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Supply chain of innovation and new product development

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ABSTRACT

This paper conceptualizes the supply chain of innovation of a company as its supply chain not related to physical goods exchanges but to R&D commodities exchanges. R&D commodities, being the outcomes of research activities, are for example patents, technologies, research services, studies, projects, etc. Specifically, we focus on the relationship between the activities of purchasing/selling R&D commodities and the propensity of the firm to develop new products; we examine how the position of the firm within its innovation network moderates this relationship. The empirical setting of the research consists of a cross-sectional dataset of 544 biopharmaceutical companies that have signed 1772 R&D agreements in the years 2006–2010. We find firstly, evidence of the supply chain of innovation (as a natural evolution of the well-acknowledged dual-market model of the biopharmaceutical industry). Secondly, we find that the relational embeddedness, coming from innovation network, influences the effect of purchasing and selling R&D commodities on new product development. Supporting our theoretical predictions, this paper offers contributions to the scientific literature on supply chain relationships in new product development.

1. Introduction

The movement of firms towards opening their new product development (NPD) process, for example by involving and integrating with suppliers, has rapidly increased since the 1990s (Harland, 1996). For this reason the operations and supply chain management academic community, in the last two decades, has deeply investigated collaboration models in NPD, such as supplier involvement (Johnsen, 2009) and customer integration (Flynn et al., 2010).

However, besides collaborating with suppliers and customers during the NPD process, companies did also start using external competencies and exploiting internal knowledge in the form of R&D commodities by directly purchasing and selling them from and to external parties. External parties include universities, research centers, other companies, but also suppliers and buyers (Pilkington, 1999). R&D commodities are R&D products or activities that can be purchased and/or commercialized, such as R&D services, projects, patents, technologies and licenses.

While the operations management literature has put much effort in exploring the effects of collaboration with traditional suppliers and buyers on NPD performance, much less attention has been paid to analyse the effect on NPD of purchasing and selling R&D commodities to and from external parties. However, a lot of empirical works have demonstrated that these more and more adopted practices strongly influences the innovation performance of the firm (Mazzola et al., 2012; West et al., 2014). For this reason, when designing the NPD process, managers should take into account precise considerations about the consequences of R&D purchasing and selling on the outcome of this process.

To fill this gap, in this paper we explore the relationship between R&D purchasing/selling activities and the firm's NPD, and we conceptualize the *Supply Chain of Innovation* (SCoI), as the supply chain not related to the material flow but to the R&D commodities flow. We, indeed, observe that the propensity of a company towards purchasing and selling of R&D brings the company to position itself along the SCoI. Positioning downstream makes the company closer to the final market, and thus it will be stimulated more than others to develop new marketable products. Conversely, positioning upstream makes it closer to the R&D market, and thus the company will be stimulated more than others to develop and sell R&D commodities instead of end-consumer products. In other words, in this paper we use the SCoI lens to understand and interpret the consequences of R&D purchasing and selling in terms of NPD performance.

Actually, besides being positioned within the SCoI, the company is also surrounded and embedded in a more complex web of

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inter-firm relationships (Wu, 2008). Each company, indeed, not just buys and sells R&D commodities in order to acquire or exploit knowledge, but also signs alliances and other bilateral agreements with other companies for similar purposes. From the complex network of relationships surrounding each company, the company itself can benefit in terms of resources and information acquisition (Granovetter, 1992). Specifically, following the recent expansion in research incorporating different strategic management perspectives in the field of operations and supply chain management (Mol, 2003; Krause et al., 2007; Meehan and Bryde, 2014), we absorb social capital view in studying the effect of "being part of a network" on the NPD process. We consider that the quality of the information that a company gains from its network depends on its *relational embeddedness* in the network, i.e. the quality of relationships that the ego firm builds with its partners (Granovetter, 1992; Uzzi, 1996; Meehan and Bryde, 2014). There is a wide consensus among researchers that the firm's embeddedness and its position in a network of relations matter for its NPD (Soh, 2003; Pérez-Luño et al., 2011; Mazzola et al., 2015). For this reason, in this paper we also explore whether relational embeddedness enhances or reduces the effect of R&D purchasing and selling on NPD.

The empirical setting of this study consists of the total set of agreements signed by biotech companies listed in *BioWorld* database 2006–2010, where biotech company means both pure biotechnological, and biopharmaceutical. We use this setting in order to find evidence of the existence of the SCoI and of the phenomenon of firms' positioning along it. Indeed, the advent of biotechnology as a new paradigm changed the shape of the classical pharmaceutical industry into a dual market structure (Pisano, 1991; Chiesa and Toletti, 2004; Narayana et al., 2014). Biotech firms are focusing on producing and commercializing different R&D commodities, and thus are positioning themselves along the SCoI.

2. The supply chain of innovation

The supply chain management literature has deeply investigated the role of collaborating with suppliers and buyers in the NPD process. For example, Twigg (1998) examines the relationships between a vehicle manufacturer and six key suppliers which contribute to the final design of products; the author terms 'design chain' the interaction of design information between each supplier and customer. In fact, several collaboration modes with suppliers and customers in NPD have been analyzed: supplier innovation generation (Jean et al., 2012); early supplier involvement (Koufteros et al., 2005; Johnsen, 2009); supplier involvement and investment (Song et al., 2011); supplier integration (Petersen et al., 2005; Ettlie and Pavlou, 2006; Swink et al., 2007); supplier development (Krause et al., 2007); and customer involvement (Flynn et al., 2010).

To achieve the same objectives of collaboration for NPD, in the last ten years companies started purchasing and selling R&D commodities in many industries: for example, this behavior has been identified as one of the main trends in the biopharmaceutical industry (Chiesa and Toletti, 2004; Birch, 2008). This phenomenon lets us argue that, mostly in high-tech industries, a new kind of supply chain is emerging: namely, the supply chain of innovation (SCoI). We define the SCoI of a company as the supply chain not related to the material flow but to the innovation flow. Physical goods are replaced by patents and the material flow supply chain is replaced by the innovation-flow supply chain.

To make our research context clear, it is essential to specify the difference between material-flow supply chain (SCoM) and innovation-flow supply chain (SCoI).

According to Christopher (1992) a SCoM is a chain (or network) of organizations that are involved in the different transformation processes that add value to one specific product and that bring it to the hand of the ultimate consumer. For instance '[…] *a shirt manufacturer is a part of a supply chain that extends upstream through the weavers of fabrics to the manufacturers of fibers, and downstream through distributors and retailers to the final consumer*' (Christopher, 1992, p. 12). And indeed, it is usually referred to as the supply chain of a product.

Contrarily, the SCoI is a chain (or network) of organizations involved in the innovation process and not in the transformation (manufacturing) process. For this reason, it is better to conceptualize the SCoI as a chain which is not product-centered, but company-centered. It is the network of businesses including buyers (and buyers' buyers) and suppliers (and suppliers' suppliers) involved in the innovation process of a given company, the focal company. This definition is also in line with one of the major use of the term 'supply chain management' as indicated by (Harland, 1996, p. 64): '*There are four main uses of the term 'supply chain management':* […] *Thirdly, the management of a chain of businesses including a supplier, a supplier's suppliers, a customer and a customer's customer, and so on*'.

To illustrate an example of SCoI, consider the following buyer–supplier relationships that Amgen, a large biopharmaceutical company, was recently involved in. We found that Amgen licensed-out 13 molecules to Takeda Pharmaceutical Co. Ltd. Conversely, Amgen has licensed-in the 'Cabily' patent family from Genentech Inc., which in turn has purchased research services on multiple drug targets from Sareum Holdings. Of course, these supply chain relationships do not necessarily refer to the same molecule, but they refer to R&D purchasing and selling related to Amgen (independently from specific molecule) with its suppliers and buyers. We also found many other companies (biotech, biopharmaceutical, big-pharma, universities, clinical research organizations, etc.) that were involved in the supply chain of Amgen.

To make clear the difference between the SCoM and the SCoI we summarize the main characteristics of these two types of supply chain in Table 1.

The typical actors involved in the SCoM are suppliers, manufacturers, distributors, and others, which buy from each other (or sell to) physical goods. The objects of each commercial transaction are raw or semi-manufactured parts and components that, thus, flow from upstream to downstream along the supply chain. Contrarily, the actors in the SCoI are research centers or high tech companies which exchange R&D commodities. A supplier in the SCoM, for example, could be a high-tech company with a large body of knowledge (and patent stock) which also sells its R&D commodities to its customers. From the customer side, a company could buy both physical materials and R&D commodities from the same supplier.

The R&D commodity (e.g. a research service, project, patent, technology, or license) is the object of the commercial transaction and the terms 'supplier' or 'buyer' are meant as provider or user of an R&D commodity. The final product (meant as final result) of the SCoM is the product on the hand of the customer. The final product of the SCoI is, instead, the final outcome of the innovation process, for example a new developed product which has not been industrialized yet.

The typical buyer–supplier relationships in the SCoM are transactional, unless products are co-produced and/or co-distributed. However, while the main goal of the SCoM is transforming raw materials into finished products, its actors are also involved in the new product development process. To this purpose, bilateral agreements (supplier involvement, customer integration, etc.) among firms are necessary to support innovative activities as they can facilitate complex coordination beyond what

Table 1
Main features of the supply chain of materials (SCoM) and the supply chain of innovation (SCoI).

	Goal	*Typical supply chain actors*	*Object of buyer–supplier transaction*	*Supply chain final product*	*Buyer–supplier relationships for material exchange*	*Buyer–supplier relationships for New Product Development*
SCoM	Transforming raw materials and parts into a finished product that is delivered to the end customer	Material Suppliers, Manufacturers, Assemblers, Distributors, Retailers	Raw materials, parts, components	End-customer products	Mostly transactional oriented	Mostly relational oriented
SCoI	Transforming ideas and knowledge into a new product not yet industrialized	Research centers, Universities, High-tech companies (also from SCoM), Knowledge brokers	R&D commodities (patents, technologies, research projects)	Prototypes, new products to be industrialized	–	Mostly transactional oriented

the market can accomplish (Teece, 1992). For this reason, in the SCoM, buyer–supplier relationships for NPD are mostly relational oriented. Besides bilateral agreements, the set of relationships the company enters for NPD purposes, is also enriched by transactional agreements that the firm signs with actors, which are not necessarily involved in the SCoM, for acquiring new knowledge. For example Amgen has licensed-in the 'Cabily' patent family from Genentech Inc. which is not a supplier of Amgen in the SCoM. The set of these unilateral and mostly transactional oriented "buyer–supplier relationships" constitutes the SCoI.

From a different perspective, the SCoI can be seen as a subset of the complex network of relationships constituting the innovation network in which the company is embedded. It includes only specific kinds of relationships, i.e. those transactional that are related to the purchase and selling of R&D commodities. Neither vertical bilateral collaborations (such as early supplier involvement or customer integration) nor horizontal bilateral collaborations (such as R&D joint venture, co-patenting or co-development) are included since they do not explicitly concern a pure buyer–supplier commercial transaction.

As an example, the lower part of Fig. 1 models the numerous actors participating in the process of innovation in the biotech industry. They include biotech firms, biopharmaceutical firms, big-pharma firms, research institutes, universities, CRO, CMO, biotech platforms, etc. Also, different typologies of relations can be found, such as alliances, licensing agreements, research collaborations, production, marketing and distribution agreements, R&D outsourcing, R&D joint ventures, co-patenting, etc. The upper part of Fig. 1 models the SCoI, and thus only reports transactional relationships of the type buyer–supplier.

The *relational embeddedness* of a company within the whole innovation network has been conceptualized by Koka and Prescott (2002) as the dimension of social capital that yields different information benefits in the form of information richness, i.e. the quality and nature of information that a firm can access through its relationships. The level of relational embeddedness of the company within the network is strictly related to its position within the complex network structure (Moran, 2005). The network structure is shaped by the intricate webs of interfirm relationships, such as buyer–supplier relationships, strategic alliances, joint ventures, R&D agreements, licensing agreements, joint memberships in industry associations, and every form of collaboration. The network created by all these inter-firm relationships (not just SCoI relationships) is a conduit for information.

The nature of this information could be beneficial for the effectiveness of R&D purchasing and selling relationships within the SCoI. This is why, besides the position of the company within the SCoI, in this study we also take into account the whole innovation network structure where the company is embedded.

3. Conceptual model

In order to develop our conceptual model (Fig. 2) we combine SCoI and innovation network views. Firstly, we explain the influence of purchasing and selling R&D on the NPD process. Secondly, we consider how the characteristics of the innovation network in which the firm is embedded may affect the benefits or disadvantages of purchasing and selling R&D, due to the information richness the company gains from its relationships.

3.1. SCoI and NPD process: the role of purchasing and selling R&D

The impact of collaboration practices in the NPD with suppliers, customers and other SCoM actors has been very much investigated in the operations and supply chain management literature

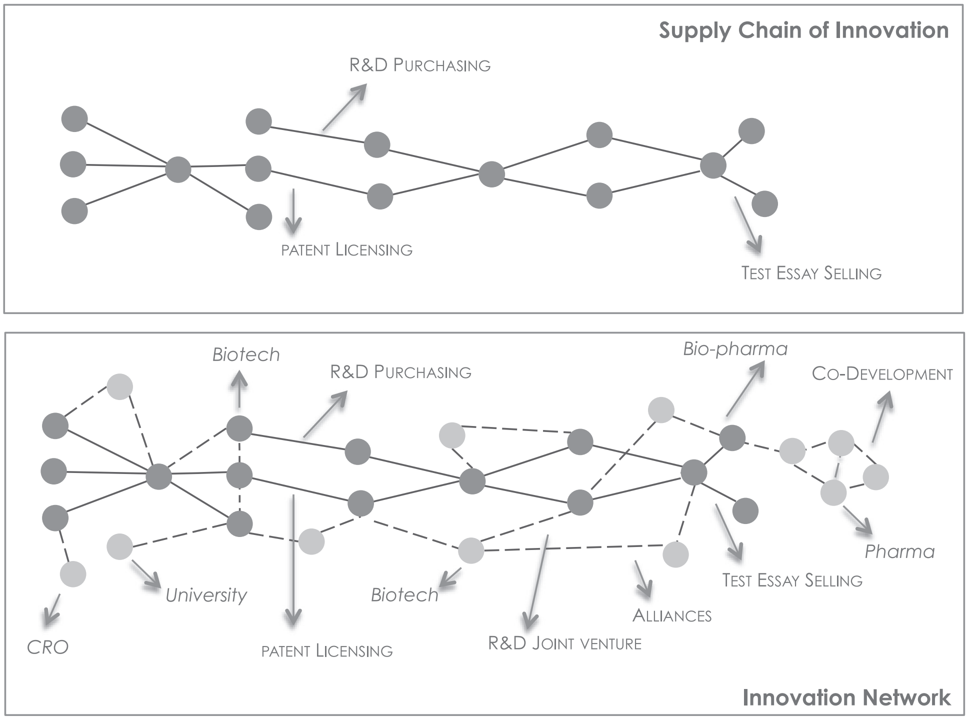

Fig. 1. The supply chain of innovation as a subset of the innovation network.

(Johnsen, 2009). For example, Salvador and Villena (2013) analyse the impact of supplier involvement on technical performance of new products. Supplier integration has been largely found to be related to product development performance (Ragatz et al., 2002; Petersen et al., 2005; Koufteros et al., 2007; Humphreys et al., 2007). Conversely, customer integration has been found to be related to customer satisfaction, both directly (Homburg and Stock, 2004) and indirectly, through its relationship to product development and innovation (Koufteros et al., 2005; Song and Benedetto 2008).

The positive effect of collaboration practices, as well as collaborative competences, on the NPD process has thus been largely demonstrated in the supply chain management literature on NPD (Mishra and Shah, 2009) and has been justified in terms of the value creation and knowledge sharing arising from the relational nature of these bilateral agreements (Menguc et al., 2014).

In fact, besides collaborating with SCoM partners, a firm could acquire external knowledge and technology by in-licensing and/or purchasing R&D services, projects, intellectual properties, and patents by other firms (Tsai and Wang, 2009; Chiaroni et al., 2010; Mazzola et al., 2012). These practices are transactional in their nature.

So, the same kind of benefits resulting from collaboration practices in SCoM could also be achieved by less costly transactional relationships in SCoI, at least in those industries where a market of R&D exists, such as in the high-tech industries. When the market offers a high number of companies that sell R&D commodities, then acquiring external knowledge by signing transactional agreements becomes a possible practice which is also less costly to coordinate respect to achieving the same objective by collaborating. For instance, in the biotech industry it is very common that companies share knowledge and create value by purchasing test assays, pre-clinical programs, licenses for using technologies and platforms, etc.

Relying on external, already-developed knowledge and technologies enables a firm to improve its NPD process since it decreases, for example, the time to develop the product, and improves its pre-emptive advantage, or limits competitors' first-mover advantages (Tsai and Wang, 2009). Given that in high-tech industry external knowledge and technologies acquisition is achieved by SCoI transactional agreements, and being R&D purchasing surely a way to acquire external knowledge, we state the following hypothesis:

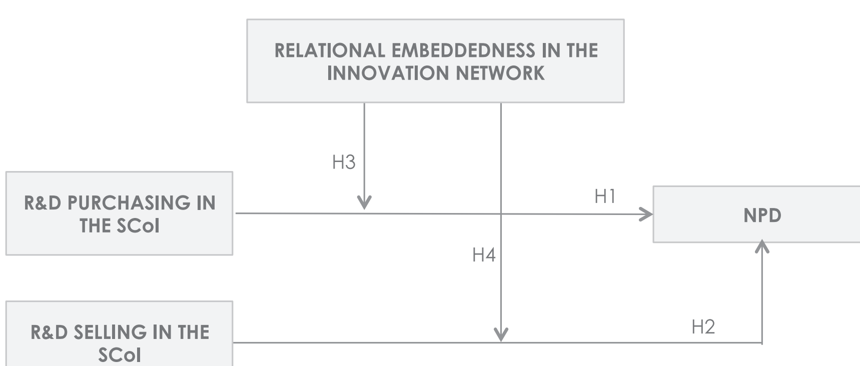

Fig. 2. The conceptual model.

H1. In a supply chain of innovation the purchase of R&D commodities is positively related to firms' new product development.

The advent of biotechnology as a new paradigm changed the shape of the classical pharmaceutical industry into a dual market structure (Pisano, 1991). Conventional big pharmaceutical firms have increasingly become dependent on small and medium biotechnology companies for new discoveries in the upstream. Without inflow of science-based knowledge, big-pharma companies face strategic challenges in competing in the global market (Powell et al., 1996; Sabatier et al., 2010). On the other hand, small and medium biotechnology firms in the upstream, by licensing-out or by forming joint ventures, can commercialize their discoveries without further developing those discoveries to a final product. In sum, it is well recognized that companies belonging to the downstream side of the Pisano's dual market structure develop more new products than those belonging to the upstream side.

In this paper, we instead argue that things are not black and white. We hypothesized that there is not just a dual market structure where companies behave in two different ways. Alternatively we think that there is a gray scale between upstream and downstream due to the existence of a complex supply chain of innovation. There are not companies that just focus on developing and selling R&D (upstream side of Pisano's dual structure) and on buying and exploiting R&D by industrializing and commercializing end-consumer products (downstream side), but there is a continuum in the propensity of a company on selling and purchasing R&D. Such a propensity determines the position of the company along the SCoI.

The more the company is specialising in developing R&D commodities and selling them in order to generate additional revenues, the more this behavior makes the R&D selling business its main business. This, in turn, will consolidate the upstream positioning of the company in the SCoI and will distance it from the stage of developing consumer-marketable products.

We thus state our second hypothesis:

H2. In a supply chain of innovation the selling of R&D commodities is negatively related to firms' new product development.

3.2. SCoI and NPD process: the moderating role of relational embeddedness

The information benefits available to a firm differ based on its network structure, its overall experience of relationships and its history with current partners. *Relational embeddedness* has been associated with richer access to information for the ego firm (Meehan and Bryde, 2014). For example, being a member of a clique (a sub-network in which any company is directly connected to any other company in the sub-network) increases the relational embeddedness of the company within the network by enhancing the connectivity density of members within the clique (Wasserman and Faust, 1994). This ensures that information introduced into the clique will quickly reach other companies in the clique. Being relational embedded also enhances the fidelity in the information received and increases the formation of trust and norms among companies (Schilling and Phelps, 2007). Being relational embedded allows companies to gather superior information on each other by reducing in this way the information asymmetry that increases the likelihood of opportunistic behavior.

Also, the information richness that a company gets from its whole innovation network positively influence its knowledge-absorptive capacity (Cohen and Levinthal, 1990), and may increase the opportunities for learning and for developing skills in managing the new product development process. Given that SCoI practices, such as purchase and selling of R&D commodities, allow knowledge to flow in and flow out, the information richness coming from the whole network (not just from the SCoI) needs to be fully considered when studying the effects of such practices on new product development. For instance, by creating routines among partners, the partner firms develop shared schemas, and better understanding of the knowledge flow coming from having purchased a specific R&D commodity. Also, the information richness may leverage knowledge use and increase knowledge-exploitation opportunities. Firms more relational embeddeded more likely are involved in a high number of R&D projects: this surely proliferates the opportunities for exploiting the knowledge arising from having purchased a specific R&D commodity.

Therefore we expect that relational embeddedness, which boosts information richness, enhances the positive effect of purchasing R&D commodities on new product development.

Summing up, this leads to our third hypothesis as follows:

H3. In a supply chain of innovation the impact of purchasing R&D commodities on firms' new product development is moderated by its relational embeddedness in the whole innovation network: the higher the relational embeddedness, the greater the benefit from purchasing R&D.

Going back to our conceptualisation of the SCoI, we consider now those firms that re-focus their core business in selling R&D commodities, and position themselves along the supply chain closer to upstream stages. We have already discussed how, in the SCoI, R&D suppliers license out or commercialize their discoveries, without further contributing to the development of those discoveries into final compounds. Once again, this specialization brings interesting results in terms of economic-financial performance while bringing negative effects in terms of the development of final products.

Now we argue that, even in the case in which the company focuses on producing and selling R&D commodities, information richness deserves to be fully considered when studying the effects of such R&D selling practices on NPD. Indeed, the information richness that a company gets from its innovation network positively affects its performance. Koka and Prescott (2002) and Malik (2012) identify a number of reasons underlying the positive link between relational embeddedness and the performance of firms. Being as the development and selling of R&D commodities is the main business of a supplier within the SCoI, the information richness positively influences its performance in conducting such business. This, in turns, enforces the company business position upstream in the SCoI, and better distinguishes its role with respect to that of a final drug developer. Therefore, we expect that this network characteristic, which boosts information richness, amplifies the negative effect of selling R&D commodities on the development of new products.

We thus state our fourth hypothesis:

H4. The impact of selling R&D commodities on firms' new product development is moderated by the relational embeddedness: the higher the relational embeddedness, the greater the damage from selling R&D.

4. Research method

4.1. Sample and data

We chose the biotechnology industry as the research setting because it is characterised by a high level of innovation processes (Rothaermel and Deeds, 2004; Sabatier et al., 2010), and because we found evidence of the existence of SCoI within this industry.

We gathered data from multiple sources about new products, number of patents, R&D purchasing and selling, and network characteristics. We obtained data on inter-firm relations through *BioWorld* database, an online information service providing daily news and analysis, stock indices, company coverage, regulatory and patent reports, and other biotechnology information. Among the different sections available on *BioWorld* database, we exclusively collected data about relations between biotech companies in the years 2006–2010, where biotech company means both pure biotechnological and biopharmaceutical. The full dataset includes 1772 agreements among 1842 biotechnological firms.

From this dataset, we then selected only public companies, specifically 544 firms, to ensure the availability and reliability of firm-attribute data. This approach is quite common in this kind of study since it does not affect the sample through selection bias (e.g. Stuart et al., 2007; Malik, 2012). Thus, we collected data about new products, patenting and firm-attributes of this selected sample. The SCoI and the whole innovation network data of each of these 544 firms are computed by considering their relationships with all the companies included in the full dataset. We retrieved data on new product development from the 'biotech products' section of *BioWorld* database. The patenting data are retrieved from the US Patents Office database. Finally, we collected firm-attribute data from the companies' annual reports.

4.2. Variable definition and operationalisation

4.2.1. Dependent variable

The dependent variable (*New products*) measures the total number of new biopharmaceutical products introduced in the market throughout 2010–2012. To assess different lag specifications between SCoI practices, relational embeddedness (*Relational_Emb*) and new products, we adopt a moving window approach (Bae and Gargiulo, 2004; Salman and Saives, 2005); following this approach, the dependent variable is calculated considering the three years succeeding the five-year biotech-biotech agreements' observations, that is the period 2010–2012. Thus, we have computed the biopharmaceutical products marketed from the end of 2010 to the end of 2012.

4.2.2. Independent variables

As concerns the SCoI, we consider the two following explanatory variables: *R&D purchasing* and *R&D selling*. We measure the variable R&D purchasing by counting how many times each company purchases R&D commodities such as R&D services, test assays, pre-clinical programs, licenses, and so on. We measure the variable R&D selling by counting how many times each company sells R&D commodities. These two measures are calculated between 2006 and 2010, by using agreements' data collected from the *BioWorld* database. For example, we selected the agreement signed by Gruenenthal GmbH and Forest Laboratories, in which the latter has licensed-in a patent from the former. The description of the agreement provided in *BioWorld* is:

> *Licensing agreement for phase 2 small-molecule analgesic GRT 6005 and follow on compound GRT 6006 to Forest Laboratories. Forest will pay an up-front fee, milestones and royalties in exchange for U.S. and Canadian rights..*

With regard to the innovation network, we consider the explanatory variable: relational embeddedness, measured through the number of cliques the company is embedded in. We adopt this measure for relational embeddedness because being part of a clique increases connectivity density of partners. Indeed, the multiple pathways between firms ensure that information will quickly reach all the companies in the clique, enhance the fidelity in the information received, and increase the trust in each other (Wasserman and Faust, 1994; Rowley et al., 2005; Vanhaverbeke et al., 2009). We measured this number by using UCINET VI (Borgatti et al., 2002), a network analysis program that computes network variables using dyadic data. Specifically, in line with the prior research (Rowley et al., 2005), we used the 'Network > Subgroups > Cliques' procedure implemented in UCINET VI to detect the presence of relevant cliques; this procedure facilitates the measuring of how many cliques each company is embedded in. To calculate this network measure we first collected *BioWorld* data into an inter-firm relationships matrix, containing all the agreements established among the 1842 biotech firms throughout 2006–2010. We recorded each agreement in five binary nxn (one per observed year) adjacency matrixes, A^t, where n^t is the number of firms present in the year t. For each matrix, the term A^t_{ij} is set to 1 if company i and j had signed an agreement in year t, otherwise 0. Then, we activated the UCINET procedure (as described above) to compute the clique value for each company for each year. Finally we computed the average clique for each company throughout the years.

4.2.3. Control variables

We include six control variables to remove any potential confounding correlation of other factors on the firms' new product development.

We control for *patent stock*, since it reflects the level of technological capital, absorptive capacity and R&D know-how of a company (Vanhaverbeke et al., 2009). Specifically, we measure the natural logarithm of the number of firm patents obtained in the thirty years prior to 2010. Following previous researches, we add the number of products in the *pipeline* as control since they represent accumulated stocks of knowledge (DeCarolis and Deeds, 1999). The firms' product pipeline is measured by the natural logarithm of the number of products companies had in each of the significant stages of the pipeline in 2010. Next, the *age* of a company is also included as control variable (Vanhaverbeke et al., 2009). We operationalize firms' age as the number of years from the date of founding to 2010. Furthermore, we include the natural

Table 2
Descriptive statistics and correlation matrix.

	Mean	*Std. Dev.*	*Min.*	*Max.*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	VIF
1. New products	0.18	0.71	0	11	1.00										
2. Patent stock	1.68	1.84	0	8.11	0.29	1.00									1.59
3. Pipeline	1.10	0.53	0	1.94	0.21	0.11	1.00								1.11
4. Age	23.14	26.94	0	358	0.07	0.26	0.09	1.00							1.12
5. R&D investment	2.69	1.78	0	9	0.33	0.57	0.25	0.22	1.00						1.62
6. Industry	0.62	0.48	0	1	0.01	0.03	−0.12	0.15	0.08	1.00					1.07
7. Nationality	0.37	0.48	0	1	−0.07	−0.12	0.08	0.07	−0.08	−0.09	1.00				1.06
8. R&D purchasing	0.90	1.68	0	23	0.11	0.15	0.06	0.02	0.10	−0.01	−0.01	1.00			1.10
9. R&D selling	0.82	1.59	0	22	0.02	0.15	0.10	0.01	0.12	−0.10	−0.01	0.26	1.00		1.68
10. Relational_Emb	0.06	0.43	0	8	0.18	0.12	0.09	0.04	0.12	−0.10	0.05	0.23	0.61	1.00	1.65

logarithm of average R&D expenditures in the years 2006–2010 as proxy of firms' *R&D investments* (Ahuja, 2000; Bae and Gargiulo, 2004). We include an *industry* dummy variable to indicate whether a company is a biotechnological or a biopharmaceutical (Vanhaverbeke et al., 2009). Finally, we consider the *nationality* of the firm as control (Ahuja, 2000; Phelps, 2010; Vanhaverbeke et al., 2009).

5. Results

The dependent variable is a count variable that takes only non-negative integer values, that is the number of new biotechnological products a firm successfully marketed 2010–2012. A Poisson regression approach provides a natural model for such typology of data (Hausman et al., 1984). However, a Poisson regression assumes that the mean and variance of the count variable are equal. This assumption is likely to be violated since over-dispersion usually occurs in new product count data. Over-dispersion requires the use of a negative binomial estimation (Un et al., 2010); therefore, we test our hypotheses by using a negative binomial regression.

Table 2 provides the descriptive statistics and the correlations between all the variables for the 544 public companies in the selected sample. The correlation coefficients between the independent variables are quite low. Also we calculate, and report in the last column of Table 2, the variance inflation factor (VIF) value, a more advanced measure of multicollinearity than simple correlations (Stevens, 1992); the VIF values are below the critical level, indicating that the explanatory variables can simultaneously be included in the models (Gujarati, 1995).

Descriptive statistics firstly show that the number of new developed product is quite low in our sample (on average 0.18 new products in three years 2010–2012). Fig. 3 shows that most of the companies - 484 over 544 - launched zero new products in the market (a) and some of them also had zero products even in their pipeline at 2010 (b), while on average the companies in our sample had 2.43 products in the pipeline.

This is exactly what we expected, given that our sample is made by biotechnological and biopharmaceutical companies that are more focused on R&D activities than pure pharmaceutical companies (*'[…] Bio-pharma companies may not have a new drug marketed every year*', Mazzola et al., 2015, p. 112). Given that on average it takes 15 years for a new product to be developed, i.e. each product stays in the pipelines 15 years on average, and for every 10,000 compound screened, only one drug will be approved (Rothaermel and Deeds, 2004), the results in Fig. 3(a) and (b) clearly show that biotech and biopharma companies are not focused in developing new products. Conversely there are more focused in doing research as it is further confirmed by the high number of patents obtained by each company of our sample in the thirty years prior to 2010, on average equal to 56.26.

Also, descriptive statistics show that the average number of R&D purchasing and R&D selling agreements in the five years is quite low (respectively 0.90 and 0.82). Fig. 4 shows the frequencies of these agreements within our sample. On average each company signs less than one purchasing or selling agreement in five years. Of course this does not exclude that companies meanwhile sign other kinds of R&D agreements, for example alliances and bilateral agreements, for innovation purposes. As we already mentioned, the supply chain of innovation is just a part that can be extracted from the whole innovation network. In fact, in our sample the average number of R&D agreements in the five years is 2.6 agreements (we calculated this number by taking into account the whole innovation network). Also, one should consider that on average an R&D agreement typically last for more than a year. For example Rosenkopf and Schilling (2007) assumed that R&D relationships would last for three years, consistently with the empirical work of Phelps (2003).

Table 3 provides an overview of the results of the negative binomial analysis. We focus on the full model (model 4) to examine the theoretical expectations addressed earlier, but also provide the basic model with only control variables (model 1), the model that includes explanatory variable related to the SCoI (model 2), and a model including explanatory variable related to the innovation network (model 3). To avoid a multicollinearity problem, we mean-center the independent variables of the regression model (Danese and Romano, 2013). Then, we also calculate for the two interaction variables the VIF test; the two values of *R&D purchasing* × *Relational_Emb*'s VIF (3.01) and *R&D selling* × *Relational_Emb*'s VIF (2.99) are both quite well below the critical level, as also is the Mean VIF of the whole model (1.79). This indicates that the interaction variables can simultaneously be included in model 4 (Jaccard and Turrisi, 2003).

Looking at the results from model 1, we observe that all the coefficients are stable over all the models, indicating the robustness of the results. Next, we find a positive and significant relation between pipeline and firms' new products, meaning that biotech companies that have a greater number of products along their pipeline tend to develop more new products. By contrast, the negative coefficient for age would indicate that newly-established firms might have a slight advantage in developing new biotechnological products. The coefficient of R&D investment is positive, and significantly related to firms' new products, meaning that the increasing in R&D investments results in increasing innovative output. There are also significant differences between

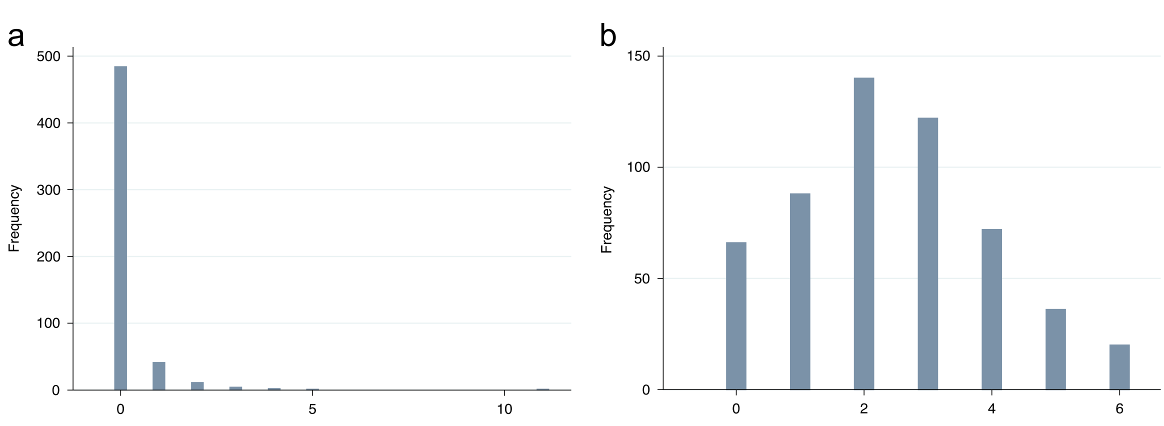

Fig. 3. Frequencies of new developed products in the years 2010–2012 (a) and new products in the pipeline in 2010 (b).

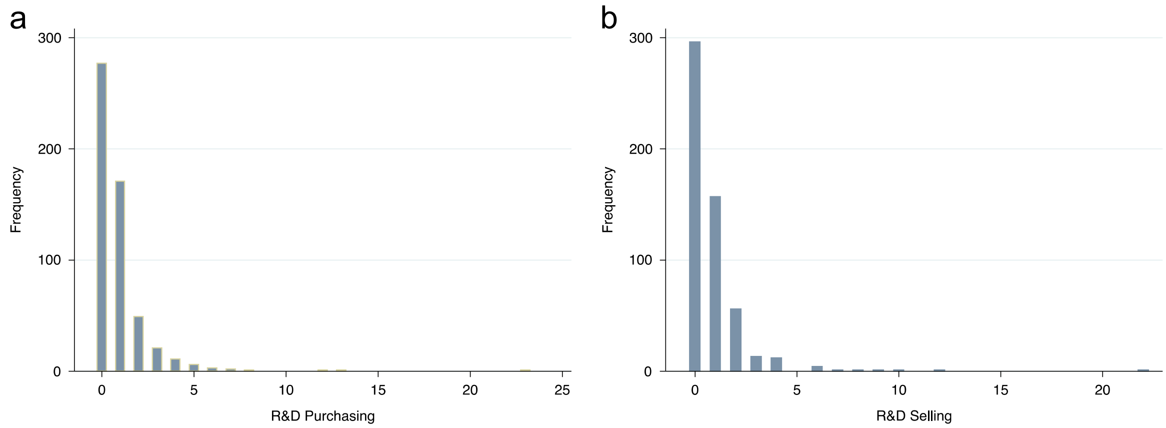

Fig. 4. Frequencies of R&D purchasing (a) and selling (b) in 2006–2010.

companies that are purely biotechnological and companies that are biopharmaceutical. Nationality variable is negative and significant in all the models; thus, as expected, US firms develop more biotech products. Finally, patent stock is not significant.

Model 2 introduces R&D purchasing and selling as explanatory variables. The coefficients of the R&D purchasing and selling variables have the expected signs, but only R&D purchasing is significant. In line with H1, the coefficient R&D purchasing is positive, implying that companies that purchase more R&D commodities also develop more new biotech products. Summing up, the first results corroborate H1 but do not support H2.

Model 3 introduces the network structure characteristic, relational embeddedness: we find that relational embeddedness is significant and positively related to NPD.

Model 4 introduces the pairwise interaction terms between the three explanatory variables to test hypotheses H3 and H4. We expect a positive interaction effect between purchasing R&D commodities and relational embeddedness (H3), and a negative interaction effect between selling R&D commodities and relational embeddedness (H4). As Table 3 shows, both the interaction terms are significant and the signs as predicted. So while H3 is fully confirmed, the same cannot be said for H4. Indeed, although the effect of the product variable (*R&D selling* × *Relational_Emb*) is significant and negative, because the main effect of the variable R&D selling revealed to be not significant (H2 not supported), relational embeddedness cannot be considered as a moderator in this case.

In addition, as also suggested by Jaccard and Turrisi (2003), to

Table 3
Results of negative binomial regression model.

	Dep. var.: new products			
	Model 1	*Model 2*	*Model 3*	*Model 4*
Controls				
Patent stock	0.177*	0.130	0.122	0.0891
	(0.0794)	(0.0814)	(0.0809)	(0.0735)
Pipeline	1.724***	1.643***	1.592***	1.422***
	(0.357)	(0.350)	(0.343)	(0.279)
Age	−0.0124†	−0.0135*	−0.0126*	−0.0132*
	(0.00632)	(0.00645)	(0.00615)	(0.00525)
R&D investment	0.415***	0.466***	0.444***	0.505***
	(0.0923)	(0.0949)	(0.0934)	(0.0880)
Industry	0.524†	0.491†	0.609*	0.793*
	(0.291)	(0.294)	(0.300)	(0.325)
Nationality	−0.596†	−0.616*	−0.652*	−0.556†
	(0.314)	(0.311)	(0.305)	(0.331)
Explanatory variables				
R&D purchasing		0.123*	0.116*	0.0251
		(0.0572)	(0.0562)	(0.0785)
R&D selling		−0.0221	−0.101	0.0313
		(0.0693)	(0.0793)	(0.0882)
Relational_Emb			0.408†	0.593*
			(0.220)	(0.257)
R&D purchasing × Relational_Emb				0.120*
				(0.0535)
R&D selling × Relational_Emb				−0.150†
				(0.0845)
Constant	−5.962***	−6.009***	−5.898***	−6.002***
	(0.600)	(0.600)	(0.587)	(0.507)
Num. obs.	544	544	544	544
Wald $\chi 2$	110.96***	115.16***	118.54***	126.74***
Log-likelihood	−197.80	−195.70	−194.01	−189.91

Standard errors in parentheses. $^{\dagger}p < 0.10$, $^{*}p < 0.05$, $^{***}p < 0.001$.

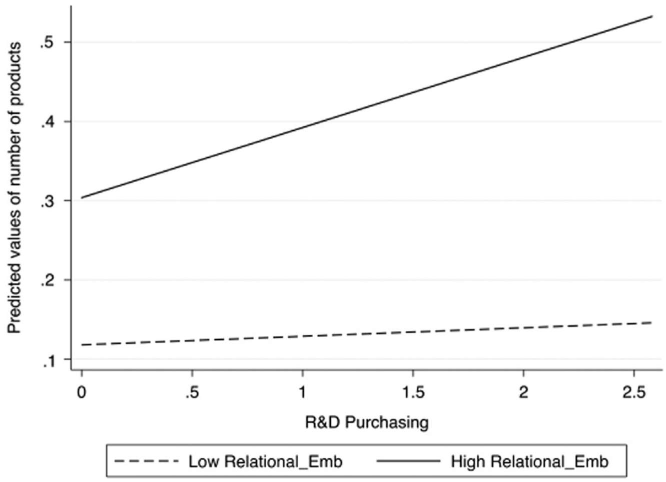

Fig. 5. Interaction R&D purchasing x Relational_Emb (Predicted probability).

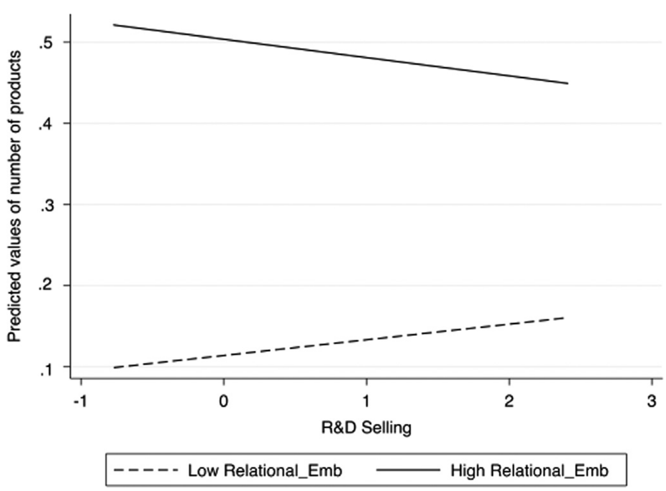

Fig. 6. Interaction R&D selling x Relational_Emb (Predicted probability).

provide even more interesting insights we compute a deeper analysis of the moderating effects (Figs. 5 and 6).

Fig. 5 plots the effect of the interaction on predicted values of new products, of R&D purchasing and relational embeddedness. In line with Danese and Romano (2013) we set two values of relational embeddedness, i.e. 'high' and 'low' respectively, as one standard deviation above and below the mean. Also, in line with Schilling and Phelps (2007), the end points of the lines are calculated at one standard deviation below and above the mean of R&D purchasing. The plot suggests that a high level of R&D purchasing should be accompanied by a high level of relational embeddedness, if the objective is to accelerate the effect of R&D purchasing on the propensity to develop new products.

Fig. 6 plots the effect of R&D selling on predicted values of new product for the same values of relational embeddedness as before. The plot shows how combining a high degree of R&D selling and a high level of relational embeddedness decreases the propensity to develop new products.

6. Discussion and conclusions

This study was motivated by important limitations of existing research on R&D purchasing and selling practices and new product development. The literature has indeed largely ignored, on one hand, that companies, by selling and purchasing R&D commodities, are positioning themselves along the SCoI and, on the other hand, the potential influence of social capital on the effectiveness of those practices.

By explicitly conceptualizing the supply chain at the innovation level, this study brings to the attention of managers the need to consider the SCoI as something different from both the SCoM and the whole innovation network (see Table 1 and Fig. 1).

In fact, this study was inspired by our conceptualisation of the SCoI. While nowadays we are assisting the establishment of supply chains of R&D, in which companies position themselves as suppliers of specific R&D commodities (we found empirical evidence for this), the literature on supply chain collaboration for NPD deals with buyer–supplier relationships that are mostly relational-oriented. Conversely, it does not explicitly consider the buyer–supplier agreements of kind R&D purchasing/selling because, although they may be used to achieve the same goal (knowledge acquisition and value creation), they are not real collaboration agreements, being mostly transactional-oriented.

We know that, especially in high tech industries, the NPD process is not accomplished by the company alone but by the company together with a number of partners. These partners and the relationships that the focal company establishes with them depend on the way in which they contribute to the NPD process. To this purpose, we identify up to three different kinds of networks surrounding the company in which the partners can belong to: the SCoM, the SCoI, and the innovation network. The nature, the goals, the structures, and the relationships within these three networks can be different. However, during the NPD process the focal company may acquire external knowledge from all the three networks above mentioned, so they all contribute to the NPD process. For example, in order to develop a new product the focal company can collaborate with a supplier of components (SCoM) by, for example, involving it in the early stages of product design; but the company can also license-in a patent from a supplier of R&D (SCoI) to include an already developed technology in the new product; finally, the company can sign an R&D joint-venture agreement with an overseas partner (innovation network) to co-develop and commercialize the new product.

The conclusion is that, when designing the NPD process, managers have to take into account precise considerations not just about their company's collaborations with SCoM partners (the literature on supply chain management is reach of studies on relational-oriented collaboration with suppliers and customers for NPD) but also about the relationships of their company with its SCoI members and, meanwhile, they do not have to neglect the effect of relational embeddedness coming from the whole innovation network. These are indeed the three different systems which contribute to the NPD process and this is why they should be considered as a whole.

This study addresses these limitations and also uses social capital theory (Coleman, 1988; Burt, 1998; Adler and Kwon, 2002; Koka and Prescott, 2002; Wu, 2008; Malik, 2012) to consider how the relational embeddedness (as driver of information richness) within the whole innovation network influences SCoI relationships' effectiveness. In doing so, this study moves beyond the dual-market structure perspective typically used in biotech industry research. The results are quite in line with the predictions of the theoretical model, and we discuss them in the following subsections where we also identify implications for research and practice.

6.1. Positioning within the SCoI

We predicted (H1) a linear and positive effect of purchasing R&D commodities on new products, and we found evidence of this. This result shows that, in biotech industry, opening the innovation process to external actors, by specifically purchasing test assays or preclinical programs (but also licensing-in patents or technological platforms), stimulates the company to develop and market new final products. Consistent with prior works on open innovation (Chesbrough, 2003; West and Bogers, 2013; West et al., 2014), this finding suggests that relying on external already-developed knowledge and technology enables a firm to improve its innovation performance, since the firm uses suppliers' systems and mechanisms that facilitate the access to new and complex knowledge (Laursen and Salter, 2006). For example, when Amgen, a biotech company, licensed-in from Genentech (another biotech company) their 'Cabilly' patent family for producing immunoglobulin, it gained access to new knowledge that allowed it to develop new antibodies. In our sample, Amgen has a high number of R&D purchasing agreements and a high number of new developed, approved and marketed products. By purchasing R&D commodities, the firm positions itself downstream in the supply chain, closer to the final market, and thus it is more stimulated than others to develop new marketable molecules and drugs.

We predicted (H2) a linear and negative effect of selling R&D commodities on new products but we did not find evidence of this. This result would suggest that, in biotech industry, selling and marketing own research services (but also licensing-out proper patents or technological platforms), does not affect the company's propensity to develop and market new final products, by either inhibiting or leveraging. Probably, the adoption of these practices influences the numbers of developed patents or another innovation outcome. However, we did not consider these other innovation outcomes in this study.

These first results have important implications in practice. In the biotech industry, companies increasingly tend to externally purchase different typologies of R&D commodities. In consequence, more and more other companies are specialising in supplying and selling those commodities. Thus managers should make precise decisions about the position of their company within the SCoI. If they position downstream, the purchasing of R&D commodities has positive effects on the development of new products. Conversely, if they position upstream, the licensing-out and the commercialization of own discoveries, while generating additional revenue to the company, seem to not have any effect on the development of products for the final market.

6.2. Relational embeddedness and the position of the firm in the SCoI

We predicted (H3) a moderating and positive effect of relational embeddedness on the linkage between purchasing R&D and the development of new products, and we found evidence of this. The higher the relational embeddedness, the greater is the benefit coming from external knowledge acquisition. Prior literature argued that a high level of relational embeddedness brings a high level of information richness (Goerzen, 2007; Wu, 2008). This result shows that purchasing R&D services (or other kinds of R&D commodities) yields greater potential for NPD under the condition of a high level of relational embeddedness. This finding may be interpreted as follows. The information richness that a company gets from its innovation network positively influences its knowledge absorptive capacity, and increases the opportunities for learning and for developing the skills in managing the NPD process. In other words, the firm, thanks to its relational embeddedness, better capitalizes on the knowledge coming from purchasing R&D.

We predicted (H4) a negative effect of relational embeddedness on the linkage between selling R&D and new products. We found a significant and negative effect of the product variable (*R&D selling* × *Relational_Emb*), and because the main effect of the variable R&D selling revealed to be not significant we interpret the result as an interaction effect. This result demonstrates that selling R&D services (or other kind of R&D commodities) yields lower potential for NPD under the condition of a high level of relational embeddedness. To interpret this finding we need to go back to the idea of firm positioning along the SCoI. Indeed, prior research tells us that the information richness from the innovation network positively affects the performance of the firm due to the organizational experience coming from routines, organizational learning, the reduction of intra-network asymmetries, and the increase in trust (Gulati, 1995; Koka and Prescott, 2002; Malik, 2012). However, with the main business of R&D suppliers being the development and marketing of R&D commodities, the information richness positively influences the outcomes of these activities, thus damagingly conditioning the firm's propensity in developing new products for the final consumer market.

When looking at the overall findings, we can draw the following conclusions about relational embeddedness and NPD process. Advantages of relational embeddedness have to be interpreted in the light of the position of the firm along the SCoI. Specifically, managers of downstream companies should consider that relational embeddedness in the innovation network brings paybacks in their SCoI practices. Analogously, managers of upstream companies should consider that relational embeddedness enforces their core business and their position in the SCoI. This, in turns, brings drawbacks in their SCoI practices, in terms of their propensity to develop products for the final market.

Our findings bring anecdotal evidence of the existence of the SCoI and of the phenomenon of firms' positioning along it, at least in the biopharmaceutical context. This calls for a number of issues still to be explored in the supply chain management stream of literature, which studies different kinds of relationships with suppliers and buyers for NPD. The results of our study suggest that when considering the knowledge flow, different actors play the role of buyer and supplier (of knowledge), rather than just the buyers and suppliers belonging to the material flow supply chain. Studying this flow and these special supply chain relationships becomes crucial in NPD process.

Finally, the research findings bring the following managerial implication. Our results show that both R&D purchasing/selling and network characteristics influence the ability of the firm to exploit external and internal knowledge to enhance innovation. However, there are important differences between these two concepts. R&D purchasing/selling activities concern a set of decisions that can be directly controlled by the firms, since managers contract with suppliers and buyers to buy or sell R&D commodities. Conversely, the characteristics of the network are not entirely under the firm's control. Indeed, the existence of cliques mainly depends on external decisions (the company cannot decide whether or not its partners are connected to each others, thus composing a clique). The effectiveness of managers' decisions regarding the purchase or selling of R&D commodities on NPD success partially depends on exogenous factors. Managers undergo their network structure characteristics (e.g. cliques), and thus have to make their SCoI decisions according to these.

6.3. Limitations and further research

The results and the contribution of this study should be considered in light of its limitations. First, the data analysis is cross-section and not longitudinal; the dependent variable is the sum of three years and is not year-specific.

Secondly, because the intention is to analyse the supply chain of innovation, this study focuses on the biopharmaceutical industry (traditionally involved in innovation processes) and excludes other types of industries. Although this approach is appropriate, it would be unwise to generalize the findings too broadly to other industries and cultural contexts. Moreover, as national diversity, being related to culture, might influence innovation attitudes, a control variable such as nationality might have helped to improve the results.

Thirdly, we built on research on social capital theory to consider how the position of the firm within the network of innovation may affect relational embeddedness, and how information richness originating from it influences supply chain relationships' effectiveness. However, social capital is a multidimensional construct that yields different information benefits, not only in the form of information richness, but also in terms of information volume and information diversity (Koka and Prescott, 2002). A complete comprehension of the moderating impact of network social capital into the linkage between supply chain practices and NPD would have required taking into account a number of network characteristics other than cliques, such as number of partners, partners of partners, structure holes, and so on.

Future research should be directed towards exploring and evaluating the influence of SCoI and relational embeddedness on companies' propensity in innovation, rather than just on developing new products. In fact, NPD is just one dimension of innovation performance, and researchers often capture innovation performance through different innovation outcomes (e.g. number of developed patents). Future research should thus be oriented to explore the effect of positioning along the SCoI, and of the innovation network on different innovation performance. We think that very interesting results could be revealed. Indeed, we showed that positioning upstream in the SCoI tends to decrease the firm's NPD propensity (this because we considered the number of new products for the final market, e.g. marketable drugs). If instead we had considered the number of patents, or the number of technological platforms, or the number of test assays, we probably would have discovered that positioning upstream tends to increase the firm's innovation performance. The same considerations hold for downstream positioning. Further study of this issue could bring very interesting implications for R&D supply chain managers.

Also, further research in this field should be directed towards investigating whether purchasing and/or selling different kinds of R&D commodities (as the object of the commercial R&D transaction) differently affects the NPD process. For example, is there any difference in purchasing patent licenses or research services? We know, for instance, that purchasing a research service surely requires a more intense integration with the supplier than purchasing a license. Does this difference influence the way in which the two R&D commodities affect the NPD process? Exploring this issue could bring very interesting insights to innovation managers in charge of supplying and selling R&D commodities.

However, overall this study opens new frontiers for supply chain management researchers. Besides adopting the SCoI perspective for studying supply chain relationships in NPD, they might use the SCoI as a new test bed where they can explore and study the same topics that they usually treat in traditional (material flow) supply chains. For example, classical topics such as single versus multiple sourcing (Burke et al., 2007), supply chain coordination or strategic purchasing decisions (Ogden et al., 2007) could be investigated for the supply chain of innovation.

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