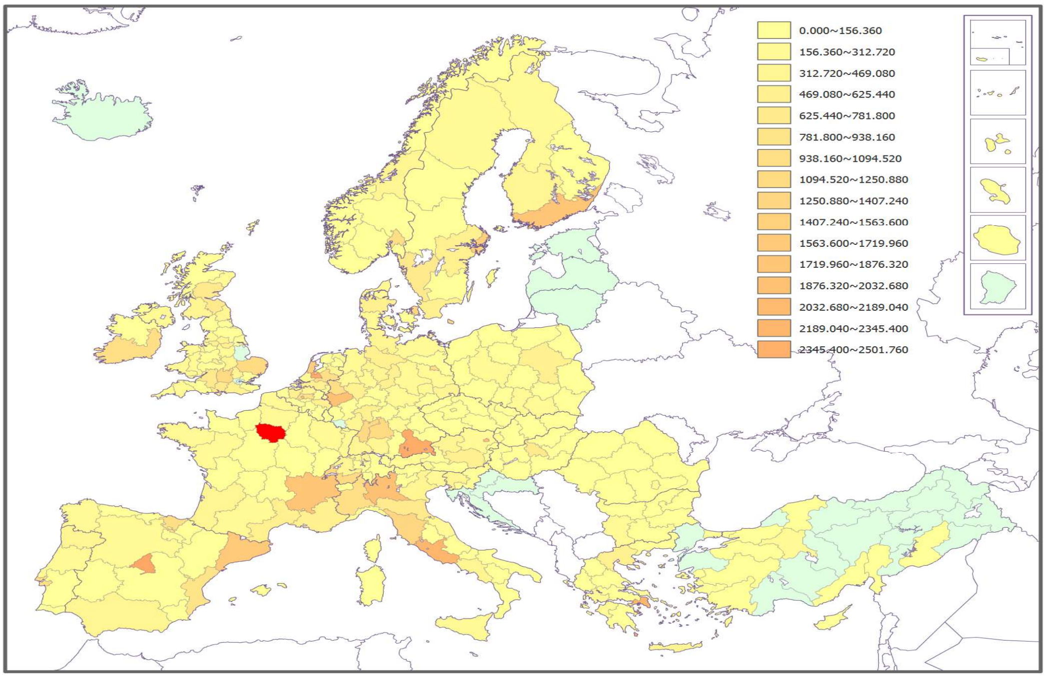

Figure 46 FP6 Network (Region)

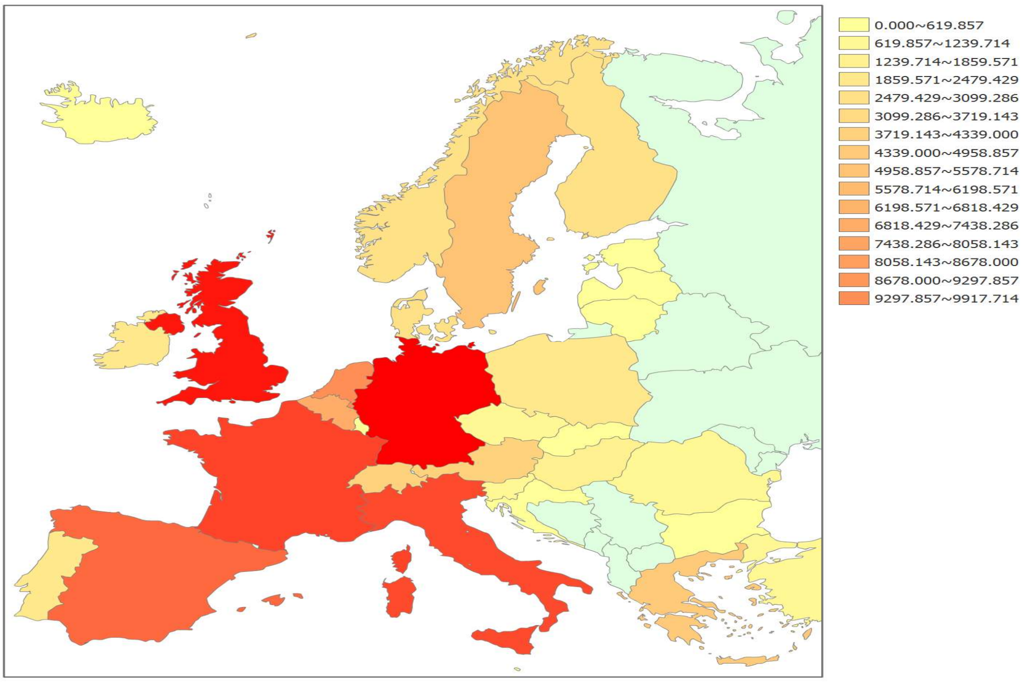

Figure 47 FP7 Network (Country)

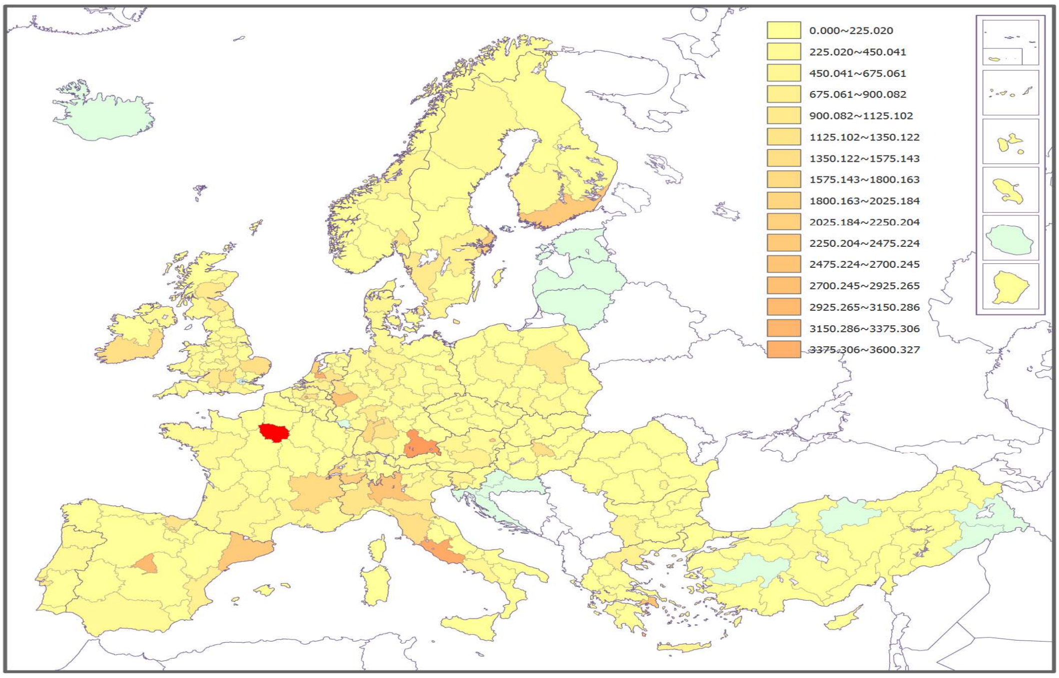

Figure 48 FP7 Network (Region)

APPENDIX C - CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Çetinkaya, Umut Yılmaz
Nationality: Turkish (TC)
Date and Place of Birth: 20 March 1978, Ankara
Marital Status: Single
Phone: +90 312 437 4303
Fax: +90 312 437 4308
email: uycetinkaya@gmail.com

EDUCATION

Degree	**Institution**	**Year of Graduation**
MS	METU, STPS	2005
MS	METU, PSPA	2004
BS	İstanbul University, Mechanical Engineering	1999
High School	Anıttepe High School, Ankara	1995

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2010- Present	YNR Consulting	Strategy Planning and Business Development Coordinator
2009-2010	TUBİTAK-ULAKBİM	Project personnel in SEERA-EI (South East European Research Area for e-Infrastructures).
2007-2009	Freelance Consultant	Consultant
2007-2008	METU-STPS	Project personnel in Networks, Industry Clusters and Innovation (KUSAI) Project: The Case of Machinery and Furniture Sectors in the Greater Region of Ankara
2002-2006	TBMM	MP Advisor
1999-2011	Özkoseoglu Ltd. Co.	Mechanical Engineer

FOREIGN LANGUAGES

English

PUBLICATIONS

1. “On the road toward EU integration in Turkey”, Entrepreneurship and SME policy Development in the BSEC Region in the Time of Emerging from the Economic Crises in the Black Sea Economic Cooperation Region, Konrad-Adenauer, Stiftung (ed.), Ankara: Konrad-Adenauer, 2012, 330-351

2.With Çetindamar Dilek "Greece: the oldest EU member country in BSEC", Strategies for the Development of Entrepreneurship and the SMS Sector in the Black Sea Economic Cooperation Region, Konrad-Adenauer, Stiftung (ed.), Ankara: Konrad-Adenauer, May 2008, 251-268

3. With Çetindamar Dilek, "Turkey: The EU candidate country", Strategies of the Development of Entrepreneurship and SME Sector in the Black Sea Economic Cooperation Region, Konrad-Adenauer, Stiftung (ed.), Ankara: Konrad-Adenauer, May 2008, 269-288.

4. Innovation Systems and Environmental Policies, STPS 2005

5. Analysis of Turkey’s National Innovation System, METU, 2005

APPENDIX D - TURKISH SUMMARY

Bu tez Avrupa Birliği'nin (AB) yenilikçiliğine odaklanmaktadır. Avrupa Birliği'nin yenilikçiliğinin değerlendirilmesi ve politika önerilerinin yapılabilmesi için farklı akademik alanlarda yapılan çalışmalar ve Avrupa Komisyonu'nun politika uygulamaları gözden geçirilmiş ve incelenmiştir. Bu tezin temel akademik çerçevesini oluşturan yaklaşımlardan bir tanesi literatürde kompleks sistem olarak kabul edilen Yenilik Sistemleri yaklaşımıdır (Lundvall, 1992 ve Katz, 2006). Yenilik Sistemleri'nin kompleks sistem olarak kabul edilmesi kaçınılmaz olarak Tez'de kompleks sistemlerin de araştırılması ve çalışılmasını gerekli kılmıştır. Kompleks sistemler değişik yaklaşımlarda ele alınmasına karşın; bu Tez'in amaçları doğrultusunda yapılan inceleme, Termodinamiğin İkinci Yasayı olarak da bilinen entropi yaklaşımını ve ağ yapı analizlerini bu Tez'de öne çıkarmıştır. Öne çıkan yaklaşımlara uygun olarak yapılan çalışmalar ışığında Topluluk Araştırma ve Geliştirme Bilgi Hizmeti'den (CORDIS) alınan verilerlerle Avrupa Araştırma ve Yenilik Ağ Yapı'sı isimli ağ yapı oluşturulmuş; Avrupa Komisyonu tarafından yayınlanan Yenilik Birliği Skor Tahtası (Innovation Union Scoreboard) ve Bölgesel Yenilik Skor Tahtası'ndan (Regional Innovation Scoreboard) faydalanarak ağ yapı ve yenilikçilik arasında ilişki kurulmuştur. Bu ilişkinin kurulması aynı zamanda Avrupa Araştırma Alanı'nın da Tez'de incelenmesini olanaklı kılmıştır. Tüm bu çalışmaların sonucu ise Avrupa'nın yenilikçiliğinin arttırılması için Tez'in son bölümünde yapılan politika önerilerinin girdisini oluşturmuştur.

Yukarıda yapılan açıklama çerçevesinde Tez'de öncelikli olarak kompleks sistemlerle ilgili literatür incelenmiştir. Kompleks sistem kavramının farklı akademik disiplinlerde kullanılıyor olması fizikten sosyolojiye veya matematikten biyolojiye kadar değişik alanlarda yapılan çalışmaların Tez'de incelenmesini gerekli kılmıştır. Diğer bir ifadeyle, Genel Sistem Teorisi, Sibernetik, Afet (Catastrophe) Teorisi, Sinerjetik, Autopoiesis, Self-Organized Critically, Entropi, Erke Tüketici Yapılar (Dissipative Structures), Ortaya Çıkış (Emergence) ve Kendi Kendine Organizasyon (Self-Organization), Ajan-Bazlı Modelleme (Agent Based Models), Ağ

Yapılar ve Kaos Teorisi kompleks sistemlerle ilgili kısımların tartışılması için incelenmiştir. Farklı akademik kaynaklardan ve çalışmalardan beslenen bu alanların incelenmesi sonucunda ise bu Tez'de bir sistemin kompleks olup olmadığını belirlemek için kullanılan bir metrik elde edilmiştir. Elde edilen metrik aşağıda verilmiştir:

1. Yeteri kadar oluşturan (düğüm) olması;
2. Oluşturanlar arasında zengin doğrusal olmayan ilişkilerin olması;
3. Oluşturanlar arasında yeteri kadar karşılıklı bağımlılık ilişkisi olması;
4. Oluşturanların arasında pozitif ve negatif geri beslemelerin olması;
5. Değişik seviyelerde ortaya çıkış (emergence) ve kendi kendine organizasyon (self organization) olması;
6. Dengeden uzak koşullarda (far from equilibrium conditions) sistemin varlığına devam ettirmesi;
7. Oluşturanların zengin iç farklılığının olması;
8. Evrim ve uyum gösterme yeteneğinin olması;
9. Dinamik karaktere sahip olması;
10. Oluşturanlar arasında işbirliği, rekabet ve çatışmanın olması;
11. Dağıtık hafıza ve öğrenme yeteneğinin olması;
12. Global malumatın (information) dışlanmadan yerel malumatın kullanılması;
13. Merkezi otoritenin olmaması; kaynakların, ilişkilerin ve geri beslemelerin dağıtık olması;
14. Yapının otonom olması bir sistemin kompleks olup olmadığına karar vermek belirlenen kriterler olmuştur.

Birinci Bölüm'ün ikinci Kısmı'nda ise ağ yapı analizleri ile ilgili temel çalışmalar ele alınmıştır. Özellikle bu alanda Rastgele (Random), Küçük Dünya (Small-World) ve Serbest Ölçekli Ağlar (Scale-Free) tipi ağ yapılarla ilgili çalışmalar incelenmiş; ağ yapının gürbüzlüğü (robustness) ile ilgili tartışmalar değerlendirilmiştir. Üçüncü kısımda ise Tez'inde en önemli teorik çerçevelerinden birini oluşturan Yenilik Sistemleri yaklaşımı ele alınmıştır. Bu kısımda yapılan tartışmalar Yenilik

Sistemleri'nin (Freeman, 1987; Lundvall, 1992; Edquist 1997; Cooke ve Memedovic, 2003, v.b.) ne olduğu üzerinde değil; daha çok Yenilik Sistemleri ve kompleks sistemler ilişkisi ile Yenilik Sistemleri ve ağ yapı arasında ilişkinin ortaya konması üzerine odaklanmıştır. Yenilik Sistemleri ve kompleks sistemler arasında ilişki kurulurken her iki literatürden faydalanışmış; her iki literatürün bazen aynı konseptlerle bazen de farklı konseptler aracılığıyla aynı kavramları anlattıkları gösterilmiştir. Her iki yaklaşımın benzerlikleri ise Tablo 1'de özetlenmiştir. Daha sona Tez'de Yenilik Sistemleri yaklaşımları ile ağ yapı analizleri arasındaki benzerliğe odaklanılmıştır. Özellikle her iki yaklaşım içerisinde malumatın (information) ve bilginin (knowledge) nasıl üretildiği, yayıldığı ve sönümlendiği (absorbe) üzerinde duran çalışmalar seçilmiş ve böylece her iki yaklaşımın da ortak paydaları otaya konabilmiştir.

Birinci Bölüm'ün 4. Kısmı ise önceki kısımlardan biraz daha farklı bir şekilde ele alınmıştır. Bu Kısım'da en temelde Avrupa'nın mevcut durumu ve geleceğe dönük yaklaşımları Çerçeve Programlar (Framework Programmes) ve Avrupa Araştırma Alanı (European Research Area) çerçevesinde ele alınmış ve ortaya konulmuştur. Bu bölümde Çerçeve Programları'nın (1., 2., 3., 4., 5., 6., 7. ve 8. Çerçeve Programları) kısa bir özeti ve değerlendirilmesi yapılmış; özellikle 2014'de başlayan 8. Çerçeve Programı'nın (Horizon 2020) amaçları ve öncelikleri ortaya konmuştur. Benzer şekilde Çerçeve Programları'nın ayrılmaz bir parçası olarak kabul edilen Avrupa Araştırma Alanı'nın da gelişimi ve bu Alan'ın Avrupa'nın rekabetçiliği ile ilişkisi yine bu Kısım içerisinde ele alınmıştır.

Yukarıda yapılan açıklamalar ve incelendiği belirtilen konular çerçevesinde; Prigogine and Stengers'inde (1984) belirttiği gibi kompleks sistemler yaklaşımının araştırma çalışmalarına değişik bir bakış açısı kazandırabileceği tespit edilmiştir. Başka bir ifadeyle, Strogatz'ın (2003) kinayeli bir şekilde belirttiği gibi 'C' harfi ile başlayan bir yaklaşım her 10 yılda bir popular olmaktadır: 1960'lı yıllarda Sibernetik (Cybernetics) yaklaşımı, 1970'li yıllarda Afet (Catastrophe) Teorisi yaklaşımı, 1980'li yıllarda Kaos Teorisi yaklaşımı ve 1990'lı yıllardan itibaren kompleks sistemler yaklaşımı. Bu bağlamda kompleks sistemler ile ilgili yapılan analitik çalışmalar kadar analitik olmayan çalışmaların da bu alanın gelişiminde kritik bir rol oynayacağı sonucuna Tez'de yapılan tartışmalar sonucunda varılmıştır. Bu noktadan hareketle, Tez içerisinde özellikle matematiksel modellerin kurulmasından; diğer bir ifadeyle geleceğe yönelik öngörülerin ve politika önerirlinin matematiksel denklemler aracılığıyla yapılmasından kaçınılmıştır. Bu sebepten dolayı Tez'de yapılan analizlerin ve politika önerilerinin en temel çerçevelerinden birini yukarıda belirtilen metrik oluşturmuştur. Diğer taraftan, Avrupa'nın yenilikçiği için yapılan tartışmaların teorik çerçevesini Yenilik Sistemleri yaklaşımı oluştururken; gerçek politika uygulamaları ve veriler ise Avrupa Komisyon'un çalışmalarından temin edilmiştir. Bunların nasıl elde edildiği, düzenlendiği ve uygulandığı ise Tez'in Üçüncü Bölüm'ünde açıklanmıştır.

Tez'in Üçüncü Bölümü'nde Tez'de kullanılan verilerin nasıl temin edildiği, temizlendiği ile Tez'de kullanılan yöntem açıklanmıştır. Tez'in kendi veritabanını oluşturulması için 3 tip veri kaynağı kullanılmıştır. Bunlardan birincisi Yenilik Birliği Skor Tahtası'dır (Innovation Union Scoreboard). Bu Tahta her sene Avrupa Komisyonu tarafından temin edilen bilgiler ışığında yenilenmektedir. Bu Skor Tahta'sı, 8 ana ve 25 ayrı alt alanda verilerden oluşmaktadır, aracılığıyla Avrupa'nın ve 34 Avrupa ülkenin yenilikçiliğini ve önemli rakiplerine göre durumu ortaya konmuştur. Bir diğer veri kaynağı ise Bölgesel Yenilik Skor Tahtası'dır (Regional Innovation Scoreboard). Bu Skor Tahtası ise bölgesel bazda yenilikçiliği ölçmek için kullanılmaktadır. En son yayınlanan Bölgesel Yenilik Skor Tahtası Skor Tahtası'nda Nuts-2 (Nomenclature of Territorial Units for Statistics; İstatistiki Bölge Birimleri Sınıflandırması) seviyesinde bölgelerin yenilikçiği hakkında veriler bulunmaktadır. Üçüncü veri kaynağı ise Topluluk Araştırma ve Geliştirme Bilgi Hizmeti'nden (Community Research and Development Information Service-CORDIS) alınan proje bilgileridir. Topluluk Araştırma ve Geliştirme Bilgi Hizmeti'nden alınan veriler iki aşamada bir araya getirilebilmiştir. Öncelikle olarak CORDIS'ın web sitesinde yer alan veriler veri madenciliği yapılarak alınmış; oldukça detaylı ve meşakkatli bir sürecin sonunda Tez'de kullanılabilecek bir hale getirilmiştir. Daha sonra Avrupa Komisyonu tarafından CORDIS web sitesinde yayınlanan projelere ilişkin sağlanan CD'deki bilgiler alınarak temizlenmiştir. En sonunda her iki taraftan elde edilen bilgiler birleştirilerek Komisyon tarafından desteklenen projelere ilişkin proje bilgileri nihai hale getirilmiştir.

Üçüncü Bölüm'üm İkinci Kısmı'nda ise Tez'de kullanılacak araçlar hakkında bilgi verilmiştir. Öncelikli olarak ağ yapı karakteristiklerini belirlemede kullanılan temel ölçümler açıklanmış (ortalama yol uzunluğu, ortalama kümelenme değeri, ortalama aradalık değeri v.s.) ve bu Tez'de kullanılan tüm bilgisayar programları hakkında bilgi verilmiştir. Takip eden kısımlarda ise Boltzman ve Prigogine'nin entropi yaklaşımlarının Tez'deki hesaplamalarda nasıl kullanılacağı açıklanmıştır.

Üçüncü Bölüm'ün son Kısmı ise Tez'in metodolojisinin (yöntemin) açıklandığı bölümdür. Diğer bir ifadeyle bu Kısım'da veri ve hesaplamaların nasıl kullanılacağı, bunlardan elde edilen sonuçların Tez'in son Bölüm'ünde politika önerileri için nasıl girdi oluşturacağı açıklanmıştır. Tez'de öncelikli olarak yukarıda açıklandığı şekliyle CORDIS verilerinden faydalanarak ağ yapıyı oluşturacak aktörler (düğümler) belirlenmiştir. Devamında aynı düğümler kullanılarak 3 ölçekte (scale) ağ yapı ortaya çıkarılmıştır. Bu aktörler arasında yapılan projeler ise düğümler arasındaki bağları (link) oluşturmaktadır. Bu ağ yapılar 'açık ağ yapı', 'kapalı ağ yapı' ve 'bölgesel ağ yapı' olarak adlandırılmıştır. 'Açık ağ yapı' ile kast edilen Çerçeve Programları'na girmiş dünyadaki tüm ülkelerin yer aldığı ağ yapıdır. 'Kapalı ağ yapı' ile kast edilen ise sadece Yenilik Birliği Skor Tahtası'nda verileri bulunan ülkelerden oluşmuş ağ yapıdır. 'Bölgesel ağ yapı' ise Bölgesel Yenilik Skor Tahtası'nda verileri bulunan bölgelerdir. Sonuç olarak Üçüncü Bölüm'de hem verinin nasıl temin edildiği hem de verinin nasıl işleneceği adım adım açıklanmış böylece Tez'in en önemli bölümlerinden olan Bölüm 4'de yapılacak hesaplamalar için analitik altyapı elde edilmiştir.

Bölüm 4'de; Bölüm 2'de yapılan teorik tartışmalar ve Bölüm 3'de açıklanan metodolojinin birleştirilmesi ile analitik analizler yapılmıştır. Öncelikli olarak Bölüm 2'nin sonunda elde edilen metrikten faydalanarak bu Tez'de yaratılan Avrupa Araştırma ve Yenilik Ağ Yapı'sının kompleks olup olmadığına bakılmıştır. Bu değerlendirmenin yapılması için yukarıda belirtilen metrikte bulunan başlıklar gruplandırılarak 9 adet ana başlık elde edilmiştir. Yapılan değerlendirme sonucunda bir başlık haricinde Avrupa Araştırma ve Yenilik Ağ Yapı'nın kompleksti kriterlerine uygun olduğu tespit edilmiştir. Diğer bir ifadeyle, Avrupa Araştırma ve Yenilik Ağ Yapı'sının 'merkezi otoritenin olmaması; kaynakların, ilişkilerin ve geri beslemelerin dağıtık olması' kriterlerini kısmen karşıladığı tespit edilmiştir. Yapı'nın bir taraftan 'kaynakların, ilişkilerin ve geri beslemelerin dağıtık olması' kriterinin karşılandığı görülmektedir (Komisyon'un kaynaklarının üyelerden sağlanması; projelerin büyük bir çoğunlukla yine bu üyelerde yer alan firma, kamu kuruluşu, üniversite, araştırma kuruluşları, v.s. tarafından yapılması; bunlar arasında pozitif ve negatif geri beslemelerin olması). Diğer taraftan merkezi otoritenin olmaması kriterinin ise Brüksel'in baskın rolü olması sebebiyle tam olarak karşılanamadığı tespit edilmiştir. Merkezi rolün ağırlığının yaratabileceği durumlar ise ağ yapı ile ilişkilendirilerek 3 farklı senaryo ortaya konmuştur. Bunlardan birincisi ağ yapıdaki aktörlerin karşılıklı ilişkilerinin artmasının uzun vadede kaynakların verimli ve tekrardan kaçınarak kullanılması gibi sebeplerden dolayı merkezileştirilmiş bir yapı doğurabileceğidir. Böyle bir durumda merkezi otoriterin gücünün artması beklenen bir durum olacaktır. İkinci senaryo ise ağ yapıyı oluşturanların sahip oldukları kültürel, sosyal, ekonomik, v.s. farklılıkların ayrıştırıcı bir etki yapacağı üzere kuruludur. Böyle bir yapı sadece Brüksel'i ve ilgili kurumlarının gücünü azaltmayacak aynı zamanda değişik seviyelerdeki otoritelerin (küresel, ulusal, bölgesel, sektörel) yıpratıcı bir rekabete girmesine; zengin-fakir uçurumunun daha da artmasına ve belli bölgelerin öne çıkmasına yol açabilecektir. Üçüncü senaryo ise ara (mezo) senaryodur. Bu durumda ağ yapının değişik seviyelerdeki otoriteler (küresel, ulusal, bölgesel, sektörel) arasında hem rekabeti hem de işbirliğini destekleyeceği varsayılmıştır. Diğer bir ifadeyle, ne birinci durumda olduğu gibi merkezi yapı aşırı baskın olacak ne de ikinci alternatifte olduğu gibi yerel aktörler aşırı baskın olacaktır. Bu Tez'de geliştirilen argümanlar dikkate alındığı zaman mezo seviyenin en iyi alternatif olduğu gözükmektedir. Bununlar ilgili hesaplamalar ve tartışmalar ise aşağıda açıklanmıştır.

Yukarıda açıklandığı üzere Tez'de 3 tip ağ yapı (açık, kapalı ve bölgesel) oluşturulmuştur. Bunların ağ yapı karakteristiklerine göre incelemeleri yapılmıştır. Bunlar yapılmadan önce Topluluk Araştırma ve Geliştirme Bilgi Hizmeti'nden (CORDIS) destek alarak yapılmış projeleri inceleyen çalışmalara bakılmış ve bu incelemeden de faydalanılarak ağ yapı analizinin çerçevesi oluşturulmuştur. Bu çalışmaların incelenmesi sonucunda iki önemli konuda literatürde yanlış sonuçlar doğurabilecek çalışmalar yapıldığı tespit edilmiştir. Bunlardan birincisi ağ yapının yapısı ile projelerin gerçekleştiği sektör arasında ilişki kurulmasıdır. Genel olarak süre geçtikçe bilginin kodlanabilir (codification of knowledge) hale geleceği zımni bilginin (tacit knowledge) azalacağı ve böylelikle ağ yapının yapısal karakteristiklerinin değişeceği varsayılmaktadır. Örneğin Avrupa Komisyonu'ndan destek alarak BİT alanında gerçekleştirilen projeler ile kurulmuş bir ağ yapının 15 yıl önce daha sıkı bağlı olduğu; fakat artık BİT alanında başlangıç dönemine göre göreceli olarak büyük bilinmezlerin azalma göstermesi sebebiyle ağ yapının yapısının daha gevşek bağlarla bağlı hale geleceği varsayılmaktadır. Fakat bu tip bir yaklaşımda gözden kaçırılan temel bir nokta vardır. O da 15 yıl önce yapılan projelere de Avrupa Komisyonu tarafından Ar-Ge (Araştırma-Geliştirme) faaliyetlerini yerine getirilmesi için fon sağlandığıdır. 15 yıl önce var olan bilgi ve imkanlar kullanılarak yapılan proje de o zamanın şartlarında zımni bilgi içermektedir. Bugün yine BİT alanında Avrupa Komisyonu tarafından Ar-Ge faaliyeti gerçekleştirilmesi için verilen destekle gerçekleştirilmiş projelerin oluşturacağı ağ yapı; bugün için bilinmezlikler ve eksikler sebebiyle zımni bilgiyi içerisinde barındırmaktadır. Dolayısıyla yukarıda belirtildiği gibi sektör ve ağ yapı arasında kurulacak ilişkiler yanıltıcı sonuçlar verebilecektir.

İkinci tespit ise ağ yapıda yer alan aktörler arasında olan ilişkilerin güçlü ve zayıf olması ile ağ yapının yapısının keşif (exploration) ve faydalanma (exploitation) için daha etkin olabileceği arasında kurulan ilişkilerdir. Örneğin Rowley (2000) düşük yoğunluklu ve zayıf bağlardan oluşan bir ağın keşif için daha uygun olduğunu tartışırken Hagedoorn and Duysters (2002) tam tersi bir argümanı savunmakta; Nooteboom and Gilsing (2004) iki görüş arasında bir yerdeki yapının daha uyun olacağını savunmaktadır. Örneklerden de görüleceği üzerine literatürde üzerinde uzlaşılan bir görüş bulunmamakta ve her bir incelemede incelenen ağ yapının yapısal karakteristikleri içinde bulunduğu şartlara göre şekillenmektedir (Kogut, 2000). Sonuç olarak bu Tez'de ağ yapı tipi ve ağ yapıdaki bağların gücü ile ağ yapının keşif ve faydalanma için uygun olup olmadığı arasında bir ilişki kurulmasından imtina edilmiştir.

Bölüm 3'ün 2. Kısmın'da öncelikle olarak projelere katılanların sayısı, projelerin süresi, projelerin bütçesi ve hibe miktarı arasındaki ilişkiye bakılmıştır. Tablo 7'den de görüleceği üzere bu değişkenler arasında güçlü bir korelasyon ilişkisi mevcuttur. Değişkenler arasında en büyük korelasyon değerine sahip olanın proje katılımcılarının sayısının olduğu tespit edilmiştir. Bu tespit aynı zamanda Avrupa Komisyonu'nun bürokratik süreçlerin azaltılması yönünde kendisi için uygun gördüğü yaklaşımla da örtüşmektedir. Bu genel incelemenin ardından bölgesel ve açık ağ yapıları incelenmiştir. Kapalı ağ yapısının bu aşamada incelenmemesinin sebebi ise düğüm sayısının (34 adet) azlığı sebebiyle sağlıklı sonuçların alınamayacak oluşudur. Tablo 8'de bölgesel ve Tablo 9'da açık ağ yapıların FP1'den FP7'ye kadar olan ağ yapı karakteristikleri sonuçları gösterilmiştir. Değişik seviyelerde kurulmuş olmasına karşın her iki tablonun da benzer sonuçlar elde edilmiştir. Her iki seviyede de serbest ölçekli ağ yapıya uygun (scale-free) dağılım, göreceli olarak kısa yol uzunluğu, yüksek kümelenme, düşük benzer seçim (assortativity) gibi özellikler tespit edilmiştir. Bu durum sadece yukarıda açıklanan metrik bakımından sistemin kompleksti ölçütlerine uygunluğu açısından fikir sahibi olunmasını sağlamamış aynı zamanda Çerçeve Programlar'ın değişen kuralları ve şartlarına rağmen kurumsal altyapının (kurallar, alışkanlıklar, davranış biçimleri, v.s.) ağ yapı oluşturma üzerine etkisinin de görülebilmesine olanak sağlamıştır. Bunların yanı sıra Küçük Dünya özelliğinin gösterilmesi (Cowan, 2006) bilginin üretilmesi ve dağıtılması açısından ağ yapının yapısının uygun olduğunu da göstermektedir. Diğer taraftan ağ yapı katılımcılarının birinci Çerçeve Program'dan Yedinci Çerçeve Program'a kadar incelenmesi sonucunda belli aktörlerin sürekli olarak katılım göstererek Avrupa Araştırma ve Yenilik Ağ Yapı'sının iskeletini meydana getirdiği tespit edilmiştir.

Avrupa'nın yenilikçiliğinin ağ yapı ve yenilikçilik arasındaki ilişki üzerinden incelenmesi ise Dördüncü Bölüm'ün Üçüncü Kısmı'nda yapılmıştır. Tablo 10 ve 11'den de görüleceği üzere ülkelerin (2006-2012 yılları arası) ve bölgelerin (Nuts-2) yenilikçilik değeri ile yapmış oldukları projeler arasında ilişkiye bakılmıştır. Temel varsayım Avrupa Araştırma ve Yenilik Ağ Yapı'sına katılım ile yenilikçilik değerleri arasında anlamlı bir ilişkinin bulunacağıdır. Diğer bir ifadeyle Avrupa Araştırma ve Yenilik Ağ Yapı'sının düğümleri ülke ve/veya bölgelerden oluşturulduğu için ülke ve/veya bölgelerin yenilik değeri ile proje sayıları arasında anlamlı bir ilişki olup olmadığına bakılmıştır. Tablo'lardan da görüleceği üzere hem ülke bazında hem de bölge bazında anlamlı ilişki bulunmuş ve ortalamada %50'lere yakın bir korelasyon katsayısı tespit edilmiştir. Coleman'ın (1988) güçlü bağlar veya Granovetter (1973) gömülülük (embeddedness) tartışmalarında hareketle kümelenme ile yenilikçilik arasında ilişki araştırılmıştır. Elde edilen sonuçlar Tablo 12'de gösterilmiştir. Her 3 tip ağ yapıda da (açık, kapalı ve bölgesel), yenilikçilik değeri ile kümelenme katsayısı arasında negatif ilişki tespit edilmiştir. Hatta kapalı ve bölgesel ağ yapılarda elde edilen değerler 2006 senesinden günümüze artarken; açık ağ yapıda bu değerin düştüğü tespit edilmiştir. Diğer bir ifadeyle elde edilen sonuçlar Avrupa'nın dışarı ile entegrasyonunun önemi konusunda bir araştırma yapılmasını tetiklemiştir. Bu araştırmanın yapılabilmesi için Yenilik Birliği Skor Tahtası'nda (Innovation Union Scoreboard) Avrupa'nın önemli rakipleri olarak belirtilen Brezilya, Kanada, Çin, Hindistan, Japonya, Güney Kore, Rusya, Amerika Birleşik Devletleri, Güney Afrika ile Avrupa'nın yenilikçilik değeri arasında ilişkiye bakılmıştır anlamlı sonuçlar elde edilmiştir (örneğin 2012 yılında p değeri 0,008471'dir). Kümelenme ile ilgili sonuçların negatif çıkması; diğer taraftan önemli rakiplerle yapılan işbirliklerinin korelasyon değerinin pozitif çıkması sadece neden Avrupa'nın dünya ile daha fazla işbirliği yapmasının gerekli olduğunu göstermemiş aynı zamanda önemli rakiplerle daha fazla işbirliği yapan ülkelerin (Tablo 14) Avrupa'nın yenilikçiliği açısından taşıdığı kritik önemi de göstermiştir.

Yukarıda da belirtilen Avrupa Komisyonu'nun bürokratik prosedürleri azaltmak için çok ortaklı proje başvurularını destekler yapısı yine Bölüm 4'ün 3. Kısmı'nda incelenmiştir. Literatüre göre düğümlerin linklerinin artması sadece düğümlerin diğer düğümlerle ilişki kurmasını kolaylaştırmamakta bazen de daha fazla iş yükü veya verim kaybına yol açarak süreci zorlaştırabilmektedir (Choi v.d., 2001; Rycroft, 2007). Bu sebepten dolayı öncelikle yenilikçilik değeri ve ortalama bağ sayısı arasındaki ilişkiye bakılmış ve bağ sayısı arttıkça yenilikçilik değerinin de arttığı tespit edilmiştir. Bağ sayısındaki artışın projedeki farklı ortak (başka ülke ve bölge) sayısı ile ilişkisine bakılmış (Tablo 17) ve projedeki ortakların farklılığını yeniliğe olumlu katkı yaptığı tespit edilmiştir.

2000'li yılların başından itibaren daha fazla gündeme gelen ve Avrupa'nın yenilikçiliği ve rekabetçiliğinde kritik bir öneme haiz olmaya başlayan Avrupa Araştırma Alanı, yine bu Tez'de oluşturulan Araştırma ve Yenilik Ağ Yapı'sı ile incelenmiştir. En temelde bilginin, araştırmacının ve teknolojinin serbest dolaşımın sağlamayı amaçlayan Avrupa Araştırma Alan'ın ne kadar hedeflerine ulaştığı incelenmiştir. Bu incelemenin yapılması için ağ yapıya giren düğümlerin (ülke ya da bölge) projelerde (bağlar) ortak seçerken coğrafik uzaklığı dikkate almadığı varsayımı yapılmıştır. Bu varsayım çok güçlü bir varsayım olsa da yine de anlamlı sonuçlara erişilmesine olanak sağlayacak bir varsayım olduğu için kullanılmıştır. Ülke seviyesin Tablo 18 ve Şekil 13; bölge seviyesinin de Tablo 31 ve Şekil 14'den görüleceği üzere iki adet sonuca ulaşılmıştır.

- Gerek bölgeler gerekse de ülkeler proje ortağı seçiminde ortağın coğrafi olarak yakın olması önemsemektedirler.

- Ülke ve bölge seviyesinde Çerçeve Programlar'a katılım ile oluşan ağ yapı karakteristiklerinin gösterildiği tablolarda da gösterildiği üzere (Tablo 7 ve Tablo 8), ağ yapılar ölçek bağımsız (scale-free) bir yapı göstermektedir. Diğer bir ifadeyle, ağ yapıya katılacak olan düğümler (ülke ve/veya bölge) öncelikli olarak popüler olan veya daha fazla bağı (link) olan düğümlere bağlanarak ağ yapıya katılmaktadırlar. Bu durum ise "zengin daha zengin olur" yaklaşımını ortaya çıkarmakta; başka bir ifadeyle ülkeler ve/veya bölgeler arasındaki uçurumun artmasına yol açmaktadır.

Bir diğer sonuç ise gerek bölgeler gerekse de ülkeler mümkün olması halinde sınır ötesi yerine sınır içi ortaklarla işbirliği yapmayı tercih etmektedir. Tablo 19'da gösterildiği gibi Birinci Çerçeve Programı'ndan Yedinci Çerçeve Programı'na kadar ağ yapılarda kendi kendine döngü (self-loop) sayısı 15,38 kat artarken düğüm sayısında artış ancak 0,7 kat olmaktadır. Her iki oran arasında büyük fark ise gerek bölgeler gerekse de ülkelerin mümkün olması halinde sınır ötesi yerine sınır içi ortaklarla işbirliği yapmayı tercih ettiğini ortaya koymaktadır. Diğer bir ifadeyle, sonuçlar kurumsal altyapının (kurallar, alışkanlıklar, davranış biçimleri, v.s.) ağ yapı oluşturma üzerine etkisini ortaya koymuştur.

Bölüm 4'de yapılan bir diğer tartışma ise Bölüm 2'de kavramsal çerçevesi verilen ve Bölüm 3'de açıklanan Boltzman ve Prigogine'nin entropi yaklaşımlarıdır. Boltzman'ın yaklaşımına göre en basit haliyle, entropi makro durumları gerekleştiren mikro durumların ölçümüdür. Başka bir ifadeyle, entropi değerinin sıfır olması sadece bir adet mikro durumun makro durumu gerçekleştiğini göstermektedir (herhangi bir belirsizlik olmadığını göstermektedir). Diğer taraftan entropi değerinin yüksek olması, birçok mikro durumun makro durumu gerçekleştiğini (öngörülebilirliğin düşük olduğunu) göstermektedir. Yenilik Sistemleri açısından bakıldığında ise birçok mikro durumun (yüksek entropi) var olması her bir aktörün yenilik yapabilme yetkinliğinin olduğunu göstermektedir. Tablo 4'de görüldüğü üzere en yüksek entropi değerinin elde edilmesi olası olayların ihtimalinin eşit olarak dağılması gerekmektedir. En düşük değer ise (yani yenilik için fırsatın en az olduğu durum) olasılığın tek bir tarafta toplanması ile elde edilmektedir. Tablo 33, Tablo 34, Tablo 35, Tablo 36 ve Tablo 37'de gösterildiği üzere ülkelerin yenilikçilik ve ilintili değerleri yıllar arasında genel olarak artmakta ama büyük zıplayışlar olmamaktadır. Diğer bir ifadeyle yenilikçilik değeri göreceli olarak sabit kalmaktadır. Boltzman'ın yaklaşımı açısından bakıldığında ülkelerin yenilik değerleri her ülkenin kendi yetkinliklerine göre dağılmış durumda olduğu; yukarıda açıklanan ekstrem entropi değerlerinden uzak olduğu görülmektedir.

Literatürde de tartışıldığı (Schilling ve Phelps, 2007; Kogut 2000) üzere düğümün ağ yapı üzerinde bulunduğu yer o düğümün etkinliğini etkilemektedir. Bu noktadan hareketle, Avrupa'nın yenilikçilik değerlerinin bu Tez'de üç ölçekte oluşturulan (açık ağ yapı, kapalı ağ yapı ve bölgesel ağ yapı) ağ yapı ile ilişkisine bakılmıştır (Tablo 20). Tablo 20'ye göre yenilikçilik değeri en fazla bağ sayısı (degree value) ve özvektör değeri (eigenvector value) ile ilintilidir. Yukarıda yapılan açıklamaya benzer şekilde, düğümlerin (ülke ve/veya bölge) bağ sayısında büyük zıplamaların olması mümkün değildir (her bir düğümün sahip olduğu yetkinlikler ve bilgi sebebiyle kurabileceği/taşıyabileceği bağ sayısı sınırlıdır). Diğer bir ifadeyle düğümlerin sahip olduğu bağ sayısının bir anda artması mümkün değildir. Bu durumda düğümlerin (bölge ya da ülke) özvektör değeri üzerinden yapılacak uygulamalar en uygun alternatif olarak ortaya çıkmaktadır.

Bu alternatifin uygunluğunun değerlendirilmesi için özvektör değeri ele alınmış; averaj özvektör değerinin ağ yapıların güç kanunu değeri (power law) ile ilişkisine bakılmış ve korelasyon katsayısı 0,7888 bulunmuştur. Bir başka deyişle güç kanunun azalması (diğer bir ifadeyle bağların daha demokratik dağılması) averaj özvektör değerinin düşmesine yol açacaktır. Diğer taraftan yenilikçilik ve güç kanun değeri arasındaki ilişkiye bakıldığı zaman ise korelasyon katsayısının -0,5247 olduğu tespit edilmiştir. Sonuç olarak averaj özvektör değeri düşmesi halinde ağ yapının güç kanunu değeri de düşecektir. Ağ yapının güç kanunu değerindeki düşüş ise yenilikçilik değerinin artmasını sağlayacaktır.

Tez'de entropi ile ilgili yapılan bir diğer çalışma Prigogine and Stengers'in (1984) çalışmasına dayanmaktadır. Prigogine and Stengers'inde (1984) de belirtildiği gibi kapalı sistemlerde entropi değerindeki artış sebebiyle entropik ölüm kaçınılmazdır. Sistem dışarıyla ilişki kurarak entropi değerini düzenlemekte ve böylece 'dengeden uzak koşullarda' (far from equilibrium conditions) varlığına devam ettirebilmektedir. Avrupa Araştırma ve Yenilik Ağ Yapı'sı incelendiğinde, ülkelerin dışarıyla ilişki kurmakta problem yaşamadığı görülmektedir (Tablo 14). Diğer taraftan Yenilik Birliği Skor Tahtası'nda (Innovation Union Scoreboard) Avrupa'nın önemli rakipleri olarak belirtilen Brezilya, Kanada, Çin, Hindistan, Japonya, Güney Kore, Rusya, Amerika Birleşik Devletleri, Güney Afrika ile Avrupa'nın yenilikçilik değeri arasında ilişkiye detaylı bir şekilde bakıldığında; Brezilya, Kanada, Çin ve Rusya ile Avrupa arasında pozitif ilişki olduğu Amerika Birleşik Devletleri, Güney Kore ve Japonya ile negatif ilişki olduğu saptanmıştır. Elde edilen sonuçlar Yenilik Birliği Skor Tahtası 2013'de Avrupa'nın önemli rakiplerine göre durumunu ortaya koyan açıklama ile birebir örtüşmektedir.

8. Çerçeve Programı (Horizon 2020) ile ilgili okumalar özellikle yeni aktörlerin çerçeve Program'a katılımının teşvik edeceğini belirtmektedir. Esasında benzer söylemler daha önceki Çerçeve Programları'nda da yer almaktadır. Diğer taraftan Tablo 8 ve Tablo 9 verilen değerler göstermektedir ki her bir düğümün (ülke ve/veya bölge) sahip olduğu bağ (link) sayısı sahip olduğu bilgi birikimi, yetkinlikler ve kaynaklarla sınırlıdır. Tablo'lar da Çerçeve Program 1'den Çerçeve Program 7'ye kadar hesaplanan değerlere göre düğümlerin tekil (unique) bağ sayısında ki artış, tekrarlanan (duplicate) bağlardan çok daha yavaştır. Diğer bir ifadeyle yüksek bir ihtimalle daha önceki Çerçeve Programlar'da işbirliği yapan aktörler (düğümler) yine yüksek oranda kendi içlerinde işbirliği yapmaya devam edeceklerdir. Bu durum hem olumlu hem de olumsuz olarak değerlendirilebilecek bir özelliğe sahiptir. Olumlu yandan yaklaşıldığı zaman, yukarıda da belirtildiği üzere, Avrupa Araştırma ve Yenilik Ağ Yapı'sının iskeleti artık oluşturulmuştur. Bu aktörler arasında karşılıklı oluşan güven ve anlayış; bilginin çok daha çabuk paylaşılmasını ve/veya üretilmesini sağlayabilecektir. Olumsuz taraftan

bakıldığında aynı aktörler (düğümler) değişik projeler aracılığıyla Komisyon'dan destek almakta ve hala Avrupa yenilikçilik değerlendirmesi açısından Amerika Birleşik Devletleri, Güney Kore ve Japonya'nın arkasında kalmamakta; Ağ'da yeni bilginin, malumatın v.s. kabul edilmesi ve uygulanması zorlaşmakta (mevcut yapı içerisindeki oligarşik durum sebebiyle); sistemin kilitlemeye (lock-in) girme ihtimali de artmaktadır (entropi tartışmasında belirtildiği gibi sistemler dışarıdan yeni bilgi, malumat v.s. almasa entropik ölüm kaçınılmazdır).

Yukarıda tartışılan önemli bir konu, ikinci Bölüm'de belirtilen metriğin bir maddesi (merkezi otoritenin baskınlığı) sebebiyle sistemin 3 farklı alternatif arasında seçim yapmasının gerekliliğiydi. Halihazırda Komisyon'un uygulamaları ve yaklaşımı dikkate alındığı zaman Komisyon'un kaynakların verimli ve tekrardan kaçınarak kullanılması gibi sebeplerden dolayı merkezileştirilmiş bir yapıya doğru yöneldiği görülmektedir. Böyle bir durumda merkezi otoriterin gücünün artması beklenen bir durum olacaktır. Bu Tez'deki yaklaşım ise orta (mezo) seviye bir uygulamanın Avrupa'nın yenilikçiliğini arttırmak için daha uygun olacağını vurgulamaktadır. Bu bağlamda merkezi otoritenin yetkisinin kısmen de olsa dağıtılması gerektiği bu Tez kapsamında yapılan tartışmalarda tespit edilmiştir. Elbette otoritenin dağılımı sadece merkezin istekliliği ve kararıyla değil aynı zamanda dağıtık yapının aktörlerinin istekliliği ve yetkinliği ile ilintili olacaktır. Bu çerçevede politika önerisi olarak Avrupa Araştırma Alanı'nın hedeflerine ulaşmasının kritik bir öneme haiz olduğu tespit edilmiştir. Alan'ın tamamlanması ile beraber ulusal ve bölgesel aktörler tarafından uygulanacak politika ve programlarda kaçınılmaz olarak eş güdüm ve uyum ortaya çıkacaktır. Bu uyum ve eş güdüm; merkezileşmiş bir yapı yerine dağıtık bir yapının hayata geçmesini mümkün kılacaktır.

Yapılan inceleme sonucunda ise Avrupa Araştırma Alanı'nın bir açıdan olumlu doğrulta ilerlediği diğer açıdan ise olumsuz doğruluda ilerlediği tespit edilmiştir. Başka bir ifadeyle, Avrupa Araştırma Alanı ile yaratılmak istenen fayda açısında dağılımın eşit olmadığı saptanmıştır. Mevcut uygulamalar ışığında değerlendirildiğinde bir anlamda Avrupa Araştırma Alanı'nın başarılı olan düğümleri (nodes) desteklediği sonucuna varmak mümkündür. Diğer taraftan Avrupa Komisyonu'nu kendi için belirlediği hedefler dikkate alındığında bir taraftan Avrupa Birliği'nin mevcut rekabetçilik seviyesini koruyacak ve/veya daha da geliştirecek; diğer taraftan göreceli olarak daha az rekabetçiliğe sahip düğümlerin rekabetçiliğin arttırarak Avrupa'da bilginin, araştırmacının ve teknolojinin serbest dolaşımın sağlayacak uygulamaların hayata geçirilmesi gerekmektedir.

Yukarıda yapılan tartışmalarda yenilikçiliğin en fazla düğümlerin sahip olduğu bağ sayısı ile ilintili olduğu tespit edilmişti. Burada düğümlerin sahip olduğu bağların kendi sahip oldukları bilgi, kapasite ve yetkinlikle sınırlı olduğu bu yüzden de kısa zamana değişmesinin mümkün olmadığı vurgulanmıştır. Örneğin bugün Almanya'nın sahip olduğu yetkinliklerin, bilginin, kapasitenin Bulgaristan'da olmaması sebebiyle; Bulgaristan'ın kısa zamanda Avrupa Araştırma ve Yenilik Ağ Yapı'sı içerinde Almanya kadar bağa sahip olması mümkün değildir.

Tez'de de belirtildiği üzere kompleks sistemlerin varlıklarını sürdürmek için kendi iç çeşitliğini dış çeşitlilikten daha fazla seviyede tutmaları gerekmektedir. Bu yaklaşım toplamda sistemin performansının düşmesine yol açabilmesine karşın sistemin hayatta kalmasını ve devam etmesini sağlamaktadır. Aksi halde, sistemin iç çeşitliğinin dış çeşitlilikten az olması halinde, sistem dışarıdan gelen etkiye ya da değişikliğe karşı bir cevap geliştiremeyecek; etkinin büyüklüğü ve yapısına göre ise sistemin hayatta kalması zorlaşacaktır.

Elbette yukarıda belirtilen ideal durumun gerçek hayatta uygulaması söylendiği kadar kolay değildir. Diğer bir ihtimalle sistemin yıkılması, bozulmazı oldukça büyük sorunlar yaratacaktır. Böyle istenmeyen bir durumun ortaya çıkması ya da asgari seviyede çıkması için bu Tez'de iki adet politika uygulaması önerilmiştir:

1. Avrupa Araştırma Alanı'nın ve aynı zamanda Avrupa Birliğinin rekabetçiliğinin arttırılması için önerilen ilk politika Tez'de geliştirilen özvektör değerinin (eigenvector value) kullanılmasına dayanmaktadır. Tablo 20'de de gösterildiği üzere yenilikçilik değeri özvektör değeri ile ilintilidir. Bunun yanı sıra Avrupa Komisyon'u bu tezde yapılan çalışma için yaratılan Avrupa Araştırma ve Yenilik Ağ Yapı'sının verilerine güncel bir şekilde erişebilmektedir. Komisyon tarafından proje başvuruları alımında uygulanacak küçük bir kural Avrupa'nın yenilikçiliğinin ağ yapıdan daha fazla faydalanarak arttırmasını sağlayacaktır. Uygulanacak basit kurala göre proje başvurularında proje konsorsiyumuna özvektör değeri düşük olan bir düğümün (bölge ve/veya ülke) eklenmesi istenecektir. Diğer bir ifadeyle, Komisyon proje konsorsiyumunun kimler tarafından kurulacağı noktasında mevcut uygulamalarını devam ettirirken; konsorsiyum başvurusu esnasında konsorsiyumda özvektör değeri düşük olan bir düğümün olup olmadığına bakacaktır. Böylelikle bir taraftan konsorsiyum istekliler tarafından büyük bir oranda serbestçe kurulabilecek; diğer taraftan konsorsiyuma giren düğüm aracılığıyla bilginin, yeteneklerin, yetkinliklerin göreceli olarak çok gelişmiş düğümlerden az gelişmiş düğümlere doğru akması sağlanabilecektir. Zaman içerisinde bu süreç sadece az gelişmiş düğümleri rekabetçiliklerinin arttırılmasına katkı sağlamayacak aynı zamanda burada biriken bilgi ve yetkinlikler Avrupa Araştırma Alanı'nın tamamlanmasına da katkı sağlayacaktır.

2. Elbette görece olarak az gelişmiş düğümlerin gelişmesi Avrupa Birliği'nin rekabetçiliğin arttıracak ve Avrupa Araştırma Alanı'nın tamamlanmasına katkı sağlayacaktır. Diğer taraftan, entropi tartışmalarında da belirtildiği üzere sistemin dışarıdan malumat, bilgi, v.s alarak entropi değerini 'dengeden uzak koşullarda' sürdürmesi gerekmektedir. Tez'de açıklandığı üzere, bu Tez'de oluşturulan Araştırma ve Yenilik Ağ Yapı'sına göre Avrupa'nın dışarıyla bağlantı kurmasında en etkin rol oynayan düğümler (geçit denetçisi; gatekeeper) Almanya, Fransa, İtalya ve İngiltere'dir. Bu çerçevede bu ülkeler bir taraftan dışarıyla ilişkilerin oluşturulması ve sürdürülmesini sağlarken; diğer taraftan sistemin de yeni bilgiyle beslenmesini sağlamaktadırlar. Yukarıda belirtildiği üzere kompleks sistemlerin çeşitliğinin korunması sistemin sürdürülebilirliği için kritik bir önem haizdir. Özellikle de dışarıyla göreceli olarak daha fazla ilişki kuran aktörlerin dışarıdan gelen bilgiyi anlayabilmesi ve sistemin içerisiyle paylaşabilmesi gerekmektedir. Bu sebepten dolayı özellikle geçit denetçisi konumunda bulunan ülkelerin içsel çeşitliğini ve soğurma (absorbe) kapasitelerinin arttırıcı uygulamaların özellikle desteklenmesi gerekmektedir.

Yukarıda belirtilen politika önerilerinin hayata geçirilmesi için kullanılması tavsiye edilen politika araçları yine tezin son bölümünde belirtilmiştir. Borrás and Edquist'in (2013) çalışmasında belirtilen kategorizasyondan faydalanarak yapılan tartışmaya göre; birinci politika önerisi için araç olarak yasal düzenlemenin (legal regulation) kullanılması; ikici politika önerisi için ise yumuşak araç olarak kabul edilen (soft tool) kamu satın alımları ve kamu-özel sektör işbirliğinin kullanılması tavsiye edilmektedir.

Yukarıda yapılan tüm tartışmaların yanı sıra bu Tez, literatürde sıklıkla çalışıl(a)mayan bir alan olan Yenilik Sistemleri'nin sistem tarafının kompleks sistemler açısından tartışmasını yaparak literatür zenginleşmesine katkı vermeyi amaçlamıştır. Değişik disiplinlerde (fizikten sosyolojiye veya matematikten biyolojiye) kompleks sistemlerin tartışmalarını inceleyerek bir yapın kompleks olup olmadığına karar verilmesine olanak sağlayacak bir metrik geliştirmiştir. Topluluk Araştırma ve Geliştirme Bilgi Hizmeti (CORDIS), Avrupa Komisyonu tarafından yayınlanan Yenilik Birliği Skor Tahtası (Innovation Union Scoreboard) ve Bölgesel Yenilik Skor Tahtası'ndan (Regional Innovation Scoreboard) alınan veriler oluşturulan Avrupa Araştırma ve Yenilik Ağ Yapı'sını incelemiştir. Bu yapının incelenmesinde ağ yapının politika geliştirilmesinde (Arnold v.d. 2009) ve/veya Yenilik Sistemleri'nin incelenmesi ve geliştirilmesinde kullanılmamasını eleştiren (Weber 2009) yaklaşımların tersine; ağ yapı analizini politika önerilerin sunulmasında bir araç olarak kullanmıştır. Son olarak ise yapılan araştırmalar sonucunda Avrupa Birliği'nin yenilikçiliğin Yenilik Sistemleri, kompleks sistemler ve ağ yapı analizi aracılıyla inceleyen ve politika önerileri geliştiren ilk çalışmanın bu Tez olduğu tespit edilebilmiştir.

Diğer taraftan bu Tez'de yapılan araştırmaların ve çalışmaların daha ileriye götürülebileceği alanlar da mevcuttur. Bunlardan bincisi, Avrupa Araştırma ve Yenilik Ağ Yapı'sı ile ülkesel ve/veya bölgesel ağ yapıların ilintilendirilmesi ve elde edilen bu büyük ağ yapının yapısal karakteristiklerinin ve evriminin incelenmesidir. Böyle bir çalışma yapılması sadece Avrupa seviyesinde değil; ülke ve bölge seviyesinde politika yapıcılar ve aktörler için önemli avantajlar sağlayabilecektir. Diğer bir ifadeyle, Malerba ve Nicholas'ında (2002) tartıştıkları üzere:

- Avrupa, ülke ve bölge seviyesinde üç katmadan oluşan; birbiriyle bağlantılı bir ağ yapının düğümleri, düğümler arasındaki bağları ve bağların bağlanış biçimlerinin incelenmesi politika yapıcıların ve aktörlerin değişik teknoloji alanlarında, pazarda ve herhangi bir rekabet alanında gerçekleşecekler hakkında daha güvenilir kestirimler bulunmasına olanak sağlayacaktır. Bu durum ise politika yapıcıların ve aktörlerin yapılan politika kestirimlerine uygun olarak politikalar geliştirmelerini olanaklı kılacaktır.

- Değişik aktörler (üniversiteler, araştırma kurumları, firmalar, kamu örgütleri, sivil toplum kuruluşları, v.b.) tarafından sağlanan farklı veri kaynaklarından (bölgesel, sektörel, ulusal, uluslararası projeler; patentler, akademik yayınları, v.s.) temin edilen girdilerden oluşan bir veri tabanından faydalanarak yaratılacak bir ağ yapı, politika yapıcıların tüm ağ yapıyı görmelerini olanaklı kılacaktır. Böyle bir yapının varlığı ise sektörel ve/veya bölgesel tercihlerin/isteklerin çok daha fazla dikkate alındığı politika uygulamalarının geliştirilmesini olanaklı kılacaktır.

- Komisyon tarafından projelerin desteklenmesinde rol oynayan en önemli sebeplerden bir tanesi Avrupa seviyesinde yaratılan katma değerin yüksek olması beklentisidir. Özellikle 2000'lerden itibaren Avrupa Araştırma Alanı kavramının tartışılmaya başlanması ile beraber katma değer kavramı sadece düğümler (ülke ve/veya bölge) arasında ağ yapının yaratılması ve geliştirilmesini kapsayan bir kavram olarak değil; aynı zamanda düğümlerin politika faaliyetlerinin koordinasyonunu ve AB seviyesinde politika geliştirilmesini ve uygulamasını da dikkat alan bir kavram olarak ele alınmaya başlamıştır. Bu çerçeve içerisinde ele alındığında değişik seviyedeki (AB, ülke, bölgesel, sektörel) aktörlerin oluşturduğu bir ağ yapının oluşturulması Avrupa Araştırma Alanı'nın ne kadar tamamlandığı ve/veya geliştiğinin anlaşılması için kullanılacak girdilerden bir tanesi olabilecektir

Tez'de yapılan çalışmaların ve araştırmaların daha ileriye götürülmesini olanaklı kılacak ikinci bir alan ise ağ yapıyı oluşturan düğümlerin fonksiyonları/görevleri ve birbirlerine olan etkilerinin dikkate alınmasıyla yapılacak olan çalışmalardır. Diğer bir ifadeyle, literatürde farklı araştırmacılar tarafından bazı önemli soruların cevapları bu tip araştırmayla kısmen de olsa cevaplanabilecektir. Örneğin düğümlerin neden ilişki kurduğuna dair en iyi sınıflandırman bir tanesi Oliver'in (1990) yılında yapmış olduğu çalışmada yer almaktadır. Oliver'e (1990) göre organizasyonlar arasında işbirliğin kuruluş sebebini açıklamak için 6 temel sebep sıralanabilir. Bunlardan birincisi yasal zorunlulukların ve hukuki düzenlemelerin karşılanabilmesi için düğümler diğer düğümlerle işbirliği yapabilmektedirler. İkinci asimetrik güç ilişkileri sebebiyle organizasyonlar birbirleriyle işbirliği yapabilmeleridir. Başka bir ifadeyle, güçlü düğümlerin diğerleri üzerinde tahakküm kurması ve/veya tamamıyla ele geçirmek istemesi gibi sebeplerden dolayı organizasyonlar birbirleriyle işbirliği yapmaktadır. Üçüncü olarak düğümler dikey ilişki için değil yatay ilişki için işbirliği yapabilmeleridir. Başka bir ifadeyle, bir önceki maddede açıklanan güç ilişkisi yerine işbirliği ve ortaklık oluşturma sebebiyle organizasyonlar birbirleriyle işbirliği yapabilmektedir. Dördüncü sebep organizasyonların içsel verimliliğini (örneğin girdi/çıktı oranı gibi) arttırmak için birbirleriyle işbirliği kurmalarıdır. Beşinci sebep organizasyonların belirsizliklere karşı pozisyon almak için birbirleriyle işbirliği içine girebilecekleridir. Altıncı sebep ise saygınlık, itibar, imaj gibi meşruiyet (legitimacy) arttırıcı sebeplerden dolayı organizasyonların işbirliği yapabilme ihtimalidir. Yukarıda belirtilen sebepler ve/veya daha fazlası; Çerçeve Programlar aracılığıyla elde edilen ağ yapıyı oluşturan düğümlerin fonksiyonları/görevleri ve birbirlerine olan etkilerinin incelenmesi ile elde edilebilecektir.

APPENDIX E - TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü ☐

Sosyal Bilimler Enstitüsü ☒

Uygulamalı Matematik Enstitüsü ☐

Enformatik Enstitüsü ☐

Deniz Bilimleri Enstitüsü ☐

YAZARIN

Soyadı : Çetinkaya
Adı : Umut Yılmaz
Bölümü : Bilim ve Teknoloji Politikası Çalışmaları

TEZİN ADI (İngilizce) : European Union Innovativeness from the Perspective of Systems of Innovation and Complex Systems

TEZİN TÜRÜ : Yüksek Lisans ☐ Doktora ☒

1. Tezimin tamamı dünya çapında erişime açılsın ve kaynak gösterilmek şartıyla tezimin bir kısmı veya tamamının fotokopisi alınsın. ☒
2. Tezimin tamamı yalnızca Orta Doğu Teknik Üniversitesi kullanıcılarının erişimine açılsın. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐
3. Tezim bir (1) yıl süreyle erişime kapalı olsun. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐

Yazarın imzası .... Tarih ....