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Hunting scale-free properties in R&D collaboration networks: Self-organization, power-law and policy issues in the European aerospace research area

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ABSTRACT

Based on previous studies of EU-subsidized research joint ventures, R&D collaboration networks, and aerospace industry, this work raises and tests a set of hypotheses in order to check whether the European aerospace research area shows a scale-free topology. Its main focus concerns the application of a proper power-law detecting methodology to most important parameters: projects' and organizations' direct and indirect centrality, organizations' membership, and finally projects' size and fund. While previous studies of other EU-subsidized research joint ventures carried on the analyses with relatively simpler methods and tested only the power-law form, our work employs minimum and significance values calculations, and contrasts the power-law with other heavy-tailed distributions, which are widely analysed and discussed. The results clearly state that some parameters can be substantially assimilated to a power-law, while others only moderately or not at all. An explanation of such differences is provided and grounded on the relation between self-organization and scale invariance, mostly confirming a direct dependence of the latter from the former. However, the peculiarities of projects' size distribution make the interpretation of that relationship more problematic and suggest the need to carefully investigate the effect produced in each specific context by external constraints. Further, the implications of the scale-free topological properties—and in particular of their occurrence in the relationship between organizations' direct and indirect connectivity—are explored and discussed also respect to the effectiveness of European research policies. Besides enhancing the understanding of EU-subsidized research joint ventures in the European aerospace research area, our work contributes to investigate the more general issues of the relationship between self-organization and power-law, and between organizations' direct and indirect connectivity within inter-organizational networks. Finally, the paper underlines the high relevance of scale-free properties—and thus, the need to follow a proper detection methodology—by showing their relationships with resilience and sustainability of socio-economic systems.

1. Introduction

European research policy over time heightened its importance among the main EU policy drivers [1,2]. The acknowledgement of the transforming process towards a knowledge-based society and economy put research and innovation policy in a prior position [3,4], and legitimated to employ a considerable amount of financial resources to its realization and governance. A fundamental instrument to this aim has been the Framework Programme (FP), which has been issued to promote cohesion, quality of life, job creation

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and sustainable development, to address problems of society, and to contribute to the implementation of the Community's research policies [5,6]. Early experiences, started with the launch of the ESPRIT Programme (1984–1988), were almost exclusively addressed to the Information and Communication Technologies sector, and mainly aimed at improving industrial competitiveness at a pan-European level. Two main discontinuities can be identified in policy maker's planning of FPs: the first one characterized the transition from the Third to the Fourth (1994–1998), where—beside a relevant increment of financial effort which rose from 6600 to 12,300 million ECU—the research fields had been significantly widened including social sciences and transport. The aim definitely shifted from industrial technological improvement to knowledge creation and diffusion among heterogeneous actors. Later on, the salience of the creation of a European research system able to integrate National Innovation Systems had been fully acknowledged, and triggered the second discontinuity of research policy occurring with the Sixth FP, which was focused on the creation of a single, cohesive, and integrated European Research Area (ERA).

During these three decades of FPs, EU-subsidized Research Joint Ventures (EURJVs)—that is the various typologies of research projects partially or totally funded by EU—played and continues to play a primary strategic role in building an integrated research area at European level, and constitute the engine of many European sectors [7,8]. For these reasons EURJVs networks gained great attention by those scholars who, especially from the last decade, are widely using network analysis. On the one hand many authors focused on the effectiveness of European research policies and on the implications of new instruments adoptions. On the other hand such networks provided interesting datasets (mainly for physicists and network analysis scholars) to analyze the features of real world networks. Many studies have been carried on to shed light on the FPs structure and to identify its key players and main properties [6,8–17], providing empirically grounded elements to discuss the degree to which this network structure may respond to EU broad policy objectives of competitiveness and cohesion and its implications for recent programmes aimed at shaping ERA. It is argued that the identification and characterization of networks that have emerged from early European Programmes represent a fundamental step for the assessment of past achievements and an important benchmark for future policy design [13]. Most contributions suggest that ERA is made of large complex networks with a more or less hierarchical structure, as several other types of real complex networks in which the distribution of nodes' connectivity decays as a power-law [18–23].

The hierarchical property is not peculiar only of EURJVs, but rather common to other well known networks in the social sciences, like the World Wide Web [18,24] and Internet [20], and several others in the natural sciences [23,25–29]. Many further examples of power-law distributions have more recently been found in social and economic networks, like the world trade web [30,31], the formation of public opinion [32], the inter-firm transactions of Japanese firms [33], the dynamics of financial markets [34], and the distribution of per-capita gross domestic product [35,36]. Among the pioneers, Barabási and Albert [37] suggested that a scale-free structure, expressed by a power-law distribution of nodes' connectivity, is generated and evolves according to a "preferential attachment mechanism", where older (and more connected) vertices increase their connectivity at the expense of the younger (and less connected) ones. Though others [27,29] proposed different mechanisms, their common logics is that they imply self-reinforcing (positive feedback) processes, which typically produce nonlinear (complex) outcomes, and often assume the form of self-organization. Consistently, most scholars underline that the scale-invariance structure is typical of self-organizing complex systems [19,22,23,38]. Hence, there would be a significant clue that the scale-free and the self-organizing properties have a strong and deep connection, which goes much further the idea of the preferential attachment mechanism.

To explore this connection, it comes interesting to underlie that most forms of inter-organizational networks are (prevalently albeit generally not completely) self-organizing networks [39–50], and that, being a sub-set of them, inter-organizational alliances plausibly share this same characteristic, as an extant literature explicitly [40,50–55] or implicitly [42,56–61] shows. Hence, due to their marked self-organizing nature, it could be legitimately and fruitfully wondered whether inter-organizational alliances could show scale-free properties as well. Moreover, for both properties can take place in different degrees, it could happen a certain positive direct relationship between the two. Being one of the many formal types of inter-organizational alliances, EURJVs present distinguishing features [62], one of which is that they are not fully self-organizing networks, because of the constraints exerted by EU on FPs governance mechanisms actuated through rules and officers' practices [7,63]. Therefore, EURJVs are good examples to empirically test the existence and the strength of a relationship between scale-free and self-organization.

So far, we know that: 1) scale-free structures are generated by self-organizing processes; 2) EURJVs networks are (partially) self-organizing systems; and 3) FPs as a whole and in some sectors are supposed to be scale-invariant. Hence, it becomes interesting to wonder whether the EURJV network corresponding to the European aerospace research sector (into FPs) shows as well scale-free properties, and eventually for which parameters and to what extent, because such properties can be more or less accentuated, depending on the specific parameter chosen for the measurement. Why the aerospace (AS) sector? In this sector, as well as in the automotive sector, the decrease of industry participation that can be seen in other areas from FP4 to FP6 had not been recorded [64]. Moreover, the European aerospace research covers a very important position in EU, because it concerns collaborations in the strategic sectors of aeronautics, avionics, and space, and it largely overlaps with defence activities. Therefore, even more than for other areas, EU policy makers aimed in the AS sector at creating and consolidating a well connected, robust, and heterogeneous R&D network: the European Aerospace Research Network (henceforth called EASREN).

Another reason to extend to AS this kind of investigation already done in other sectors—ICT, and the whole FP [5,8–11,13]—is that previous studies carried on the ERA

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