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Assessing the Importance of Local Supporting Organizations in the Automotive Industry: A Hybrid Dynamic Framework of Innovation Networks

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Abstract *The advancement of knowledge on networks entails acknowledging the heterogeneity of their participants, more precisely, the organizations that lie beyond the scope of the activities of firms. Adopting a dynamic perspective of networks, and considering different types of innovation exchanges, we propose a hybrid and wider notion of industry which implies taking account of a set of local supporting organizations (LSOs) in domains such as research and technology, production factors, consultancy and training, and public support. Based on a rich data set built from face-to-face interviews with Portuguese automotive organizations, which resulted in a network comprising 867 organizations, we apply social network analysis techniques to analyse the structure, content and dynamics of the networks. The evidence gathered unveiled huge industry turbulence and significant changes in the boundaries of the Portuguese automotive networks over a 20-year period, with the emergence (and decline) of different prominent organizations. Specifically, following AutoEuropa major foreign direct investment (in 1995), the analyses reflect a clear increase in connectivity within the industry (from 524, before 1995, up to 2327 connections after 1995), with greater involvement among suppliers and between suppliers and LSOs, with the latter achieving top positions in the ranking of innovation networks.*

1. Introduction

In the sphere of the social sciences, debate on network forms of organization is definitely not new and is undoubtedly widespread (Leite & Teixeira, 2012; Tomlinson & Fai, 2013). Indeed, networks seem to have risen significantly in appeal (Phelps *et al.*, 2012), as a

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concept that has gathered theoretical keywords from several academic disciplines, namely economics (Freeman, 1987; Sturgeon, 2002), management (Dyer & Nobeoka, 2000), economic geography (Simmie & Hart, 1999; Schamp *et al.*, 2004) and sociology (Granovetter, 1973, 1985; Powell, 1990).

The vast literature on networks seems to share the generic ideas inherent to networking: a set of nodes each connected by some type of link. However, scholars have approached networks from a wide range of perspectives (Almodovar & Teixeira, 2012). Network forms have mushroomed with a variety of attributes and have been characterized as impacting on core domains of economic activity.

We echo Sternberg (2000, p. 393) in recognizing that "the abundance of literature on networks makes it rather difficult to provide a systematic and extensive overview since the term network is interpreted quite differently". However, the apparently overwhelming variety of networks coupled with the fuzziness of the theoretical debate should not distract us from one key fact. Empirically, there are a number of examples of network-based phenomena (production, innovation, entrepreneurship and policy-making) with important repercussions on the organization of economic activity (Gebreeyesus & Mohnen, 2013). In this context, it is necessary to put forward a network approach that is able to (i) account for the context of variety in which networks are approached and (ii) benefit from different disciplinary contributions. In particular, a critical element contributing to a systematic network approach is related to its boundaries, that is, the definition of the participating organizations. Indeed, most of the network studies, while generally recognizing the existence of a broad range of organizations, such as firms and a set of supporting organizations (Koschatzky, 1999), tend to only address the participation of homogeneous organizations, in the form of inter-firm networks. In the present study, we aim to overcome such a limitation by putting forward an approach to networks based on a wide spectrum of network organizations, which explicitly accounts for their heterogeneity and dynamics.

The paper starts with a discussion of the state-of-the-art of the network debate (Section 2) and justifies the relevance of framing networks from a wider perspective. Section 3 lays out the methodological strategy followed to address this view and discusses the empirical context which is used to exemplify our argument. Section 4 is dedicated to the analysis of the changing structure of innovation networks, before and after the start (in 1995) of a major foreign direct investment in the Portuguese automotive industry Portugal, the AutoEuropa project, involving automotive suppliers and local supporting organizations (LSOs). The concluding section summarizes the main findings of the study.

2. Literature Review on Networks: The Quest for a Hybrid and Wider Approach

2.1 *The Innovation Network Framework*

Networks are seen as a form to accommodate the collective dimension of the innovation capabilities of firms (Mei & Nie, 2008). The reliance of innovation activities on networks of actors is associated to the increasing distributed nature of knowledge (Coombs & Metcalfe, 2000; Coombs & Georghiou, 2002) and, consequently, to the need for firms to relate to their external environment (Plum & Hassink, 2011).

Under the umbrella of the theory of the firm and the capabilities view, a series of works have come to highlight the importance of external resources for firm innovation and the need to network. By placing at the core of innovation capabilities "the ability of a firm

to recognise the value of external information, assimilate it and apply it to commercial end", Cohen and Levinthal (1990, p. 128) suggest that absorptive capacity is best achieved through networks of internal and external relationships. Other scholars, such as Leonard-Barton (1995) and Teece *et al.* (1997), view technological capabilities in terms of market responsiveness and point out the need to coordinate and redeploy external capabilities.

The view of innovation as a network-based phenomenon is also acknowledged by the innovation systems (IS) literature (Freeman, 1987, 1991; Lundvall, 1988; Edquist, 1997), regarding innovation as an eminently interactive process (Lundvall, 1988) where networks emerge as an appropriate form of accommodating novelty, reflected in activities of resource creation.

Three central elements stand out that contribute to a systematic approach to networks (Liu & Chaminade, 2010; Molina-Morales & Martínez-Fernández, 2011; Ceci & Iubatti, 2012): the dynamic perspective, heterogeneity of actors and nature of the link. Figure 1 represents this network framework and summarizes the contributing elements from different strands of the literature. The strength of this framework resides in bringing together complementary elements from different perspectives into a single approach.

The dynamic perspective of networks not only looks at the existing but also persisting patterns of industrial innovative interaction. It focuses on the processes of network change, which can relate to its participants, links or both. While we note an emphasis in the current literature on static approaches that study the outcome of interaction, namely the rationales of network formation (Powell, 1990; Freeman, 1991; Camagni, 1995; Podolny & Page, 1998; Huggins *et al.*, 2012), there is an emerging range of studies dedicated to the dynamics of networks (Liu & Chaminade, 2010). In concrete, economic approaches such as those put forward by Cantner and Graf (2006) and Deroïan (2002) are mainly interested in capturing the dynamics of innovation and the benefits for participants. Management studies look at how participation in a network over time aligns with the firm's resource needs (Hite & Hesterly, 2001), type of knowledge (Rothaermel & Deeds,

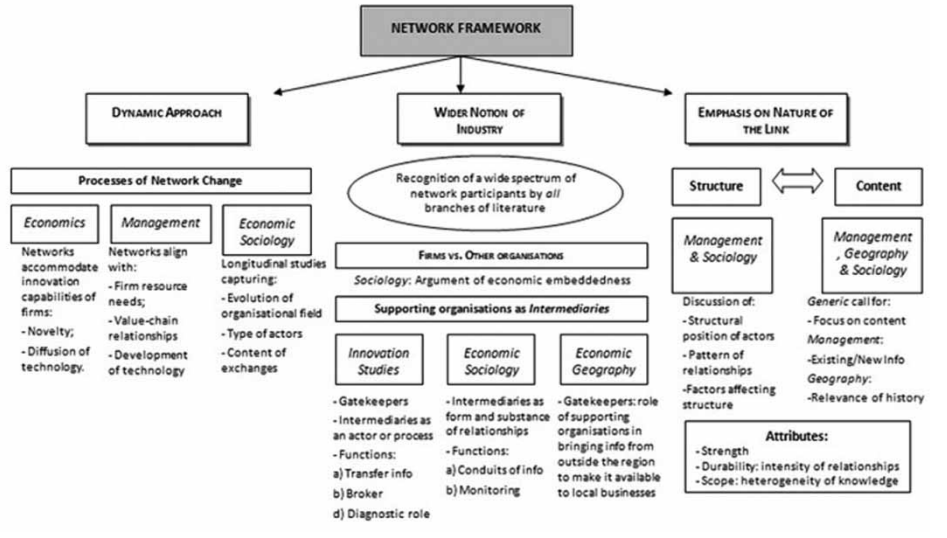

Figure 1. Network dynamics, structure and content: contributions from the literature.

2004) and need to adapt and learn from other organizations (Dyer & Nobeoka, 2000). The sociological contributions highlight the dynamics of dyads (Stuart, 1998) and entire networks (Powell *et al.*, 2005), tracking the development and reproduction of networks.

The wider notion of industry consider in the present study (cf. Figure 1) takes into account the heterogeneity of organizations participating in a network. It integrates different types of organizations translated in their scopes of activity and resources. Although we find that there is a general recognition, in all branches of literature, of a wide spectrum of network organizations, most scholars tend to limit the boundaries of their inquiries to the study of inter-firm networking in their empirical work (Moran, 2005; Ozman, 2009; Ceci & Iubatti, 2012). The role of supporting organizations and their intermediary status has been partially addressed by innovation scholars (Howells, 2006; Kirkels & Duysters, 2010), sociologists (Smith-Doerr & Powell, 2005) and economic geographers (Diez, 2000; Schamp *et al.*, 2004). We view the activities and resources of supporting organizations as important for the firms' activities and, hence, key partners to be taken into account if the aim is to provide a comprehensive picture of the process of industry networking.

The network literature is very focused on the level of the structure, that is, the overall pattern of relationships (Granovetter, 1973, 1985; Burt, 1992). An emphasis on the nature of the link implies opening the black-box of what goes on inside the network and classifying distinct innovation-related contents.

More recently, there have been a series of valuable contributions that provide insights into how network contents relate to the achievements of managers (Rodan & Galunic, 2004), to innovation (Rothaermel & Deeds, 2004; Moran, 2005) and the goals of firms (Doloreux, 2004). These studies call for a clearer differentiation of the contents of networks in the process of innovation. As put forward by Lambooy (2004, p. 644), "it is necessary to know more about the ... nature of both the communication and the transfer of content".

2.2 *Heterogeneity of Actors: The Role of Supporting Organizations*

Networks are defined by their ability to exchange sources of information and expertise that are relevant for the firms' ability to innovate (Laursen & Salter, 2004). The collective dimension of innovation capabilities results from the distributed nature of knowledge (Coombs & Metcalfe, 2000) and implies relationships that are not reducible to the sum of individual firm activities.

Extant literature put forward different criteria for affiliation in a network, which have impact on the type of participant organizations. First, there are networks where the main criterion is associated with the need to collectively solve a problem. The case of scientific networks in the biotechnology sector constitutes an example of collective stabilization of the knowledge base and the definition of standards. These networks tend to include specialized actors (Powell *et al.*, 2005). Second, we find networks where membership relies on a criterion of strategy. In this case, it is important to guarantee that influential organizations in the specific field are included in the network. In the stream of management studies, McEvily and Zaheer (1999) document the importance of interacting with lead suppliers and lead customers. Deroïan (2002), in turn, stresses the role of early adopters in the diffusion of a technology and their influential impact on other adopters.

Third, there are resource-based networks where the inclusion of actors is based on the diversity and complementarity of the resources they can each offer to the networking activities. Dyer and Nobeoka (2000) contend that a network has the ability to learn and share knowledge within the diversity of statuses/resources of automakers, suppliers and interface organizations. The work by Obstfeld (2005) also stresses how individual knowledge bases are important for the combinatorial process of innovation. Another study by Rulke and Galaskiewicz (2000) questions the variety of knowledge resources in the network by showing how networks with common knowledge bases outperform groups where individuals possess specialized knowledge.

Fourth, a criterion that is dependent on political factors. These power-based networks tend to be restricted to members that are politically influential and affect decision-making. The most frequent example of a political network involves acquaintances and relatives (Copus & Skuras, 2006). But it is also possible for "less-powerful" actors to participate in these networks: Stevenson and Greenberg (2000) describe how peripheral actors may influence policies in environmental issues by using a direct-contact strategy.

Apart from the criteria of affiliation, network studies also apply different units of analysis (cf. Figure 2). There is a consensus across the body of network studies as to how firms are referred to in their various modalities (subsidiaries, small and medium enterprises and multinational corporations) as key network actors. However, the distinction between the individual and organizational level of analysis underlines a number of specificities for each strand of the network literature.

At the individual level, economic studies tend to emphasize the role of scientists (Wagner & Leydesdorff, 2005) and innovators (Cantner & Graf, 2006); management studies focus on the role of managers (Rodan & Galunic, 2004), political actors (Stevenson & Greenberg, 2000), types of personality (Mehra *et al.*, 2001) and entrepreneurs (Dodgson, 2011); and economic geography studies draw on the importance of entrepreneurs (Jenssen & Koenig, 2002; Nijkamp, 2003).

At the organizational level, the literature survey yields a varied set of organizations. In the economic network literature, a study by Corrado and Zollo (2006) focuses on the role of government intervention in shaping the evolution of the relationships binding firms.

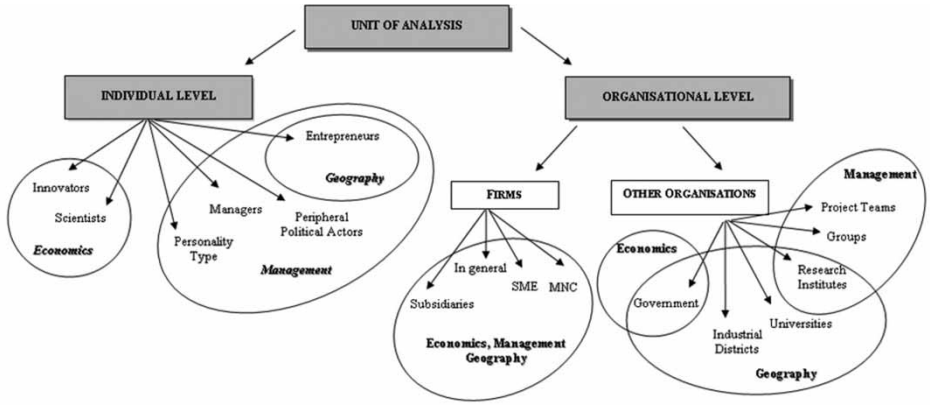

Figure 2. Unit of analysis in networks: individual vs. organizational.
Source: Authors' compilation.

Besides government, the economic geography literature examines the importance of networks for organizations such as industrial districts (Rama *et al.*, 2003; Howells & Bessant, 2012), universities (Lambooy, 2004) and research institutes (Diez, 2000). Management studies tend to focus on research institutes (Nicolaou & Birley, 2003), groups (Rulke & Galaskiewicz, 2000) and project teams (Reagans *et al.*, 2004).

There is a general acceptance among scholars that networks integrate a variety of members (Lee, 2010; Phelps *et al.*, 2012). It is nevertheless possible to draw a boundary with regard to the role of these members. We find that while organizations such as research and training institutes, state agencies and investment-based centres (Koschatzky, 1999) are meant to comprise a supporting network, there is however a core component of networking among firms, namely suppliers, distributors and competitors. In fact, Jones (2005, p. 186) noted that "the performance of firms within a region will be driven, in part, by the extent and quality of positive, sustained relationships across a variety of organisations". This distinction of nodes among firms and supporting organizations predefines a functional division between economic/business transactions and support transactions.

Beyond the explicit network approaches, there are other approaches that analyse the role of supporting organizations in networking processes. The literature on industrial districts highlights a setting in which not only firms but also a supporting environment, comprising public and private organizations, collaborates (Molina-Morales & Martínez-Fernández, 2011).

In evolutionary economics, in general, and IS, in particular, we also find references to supporting organizations as relevant entities in innovation networks. Nelson (1986, p. 186) recognizes their role in the "generation and spread of technological knowledge". In the same vein, Antonelli (2005, p. 65) argues that technological knowledge is the result of a collective process based on "a myriad of heterogeneous and interacting agents rooted in a well-defined set of scientific, technical, geographic, economic, and commercial circumstances". The IS literature also refers to supporting organizations as important players in innovation outcomes. Their systemic view of innovation integrates a rich ecology of actors which contribute with complementary knowledge resources (Freeman, 1987).

An understanding of network participants in more or less network-focused studies can be summarized in two main points. First, it is generally recognized that a large spectrum of actors are involved in networks, which includes, among other, firms, research and training organizations, public institutes, banks and industrial associations (Corsaro *et al.*, 2012). Second, scholars tend to limit the boundaries of their inquiries to the study of inter-firm networking, based on the assumption that such a configuration is exhaustive in terms of the way networks operate and develop (Poorkavoos *et al.*, 2011). This option places emphasis on homogeneous actors whose goals and scope of activities are similar.

By extending the study of networks to embrace other organizations rather than firms and their business transactions, we are explicitly addressing the heterogeneity of network actors and, hence, improving our understanding about network dynamics. Granovetter (1985, 2005, p. 35) puts forward an embedded view according to which "the extent to which economic activity is linked to or depends on actions or institutions that are non-economic in content, goal or processes". This phenomenon reflects the inclusion of actors whose activities are essentially non-economic in nature but still impact on the sphere of economic activity. This is also in line with the contributions of Woody Powell and his colleagues regarding network dynamics and field evolution. Powell *et al.* (2005, p. 1134) view an organizational field as a "community of organisations

Table 1. Intermediary functions

Function	Specification	Content
Transfer of knowledge	Specialized and expert knowledge (new or existing)	Selection and articulation of technologies
Experience sharing	Carry experiences and ideas from one context to another	Locating sources of knowledge
Marriage broker	Providing users with a single point of contact through which to access a wide range of specialist services	Provision of training and project management
Diagnostic role	Helping users articulate and define their particular needs	Investment appraisal

Source: Based on Bessant and Rush (1995, pp. 101–102).

that engage in common activities and are subject to similar reputational and regulatory pressures". By considering various organizations in the field of life sciences, the scholars investigated the evolution and reproduction of networks.

We therefore adopt a hybrid and wider notion of industry which includes not only firms but also a set of supporting organizations in domains such as research and technology, consultancy and training, as well as the public sector. The supporting organizations are further characterized by (i) their intermediary position: they bridge resources and competencies relevant to the firms' activities and (ii) their localized nature: supporting organizations tend to spatially concentrate around critical masses of industrial activity.

Smith-Doerr and Powell (2005) acknowledge two main functions of "supportive intermediary organizations". First, they are *conduits of resources* and act as promoters of enhanced flows of ideas and skills. Second, they perform a role in *network monitoring* through the guidance and management of inter-firm collaboration. More specifically, the study by Diez (2000) views public research institutes as gatekeepers due to their ability to bring information from outside to a region. Schamp *et al.* (2004) point out the intermediary role of knowledge-intensive services through their activities of information transmission.

An encompassing review by Howells (2006) on the role of intermediaries in innovation stresses the gatekeeper status of supporting organizations in making certain resources accessible to firms. Based on the work by Bessant and Rush (1995), Howells (2006) summarizes the functions performed by intermediaries (cf. Table 1) which we apply to the scope of activities of supporting organizations.

In this context, the activities of supporting organizations, such as searching for, managing and transmitting information; bridging communication between firms; and advising, are important sources that feed into the firm's operation. This set of functions and their guarantors need to be taken into account if we intend to provide a comprehensive picture of the process of industry interaction.

3. Methodological Underpinnings

Adopting a hybrid framework of analysis which enables to account for the heterogeneity and dynamics of actors, linkages and contents in innovation networks, the present study seeks to address the role of LSOs in such networks.

Using social network analysis (SNA) techniques (Scott, 2000), and combining qualitative and quantitative methodologies, we analyse the importance of LSOs over time in terms of the creation/endurance of networks, as well as in the support provided to firms' innovation activities.

The Portuguese automotive industry stands as a particularly suitable scientific context for analysis. In fact, the automotive industry is fertile ground since it involves the participation of a wide spectrum of organizations (e.g. assemblers, suppliers, research centres and governments) over time. An important trend affecting the dynamics of automotive networking is related to the nature of innovation activities. Knowledge in the automotive industry is highly distributed and hence innovation is particularly reliant on several players. According to Sako (2003, p. 246), "the car has always been a complex multi-technology product, but the range of new technologies . . . has increased over time, with greater electronics content, new materials, and new energy sources". In this context, an industry that was basically centred on mechanical engineering is now embracing critical input from a vast array of technological fields, such as information technologies, electronics, nanotechnologies, ergonomics, plastics, etc.

There are several drivers of technological change in the automotive industry. Consumer preferences and national frameworks impact on automotive technologies in terms of environmental regulations (Preissl, 2000); demand for customized vehicles (Holweg, 2005); and calls for improvements to technologies, such as driver amenities, driving performance or safety standards (Veloso *et al.*, 2000). As a result, a substantial part of technological developments is demand-led, based on improvements, and forces automotive players to reduce their development cycles. In this context, modularity and functional relationships are key factors. Not only do they affect the generation and diffusion of technologies (Lorentzen *et al.*, 2003), but they are also seen as a response to manage such a multi-technology product as the automotive (Frigant & Talbot, 2005).

Managing complexity in the automotive industry calls for intense networking among its players, who possess different, complementary knowledge resources. This is reflected in cases of horizontal and vertical networks. Regarding the former, the relationships between original equipment manufacturers (OEMs) involve various forms of formal collaboration (joint ventures and acquisitions) and standardization procedures (co-development or common platforms), and the relationships between suppliers are based on their set of complementary areas and technological capabilities. Respecting the latter, as an assembly industry, the automotive is increasingly calling for more networking between OEMs and suppliers. This is perceptible in the OEMs' trend to shift their activities to suppliers, not just at the manufacturing stages but also at the developmental.

The Portuguese case in particular is fertile ground for the study of networking among various players and its dynamics. As a small, peripheral and newcomer economy, one would expect its odds to be rather slim in a competitive arena such as the automotive industry. The industry's global reach, complexity and technological diversity seem particularly challenging for a country whose automotive industry only started to consistently develop from the 1980s onwards. However, the Portuguese automotive industry has improved its capabilities, attracted foreign direct investment, and reinforced its market (Wielgat, 1997; Taylor, 2011). Moreover, the industry's development has revealed a significant amount of change in terms of the continuous emergence of players (Faustino & Leitão, 2011).

Between the 1960s and 1970s, Portugal implemented a protectionist policy with an assembly law that restricted the number of imported vehicles. Although this setting allowed for the establishment of key OEMs (e.g. Ford, GM, Citroën and Renault), it imposed rigidities that hindered the improvement of the local supply value chain (Féria, 1999).

The early 1980s introduced a new phase in the Portuguese automotive industry. Not only were there considerable changes in terms of policy, which promoted exports and the local supply industry, but a green field investment was also made by a major OEM. Renault's investment involved two plants: one for vehicles and the other for gear boxes and water pumps. Such an investment had important repercussions on the local industry, as it enabled (Féria, 1999) the consolidation of competences related to quality standards, costs and timings; attracted further foreign investment; induced contacts by Portuguese suppliers with the global industry; and fostered technological, organizational and commercial learning processes (Table 2).

The beginning of the 1990s entailed a second milestone for the Portuguese automotive industry—AutoEuropa. This investment resulted from a joint venture between Ford and Volkswagen for the production of a multipurpose vehicle (Simões & Cartaxo, 2011). According to Vale (2004), the main factors explaining the choice of locating AutoEuropa in Portugal resulted from a set of government incentives; the qualification of the labour force; the country's geographical location; a hub of related activities; and the region's prior experience with the Renault plant. In terms of suppliers, AutoEuropa's network revealed to be more diverse and concentrated than Renault's. Not only did it encompass

Table 2. Main stages of the automotive industry in Portugal

	Protected market 1960s–1970s	Renault project 1980–1990	AutoEuropa project 1991–1999	VW AutoEuropa 2000–···
Public policy	Imports substitution Minimum % of national incorporation	Exports promotion Incentives to FDI	Open market Incentives to FDI	FDI incentives Consolidation of CEIIA
		Integration in ECC	PEDIP programme	Promotion of cooperation
OEM strategies	High number of OEMs assembling "Completely knock down" units	Predominance of Renault project	Joint-venture between Ford and VW	Predominance of VW AutoEuropa
Suppliers behaviour	Incipient automotive supply industry	Consolidation of automotive suppliers	Dynamism of automotive suppliers	Automotive supply facing new challenges
	Low value-added of components	Improvement at level of quality, cost and timings	Improvement of engineering capabilities	Engineering and development capabilities: challenges
	Internal market orientation	Openness to global markets	Internationalization of firms	Continuous openness of supply firms

Source: Based on Selada and Felizardo (2002) and NORTINOV (2004).

a wider spectrum of supply sectors, but it was also more concentrated spatially (Vale, 2004). Although the agreement was signed in 1991, it was not until 1995 that the plant started operating in Palmela (district of Setúbal, in Lisbon NUTS II region). This time gap gave local suppliers the opportunity to upgrade their capabilities and foreign suppliers to invest locally. AutoEuropa is viewed as a critical project for the Portuguese automotive firms as it encouraged the development of engineering capabilities, an increase in production scale, as well as further contacts with and adaptation to global automotive standards (Veloso *et al.*, 2000). More generically, the establishment of AutoEuropa was very important for the Portuguese economy as it represented the most important foreign direct investment in the country to date (Moreira & Carvalho, 2012).[1]

A descriptive statistical overview of the Portuguese automotive industry reveals its small size in terms of OEMs (4) and automotive suppliers (180 spread over various interlinked sectors). The data also show a sector with a productivity level above the national average, geographically concentrated around local OEMs, as well as dependent on Europe as its main export destination (most notably, Germany, Spain and France). The majority of the suppliers are certified but remain small, both in terms of turnover and employees; and mainly focused on the manufacturing stage with limited efforts in terms of development (AFIA, 2005).

The sources for the primary data collection involved a survey, in which the elements of the network framework were applied, complemented with face-to-face interviews, which facilitated the collection of relational data and provided the organizations' historical background.[2]Figure 3 represents an extract of the survey and its main elements.

The wider notion of industry, accounting for both the role of firms and supporting organizations, is addressed through a functional classification of automotive players (cf. Table 3). This classification is applied as a means to map the relationships among these players and provides information about who interacts with whom.

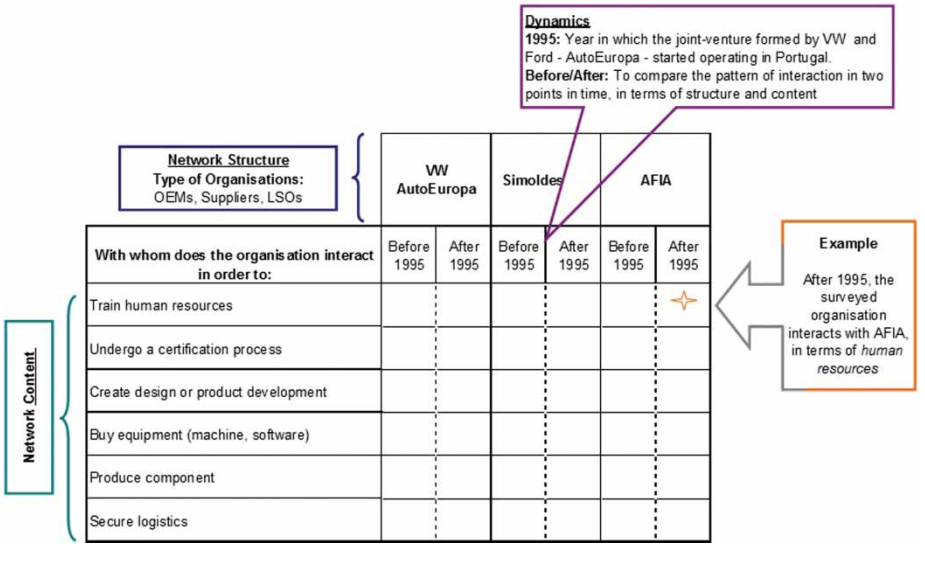

Figure 3. Extract of the survey—main elements.

Table 3. Network structure—typology of automotive organizations

Type	Organization
Firms	Automotive suppliers
	OEMs
LSO	*RTO*
	Technological centres
	Technological interfaces
	University and polytechnic departments
	Public laboratories
	PBO
	Raw material suppliers
	Equipment suppliers
	Logistics
	SFP
	Consultancy and IT
	Training organizations
	Certification organizations
	Facilitators
	Industrial/commercial associations
	Governmental agencies

Source: Authors' compilation.

Our analysis takes into consideration not only automotive firms—OEMs and suppliers—but also a set of supporting organizations in various domains, as part of a broader institutional endowment. Specifically, the LSOs are divided into four main domains: research and technology; production factors; consultancy and training; and facilitators. "Research and technology organizations" (RTOs) include both private (technological centres and interfaces) and public organizations (laboratories and university departments) supporting the automotive industry. The automotive industry, as a technology-intensive sector with constant demands for improvement, frequently interacts with local RTOs. "Production-based organizations" (PBOs) include suppliers of raw materials, equipment and logistics. These domains are grouped according to a production-chain logic, since they include the key resources automotive firms (OEMs and automotive suppliers) require to operate. In the same line, "strategic factor providers" (SFPs) include suppliers of resources for the firms' activities, but at an intangible level—training, consultancy and certification. Because OEMs and some automotive suppliers (in upper tiers) are major players in the industry, they also guarantee the critical mass necessary to outsource services both upstream (PBOs) and downstream (SFPs). Finally, "facilitators" include institutional support from industrial associations and government agencies. Our automotive framework accommodates the role of facilitators in terms of the impact of national frameworks on the automotive dynamics. Indeed, the choice of location of major automotive multinationals is driven by these frameworks, which contain elements in terms of regulations, incentives and public policies (Jacobs, 2012). The interaction with public agencies and industrial associations is an integral part of the automotive players' investment process.

In our approach to innovation networks, we have established two main categories, product and process, and adapted them to the automotive industry (cf. Table 4).

Table 4. Examples of network contents

Content of interaction	Indicative examples: We are interested in instances where the surveyed organization interacts with other organizations to
Product	Elaborate prototypes
	Develop new materials
	Develop any of the following techniques: simultaneous/concurrent/parallel/ forward engineering, collaborative product development, digital production, team approach
	Implement any of the following digital *t*
Process	Optimize equipment to make production process more efficient
	Fine tune of equipment
	Broaden functions of the equipment
	Industrialize production process
	Validations and upgrades of production process

Source: Authors.

Table 5. Automotive organizations: target population and sample

Type of organization	Target population no.	Sample no.
Auto suppliers	43[a]	28
OEMs	4	3
LSOs including	38	26
RTO	*16*	*11*
PBO	*3*	*2*
SFP	*7*	*5*
Facilitators	*12*	*8*
Total	85	57

Source: Authors.
[a]Besides the 41 suppliers which are members of AFIA, we interviewed another 2 suppliers—Ipetex and Sunviauto.

The process of defining the sample of organizations benefited from a contact with AFIA—the Portuguese industrial association of automotive suppliers—which provided access to their list of members and more direct contacts with the industry players. We interviewed a total of 57 automotive organizations, including 28 automotive suppliers, 3 OEMs and 26 LSOs (Table 5).

Because it was up to the respondents to list the organizations with which they interacted (free recall) and there were no restraints as to the number of organizations they could mention (free choice), these 57 interviews generated a network comprising 867 organizations (Table 6).

4. Innovation Networks in the Portuguese Automotive Industry: Empirical Results

While we have discussed a hybrid and wider notion of industry involving firms and LSOs, in this paper, we have placed particular focus on the network of suppliers and LSOs. This

Table 6. Portuguese automotive network: type of organizations

Class	Type of organization	No.	%
1	Automotive suppliers	346	39.9
2	OEM	60	6.9
3	RTO	104	12.0
4	PBO	178	20.5
5	SFP	84	9.7
6	Facilitators	95	11.0
	Total	867	100

Source: Authors; *Pajek*—partition classes.

option is rooted in the importance of suppliers for the local automotive industry and the challenges suppliers face in terms of upgrading innovation capabilities.

The Portuguese network of relationships among suppliers and LSOs, regardless of the content of interaction, is composed of 807 organizations. The dynamics of networking among suppliers and LSOs is represented in Figure 4.

While the maps reflect a clear increase in connectivity, density, although registering some growth, it remains at rather low levels. This is related to the high number of organizations composing the network. More remarkable is the fact that the number of isolates in the network decreased from 517 to just 60. Accordingly, the number of relationships evolved from 524 to 2327 after 1995. Overall, the context is of greater involvement among suppliers and LSOs, after 1995, which constitutes an initial sign of the importance of LSOs for suppliers.

By analysing the degree centrality of this network, we can determine which types of players maintain more links and, hence, are more popular in the network (cf. Table 7). This network of relationships demonstrates the popularity of LSOs at various levels—facilitators, RTOs and SFPs. Nevertheless, suppliers occupy top positions in this ranking of degree centrality, especially after 1995.

Figure 5 maps the links between suppliers and LSOs before 1995, and labels the top 15 organizations. The grey nodes (facilitators) lie at the core of the network as a sign of their high number of links. As for industrial associations—AFIA (suppliers), ANEMM (metal mechanics), AIMMAP (metallurgy), APIP (plastics), APF (foundry) and ANIMEE (electronics)—we attribute the network relevance to their vocation. In particular, all interviewees of these associations pointed out their role in representing members as well as offering a bundle of services related to that affiliation.

Industrial associations are a typical case of localized and intermediary organizations, which specialize in providing information, representing firms and, hence, they replace individual efforts of automotive suppliers. In addition, they maintain links with foreign counterparts confirming their status as network intermediaries between local suppliers and global organizations.

As for facilitators, we find that three entities in the top 15 of degree centrality after 1995 (Table 7) are public. INETI is a public laboratory in the field of engineering, science and technology. IAPMEI is the governmental agency in charge of providing support to small and medium enterprises. INTELI is a consultancy agency focused on the automotive and other related industries, namely aeronautics. Their relevance suggests that the public domain is also interacting with automotive suppliers.

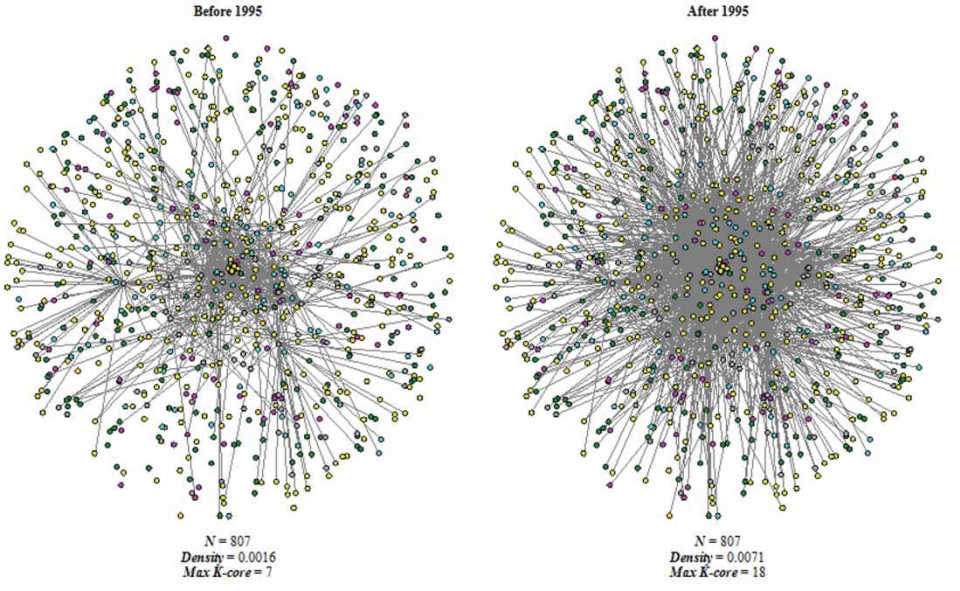

Figure 4. Dynamics of networking: automotive's suppliers and LSOs.
Source: Authors.
Note: Yellow nodes, suppliers; blue nodes, RTO; green nodes, PBO; pink nodes, SFP; grey nodes, facilitators.

Table 7. Degree centrality—top 15 automotive suppliers and LSOs

Before 1995				After 1995			
Organization	Type		Degree	Organization	Type		Degree
AFIA	LSO	Fac	45	AFIA	LSO	Fac	126
ANEMM		Fac	43	Inapal Plasticos	Supplier		96
AIMMAP		Fac	34	MCGraca			88
APIP		Fac	31	Inapal Metal			86
IAPMEI		Fac	31	INETI	LSO	RTO	85
APF		Fac	29	IAPMEI		Fac	78
Faurecia	Supplier		25	INEGI		RTO	73
ANIMEE	LSO	Fac	25	Simoldes Plasticos	Supplier		71
Couro Azul	Supplier		22	INTELI	LSO	SFP	71
Inapal Metal			21	Sunviauto	Supplier		71
UP-FEUP-DEMEGI	LSO	RTO	19	Epedal			70
INEGI		RTO	19	CENTIMFE	LSO	RTO	67
Kupper & Schmidt	Supplier		18	Kupper & Schmidt	Supplier		65
KROSCHU			16	Fabrilcar			65
CATIM	LSO	RTO	16	Edaetech			65

Source: Authors' calculations.
Note: RTO, research and technology organizations; PBO, production-based organizations; SFP, strategic factor providers; Fac, facilitators.

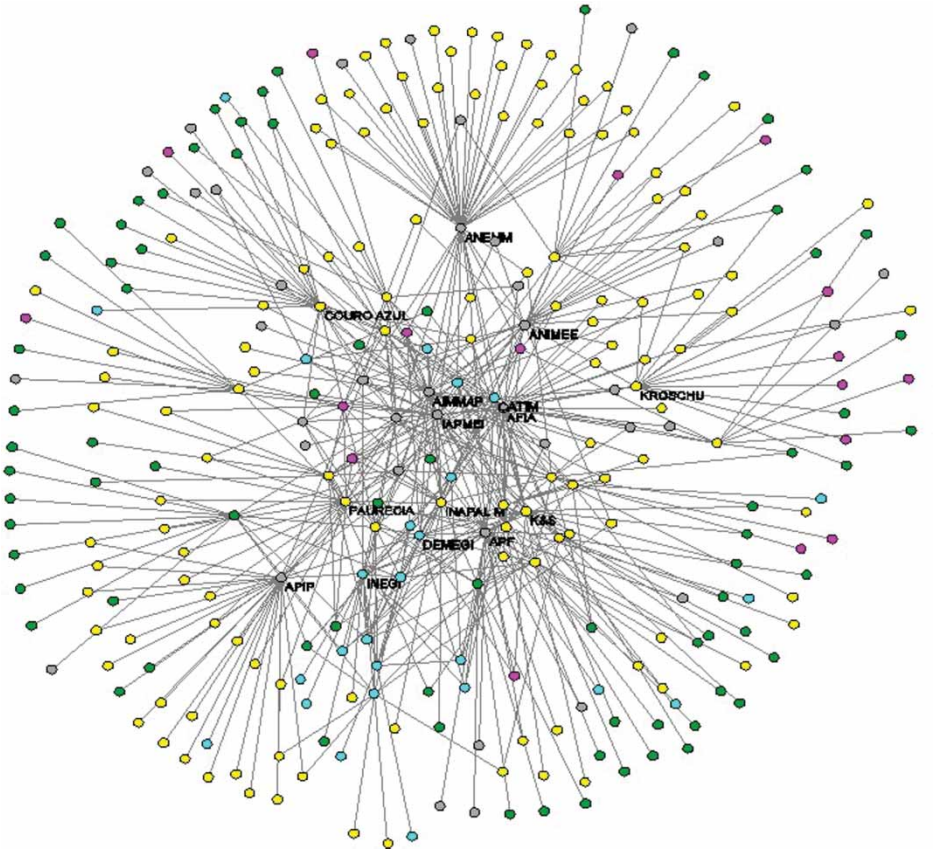

Figure 5. Networking among automotive suppliers and LSOs—before 1995.
Source: Authors.
Note: Yellow nodes, suppliers; blue nodes, RTO; green nodes, PBO; pink nodes, SFP; grey nodes, facilitators.

Other central LSOs in Figure 5 are RTOs represented as "blue" nodes. Among the three RTOs featured in the ranking of organizations before 1995, two are inserted in the area of mechanical engineering of the University of Porto—a department (DEMEGI) and a technological interface (INEGI). The high-degree centralities reveal their popularity and inherently their ability to interact in the automotive industry. Several local suppliers feature on their list of relationships. Another popular RTO is the technological centre for the metal industry, CATIM, which, according to the respondents, offers firms competitive prices for technical services, when compared with specialized suppliers whose logic is profit-seeking.

The last group of prominent organizations before 1995, in terms of number of relationships, is automotive suppliers ("yellow" nodes). The key element to highlight is that these suppliers maintain a series of links with supporting organizations. Apart from Faurecia, a first-tier supplier of seats, whose majority of links before 1995 occur with suppliers, the other suppliers in the top 15 organizations of degree have an interaction profile where

links with LSOs are very relevant. This context reinforces the role of LSOs as relevant knowledge possessors for automotive suppliers. For instance, Couro Azul, a supplier of leather components, maintains 22 links in the network. Most of these links occur with LSOs, ranging from PBOs, SFPs, research/technology organizations to facilitators.[3]

In terms of prominent automotive players, while AFIA, the Portuguese industrial association of automotive suppliers, remains the organization with the highest number of links after 1995 (cf. Figure 6), the generic picture post-1995 changes. Not only do automotive suppliers dominate the ranking of top 15 organizations in terms of degree centrality, but LSO facilitators are also replaced by RTOs. More importantly, the top automotive suppliers (Inapal Plásticos, Manuel da Conceição Graça and Inapal Metal) maintain a large number of links, many of which are established with LSOs. Another two automotive suppliers (Sunviauto and Fabrilcar), which have shifted towards niche segments, particularly demanding technologically, have also reported that the coordination of their technological efforts is being made with the collaboration of supporting organizations, namely research and technology ones.

The network cohesiveness is another indicator showing the relevance of LSOs in the network. Figure 7 portrays the maximum K-cores as a measure of cohesiveness. Before

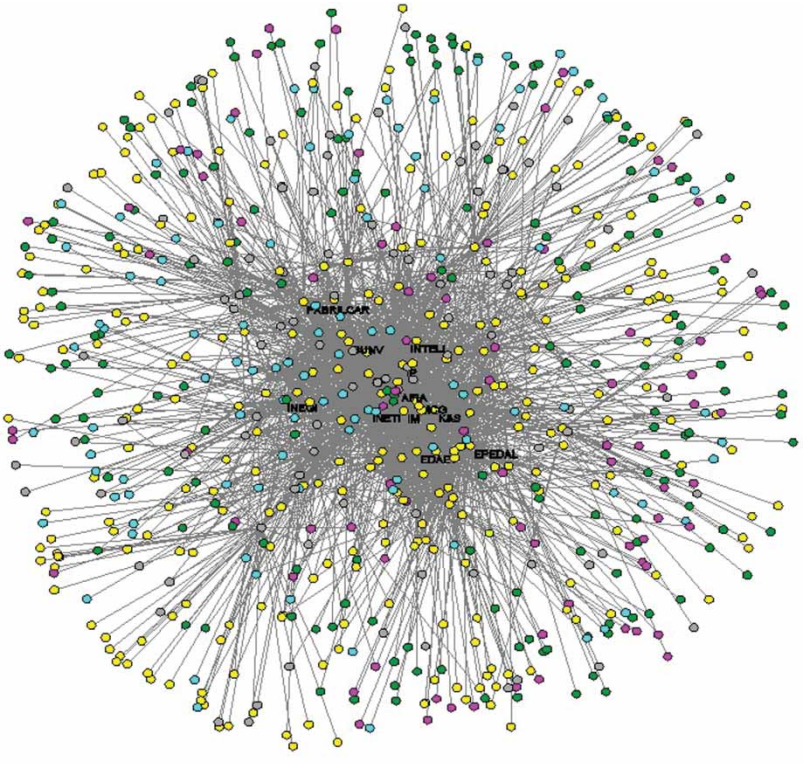

Figure 6. Networking among automotive suppliers and LSOs—after 1995.
Source: Authors.
Note: Yellow nodes, suppliers; blue nodes, RTO; green nodes, PBO; pink nodes, SFP; grey nodes, facilitators.

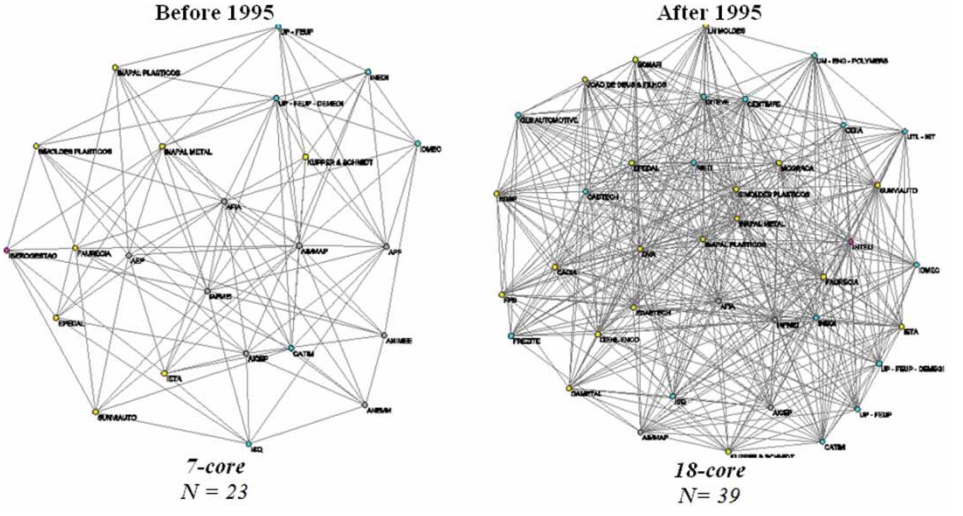

Figure 7. Automotive suppliers and LSOs: max K-cores, before and after 1995.
Source: Authors.

1995, the maximal subgroup was composed of 23 organizations, 16 of which are supporting organizations. In particular, facilitators (grey nodes) and RTOs (blue nodes) maintained important links with suppliers.

After 1995, the 18-core represents a subgroup of 39 suppliers and LSOs whose interaction is inserted in several projects (e.g. INOCOP; MIT programme). Initiatives like these reveal the importance of supporting organizations and their resources for the dynamics of industrial interaction.

Focusing our analysis on "innovation" networks among suppliers and LSOs, namely product (cf. Figure 8) and process (cf. Figure 9) innovation networks, we perceive how suppliers are developing their innovation activities and interacting with LSOs in the pursuit of their goals. Figures 8 and 9 provide a visual insight as to how different types of innovation exchange generate different structures of interaction, sizes of networks, as well as levels of density/cohesiveness.

In relation to the overall pattern of relationships, the exchanges of "product innovation" between suppliers and LSOs are more hierarchical than those for "process innovation". For the "process innovation" network, whereas the pattern is hierarchical in the periphery, the core is looser with organizations interacting through various and interlinked paths. Both innovation networks perform well in terms of density, which implies that relationships between suppliers and LSOs in terms of product development as well as industrialization/upgrades/validations of the production process have increased. Table 8 compounds the top six organizations, in terms of degree centrality, per content. The set of rows "All" indicates the organizations with the highest number of links regardless of content.

The selection of different contents of exchange refines our analysis on the role of supporting organizations. First, it confirms that LSOs achieve top positions in the ranking of degree, which reinforces their status on industrial networks. Second, it shows the emergence of different types of LSOs depending on the type of exchange.

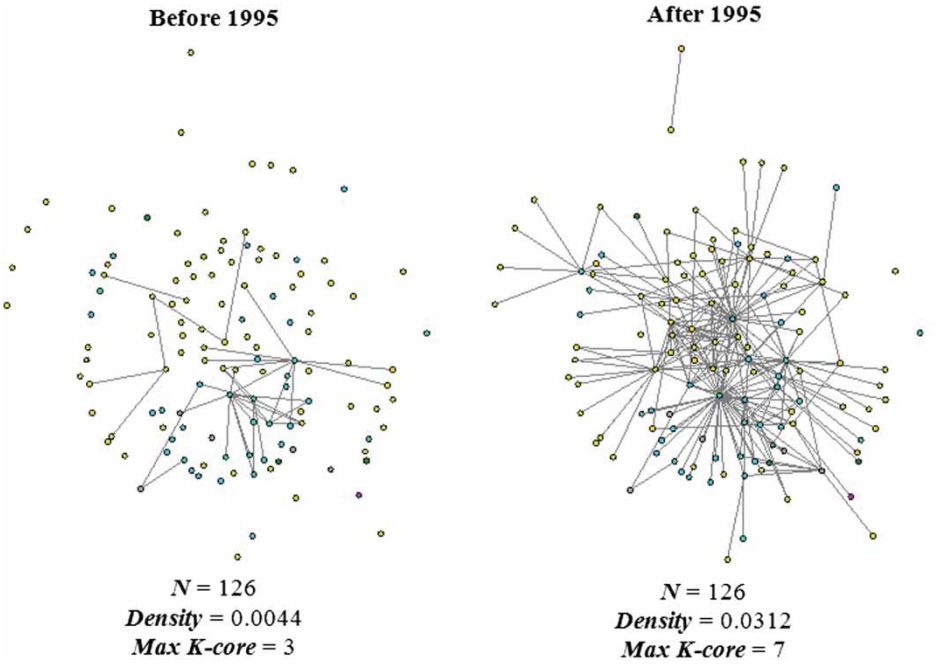

Figure 8. Dynamics of product innovation networking: suppliers and LSOs.
Source: Authors.
Note: Yellow nodes, suppliers; blue nodes, RTO; green nodes, PBO; pink nodes, SFP; grey nodes, facilitators.

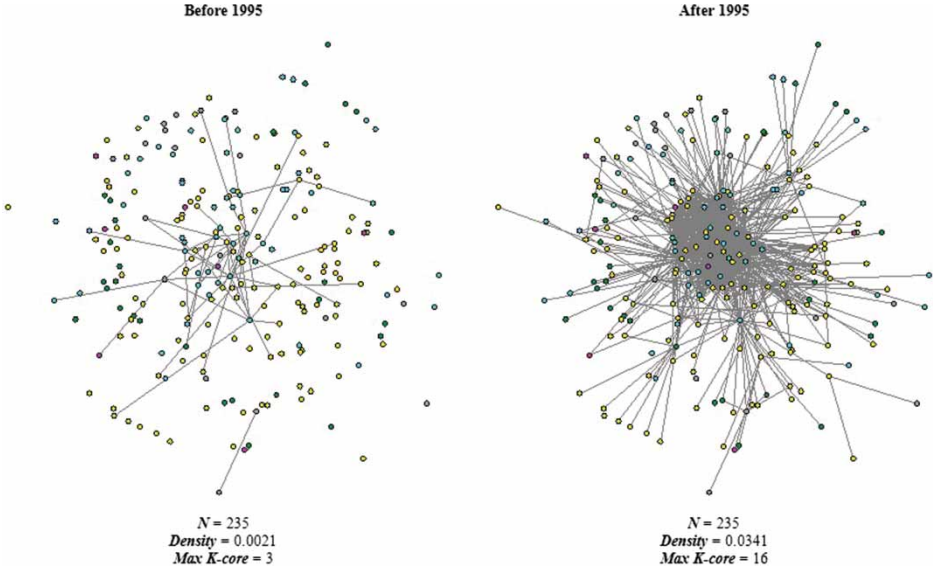

Figure 9. Dynamics of process innovation networking: suppliers and LSOs.

Table 8. Dynamics of content—top six organizations

	Before 1995			After 1995		
Content	Organization	Type	Degree	Organization	Type	Degree
All	AFIA	LSO Fac	45	AFIA	LSO Fac	126
	ANEMM		43	Inapal Plasticos	Supplier	96
	AIMMAP		34	MCGraca		88
	APIP		31	Inapal Metal		86
	IAPMEI		31	INETI	LSO Fac	85
	APF		29	IAPMEI		78
Product	INEGI	LSO RTO	10	INEGI	LSO RTO	44
	UM-Eng-Polymers		8	CEIIA		42
	UP-FEUP-DEMEGI		6	Sunviauto	Supplier	17
	Sunviauto	Supplier	3	INTELI	LSO SFP	16
	Simoldes Plásticos		2	Simoldes Plásticos	Supplier	15
	Kupper & Schmidt		2	UM-ENG-Polymers	LSO RTO	15
Process	CATIM	LSO RTO	11	Inapal Plasticos	Supplier	70
	ISQ		8	Inapal Metal		69
	UM-ENG-Polymers		8	MCGraca		67
	UP-FEUP-DEMEGI		7	CENTIMFE	LSO RTO	64
	INEGI		6	Simoldes Plásticos	Supplier	51
	INESC Porto		5	INEGI	LSO RTO	48

Source: Authors' calculations.
Note: RTO, research and technology organizations; PBO, production-based organizations; SFP, strategic factor providers; Fac, facilitators.

For "product innovation" networks, RTOs are popular organizations before and after 1995, reflected in their high number of links in the network. The technological interface related to mechanical engineering from the University of Porto (INEGI) is the most popular organization in the two periods. CEIIA, the centre of excellence and innovation in the automotive industry, maintains 42 "product innovation" links in the network after 1995. These links involve activities of product design and development. The emergence of the centre was the result of an opportunity to articulate a collective dynamic of innovation and improve the value-chain of suppliers in Portugal. In this context, CEIIA is a post-1995 organization, which represents the joint effort of public and private domains: 32 of its 42 links occur with automotive suppliers, a result that confirms the success of this public initiative. Sunviauto, an automotive supplier of seats and its components, is also relevant in this network. Among its links are ACECIA, the collaboration project for the design and development of a seat module; relationships with two technological organizations—CEIIA and INEGI; and links with first-tier seat suppliers (Faurecia, Lear, Johnson Controls and Magna).

In relation to "process innovation" networks, LSOs are also relevant automotive organizations but suppliers, especially after 1995, achieve top positions in terms of degree centrality. Before 1995, the top positions were disputed among the two technological

centres—CATIM (metal) and ISQ (welding)—and one university department—polymers from the University of Minho. Helena Gouveia, from ISQ, mentioned the centre's work with several automotive suppliers (e.g. CACIA, IETA, DVA, MCG, SGSP, MDF and Tavol) in terms of the production process in areas such as maintenance, welding, quality control, standards and technical assistance. The department of polymers engineering of the University of Minho revealed a tradition of links with plastic component suppliers (e.g. Simoldes plásticos, AIS, Celoplás, Plasdan, Yazaki saltano and Key plastics) for technical support to their production process (optimizations of the process and adaptations to the equipment).

5. Conclusion

Three main research gaps in the domain of networks motivated the present empirical study. First, the fact that most of the network studies, while generally recognizing the existence of a broad range of organizations (Koschatzky, 1999; Molina-Morales & Martínez-Fernández, 2011), tend to mainly address the participation of homogeneous organizations, in the form of inter-firm networks; the role of supporting organizations and their intermediary status has been only partially addressed. Second, the need for a clearer differentiation of the networks' contents in the process of innovation (e.g. Lambooy, 2004; Moran, 2005; Rothaermel & Deeds, 2004). Third, the neglecting of the networks' dynamics (Bessant *et al.*, 2012)—current empirical literature emphasizes static approaches that study the outcome of interaction, namely the rationales of network formation.

This study aimed to overcome such lacunas by proposing a hybrid and dynamic approach to networks based on a wide spectrum of network organizations, which explicitly takes account of their heterogeneity.

Using as empirical basis the evolution of the industrial networking of the Portuguese automotive industry, comparing the structure, boundaries and content of the network

Table 9. Summary of main findings

	Before 1995 (Importance)					After 1995 (Importance and trend)				
	Suppliers	RTO	PBO	SFP	Fac	Suppliers	RTO	PBO	SFP	Fac
All contents	++	+	0	0	+++	+++ ↑	+ →	0 →	0 ↑	+ ↓
Product Innovation	+++	+++	0	0	0	+++ →	+++ →	0 →	++ ↑	0 →
Process Innovation		+++	0	0	0	+++ ↑	++ ↓	0 →	0 →	0 →

Source: Authors computation and summary based on a network of relationships among suppliers and LSOs composed of 807 organizations (regardless of the content of interaction), derived from face to face interviews to 28 automotive suppliers and 26 LSOs.

Notes: RTO—research and technology organizations: private (technological centres and interfaces) and public organizations (laboratories, university departments); PBO—production-based organizations: suppliers of raw materials, equipment and logistics; SFP—strategic factor providers: suppliers of resources for the firms' activities, but at an intangible level—training, consultancy and certification; Fac—facilitators: institutional support from industrial associations and government agencies.

before and after 1995 (the start of operation of the AutoEuropa, a major FDI investment) and applying SNA techniques, we managed to uncover some interesting findings.

The hybrid and wider framework of analysis permitted to disclose that similarly to organizations, networks present over time substantial turbulence in their structure. Some actors (e.g. suppliers, RTOs and SFPs) gained prominence in the innovation networks whereas others (e.g. facilitators) faded away (cf. Table 9). Moreover, the relative importance of actors in the networks was intimately dependent on networks' content. Indeed, the centrality of suppliers and RTOs was particularly notorious in product innovation networks.

It was demonstrated that in a peripheral context (Portugal), the successful broad implementation and operationalization of a major project in a technological complex and dynamic industry (automotive), where knowledge is highly distributed and hence innovation is particularly reliant on several players, was strongly dependent on the LSOs, most notably RTOs. These organizations were fundamental for the enhancement of suppliers' (firms) innovation and absorptive capabilities. Indeed, the increase in density and cohesion levels after the start of AutoEuropa foreign direct investment reveals that interactions between automotive suppliers and LSOs bolstered over time. Despite the importance of LSOs, suppliers emerged as increasingly central actors in innovation networks, consistent with the identified global challenge on the side of automotive suppliers of assuming more developmental responsibilities (ITA-USA, 2011).

By addressing different types of innovation exchanges (namely product and process innovation)—a key source of networking—we were able to determine how firms (automotive suppliers) are developing their activities and interacting with (and each type of) LSOs. We found explicit evidence for the intermediary role of LSOs in terms of the innovation activities of suppliers. As possessors of relevant resources for product innovation, as well as upgrades and validations of the production process, LSOs are key innovation partners for automotive suppliers.

Acknowledgements

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Notes

1. In 2001, it accounted for 2.5% of the national GDP, 11% of total exports and generated nearly 3600 direct jobs (NORTINOV, 2004). AutoEuropa, now (2012) fully owned by Volkswagen, has consistently been among Portugal's top three exporters (Simões & Cartaxo, 2011).
2. The face-to-face interviews were carried out in 2007. The interviews were recorded and lasted, on average, 1 hour and 15 minutes. The interviewees were top managers/directors that were in the organizations before and after 1995 (when AutoEuropa started operating). The respondents were asked in 2007 about their pre- and post-1995 perceptions about networking. Although the data reflect subjective perceptions, the interviewees' responses were, in general, complemented with documentation which confirmed the referred linkages among organizations.
3. Couro Azul stands as a specific example of a supplier that accesses technological resources outside its boundaries, by networking with supporting organizations. Pedro Carvalho, director of Couro Azul, explained how the in-house technological efforts were complemented with collaborations with universities, technological centres and interfaces.

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