Forest Policy and Economics 97 (2018) 9–20

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Knowledge networks for innovation in the forestry sector: Multinational companies in Uruguay☆

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ARTICLE INFO

Keywords:
Innovation systems
Forestry firms
Multi-national companies
Social network analysis
Uruguay

ABSTRACT

In this paper, we analyse the role that inter-agency and inter-business linkages have in the process of technological innovations in the forestry sector in Uruguay. We focus on what types of interaction prevail in the process of creating new knowledge and diffusing existing ones and what role different types of organizations have during this process. This paper offers new insights into the role that innovation in multinational firms has on knowledge creation and diffusion in developing countries as they interact with and reinforce weak sectoral innovation systems. Our findings indicate that multinational companies follow three main strategies to cope with the limitations of the local innovation system: cooperate among them, establish links with international research centres and, have a network of suppliers of technology. The spillovers to local agents are greater in case of networks established with the purpose of generate new knowledge.

1. Introduction

Although different definitions for innovation have been put forward in the literature, probably, the most accepted is the one provided by the Oslo Manual (OECD and Statistical Office of the European Communities, 2005). According to this manual, innovations can be classified in four types: product, process, marketing and organizational. Product innovation implies a good or service that is new or significantly improved. There is process innovation when a new or significantly improved production or delivery method is introduced. Marketing innovation exists when a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing is introduced. Finally, organizational innovation implies a new organizational method in business practices, workplace organization or external relations.

The literature in the last decades has shown that the process of introduction of innovations has a non-linear nature. It is an iterative process that involves various actors (entrepreneurs, public organizations, academic institutions, firms, clients, etc.) that interact through formal and informal networks (Caraca et al., 2009).

To understand this complex process, the innovation system (IS) approach was developed as a policy concept in the 1980s (e.g. Freeman, 1987; Nelson and Rosenberg, 1993). Since then, it has gained relevance in the innovation literature (Lundvall et al., 2002; Edquist, 2001). Lundvall (1992) defines an innovation system as “the elements and relationships, which interact in the production, diffusion and use of new, and economically-useful, knowledge”. Focusing on the IS at a sectoral level, it provides a framework to study how agents interact through networks to introduce novelties (e.g. Breschi and Malerba, 1997).

Despite the growing interest in the innovation process as a system, there is no agreement about the role of different actors in these systems and the type of relationships (training, technical assistance, exchange of information, financial, etc.) that lead to different types of innovation (Tödtling et al., 2009). Within the same country, sectoral differences affect access to resources required for innovation and thus firms' networking strategies (Salavisa et al., 2012).

Some recent studies have analysed the configuration of networks for innovation in high-tech manufacturing: optics and electronics (Quimet et al., 2004); chemicals, biotechnology, telecommunications, and semiconductors (Hagedoorn et al., 2006) and knowledge-intensive business services (Tödtling, 2009). However, only a few studies focus on agro-based sectors that capture a big share of public R&D expenditure in many developing countries. In these studies, network

☆ This work was possible thanks to the support of Red Sur; the International Center of Research for Development (IDRC, Canada); Pérez-Guerrero Trust Fund for South-South Cooperation, Group of 77, United Nations.

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https://doi.org/10.1016/j.forpol.2018.08.013
Received 13 February 2018; Received in revised form 21 August 2018; Accepted 25 August 2018
1389-9341/

analysis has been applied mainly to explain the role of social and interagency networks for the diffusion of innovations rather than innovation creation (Perez and Hartwich, 2008; Boahene et al., 1999; Nyblom et al., 2003, and Bandiera and Rasul, 2006).

Kubeczko et al. (2006) and Rametsteiner and Weiss, 2006 study the forest innovation systems in several European countries finding that forestry institutional systems are limited to diffusion programs in selected topics rather than to provide systematic innovation support. Jarský (2015) evaluates the forestry IS in the Czech Republic and concludes that it provides sufficient innovation support but only partially fulfilling its information function. Giurca and Späth (2017) applies an IS approach to study how actors from different sectors interact in an emerging innovation system in Germany. However, these studies do not address in detail the question of how firms develop strategies to generate or incorporate new knowledge in these settings of incomplete IS.

The literature on innovation systems in developing countries converges on the high influence of foreign sources of technology, knowledge and innovation (Pietrobelli and Rabellotti, 2012). However, only a few studies highlight the role that innovation in multinational firms has in knowledge creation in developing countries as they interact with and reinforce the existing sectoral innovation systems (e.g., Niosi and Bellon (1994, 1996) and more recently Carlsson (2006), Fromhold-Eisebith (2007), Spencer (2008), Quan (2010)).

Our work contributes to this literature by considering the international dimension of innovation networks in the forestry sector in developing countries with incomplete IS and analysing the potential of knowledge exchange and collaboration for innovation. In particular, we are interested in the role that inter-agency and inter-business linkages have in the process of innovations. We aim to understand what types of interaction prevail during the creation and diffusion of knowledge and how they favor or not knowledge spillovers. More generally, we expect to contribute to an open question on what is the role that MNC can play for the technological dynamisms of developing countries (Marin and Arza, 2009).

We focus on innovations performed in the primary stage of the forestry value chain. A particular element of the forestry sector in Uruguay is that since the beginning of forestry policies in the country, 40 years ago, the sector has attracted leading international companies with a long history of R&D in their home countries.[1] This peculiarity puts forestry in a different context with respect to the more traditional natural resources activities in which the rule has been that public research organizations and universities have had (or shared) the leadership in knowledge creation and innovation. We understand that this feature represents a challenge for innovation policies, and it could apply to other developing countries.

Uruguay has a production structure that is intensive on natural resources; consequently, it is in these sectors that the greatest public and private R&D efforts are made (Aboal et al., 2017). Forestry in Uruguay is characterized by its recent and increasing production and export dynamism, further propitiating investments in innovation activities.

Our empirical analysis has two parts. First, using micro data from the official Uruguayan Forestry Innovation Survey for the period 2007–2009, we analyse which are the characteristics of the more innovative enterprises in the sector and whether they engage with other actors from the IS to carry out innovation activities (section 4.1). Our objective here is to understand, at a macro-sectoral level, the type of agents and cooperation that help introducing innovations in the forestry sector.

Second, in Section 4.2 we provide evidence regarding the inter-organizational interactions in an innovation program carried out by a leading multinational company (MNC), and its implications for the sectoral IS. The program seeks to adapt an imported species to the national climatic conditions to improve forest productivity in cold zones. This case study will allow us to explore how innovation happens in this type of firms, emphasizing the way in which inter-institutional networks develop around an innovation project. We also use this case study to understand whether the relationships between actors are different according to the type of knowledge created or diffused. We apply descriptive network analysis techniques to characterize the network generated by the MNC with national and international actors.

The paper is structured as follows. Section 2 provides a brief overview of the forestry industry in Uruguay. Section 3 presents the methodology. Section 4 discusses the main findings. Conclusions are presented in Section 5.

2. Uruguayan forestry sector

In the past 25 years, the Uruguayan forestry sector has grown steadily. According to official information, the planting surface increased by 30 in that period.[2] The main use of round wood is in the production of wood pulp (64% of the volume in 2009), but also chips, sawn timber, and pulpwood logs. Exports of forest-based products have grown significantly in the last 10 years. In 2017, the exports of cellulose pulp reached 1.3 billion dollars. Cellulose pulp ranked as the second most exported product in Uruguay, only behind beef-related products. In 2016, Uruguay was the 8th largest exporter of pulp for paper in the world.[3] In this context, the sector has gained productive and export dynamics, defining an auspicious setting for augmenting global investments in this activity, particularly for increasing innovation efforts.

Multinational firms account for a big share of wood-related production and exports in the country. As a general feature, these firms have industrial plants and subsidiaries in the primary stage of production. This means they have fully integrated production, starting with locally based tree breeding programs up to pulp production or warehouse.

During the 90s, some global players built plants in the country. Subsidiaries of multinational companies (Shell, Ence, UPM-Kymmene, StoraEnso, Weyerhaeuser) were attracted by Uruguayan tax incentive policies and availability of raw material. By the end of the decade, their plantations dominated most of the forested areas (Durán, 2003). Multinational companies introduced new technologies from abroad and new species and carried on genetic improvement programs that resulted in productivity increases. Innovation efforts were largely concentrated in the adaptation to local conditions of species brought from abroad.

Besides MNCs, > 700 micro, small and medium-size forest producers are part of the forest sector in Uruguay. Many of these firms have little or no capacities to carry out their own breeding development programs. They use mainly those developed by public research institutes or multinational companies.

Three main public R&D institutions are active in forest research: the National Institute of Agricultural Research (INIA), the Technological Laboratory of Uruguay (LATU) and the University of the Republic of Uruguay.

3. Methodology

Although the importance of innovation networks has been emphasized in the literature for a long time, only recent studies have

[1] Before 1967 there was no promotion or regulation of forestry activities. In that year, the first forestry law was approved; but it was operative only in 1975. However, it was with the 1988 Forestry Law that the activity was actually promoted with a set of tax incentives. A greater detail of the evolution of the forestry policy in Uruguay can be found in Soust (2012).

[2] Report on Investment opportunities in the forest sector. Uruguay XXI (2013, 2017).

[3] Food and Agriculture Organization (FAO) statistics (accessed 08/04/2018): http://www.fao.org/forestry/statistics/80938@180724/en/

highlighted the relevance of formally modelling the nature and pattern of innovation networks, identifying different sources of knowledge, type of communication channels or geographical location of actors (Todtling, 2009). Network approaches allow to study the roles of different actors in the innovation process, for instance, of customers, clients and competitors that have been identified as decisive for firms' innovation activities (Porter, 1998; Malmberg and Maskell, 2002; Tödtling et al., 2009).

Recent work in forestry has used network approaches to understand trade flows of wood and non-wood forest product (Lovrić et al., 2018), how actors from different sectors interact in emerging innovation systems (Giurca and Späth, 2017) and the type of information flows and frequency (Giurca and Metz, 2018). Aurenhammer (2012, 2016) provides a review of applications of actor center networks in forestry development policies.

Some research has emphasized that through the internationalization of firms and markets, MNCs increasingly shape the development of innovation systems (Sharif, 2006). MNCs transfer knowledge across national boundaries through their subsidiaries (Frenkel, 2008). Moreover, in recent years, it has increasingly been stressed that the innovation system approach needs to be enriched by the international dimension (Asheim and Herstad, 2005; Bunnell and Coe, 2001; Carlsson, 2006; Fromhold-Eisebith, 2007).

Multinational companies use their home countries as their preferred R&D locations (Patel and Vega, 1999; Narula, 2002). Hence, the internationalization of the innovation activities of MNCs lags behind the internationalization of their productive activities. In spite of this, in the agricultural sector and particularly in forestry, some innovation activities might be more efficiently delivered in the host country because they require proximity to local resources. Based on this, we expect forestry MNCs to carry out part of the innovation activities in the host country. They might also require a certain cognition, recognition and incorporation of national knowledge. In this context, it is important to understand whether they require national or international knowledge for local innovation activities.

Some of the largest R&D efforts of forestry enterprises are related to pulp quality improvement. Because natural resources are “country-specific”, firms need to incorporate domestic knowledge in terms of soil, weather, landscape or even local regulation. Therefore, it is expected that firms engage with local R&D institutions and universities, even though these are sensitive assets for enterprises.

A case study approach to understand the knowledge network conformation seems to be a suitable methodology to analyse the complexities of the interrelationships between the MNC and local or international actors when it comes to innovation efforts. The network structure together with a more general understanding of cooperation strategies to innovate in the sector can give some useful evidence for policy purposes.

Before explaining the empirical strategy to deliver our analysis and in view of the fact that quite different SNA approaches exist, we introduce some basic concepts. In SNA, a network can be represented as a set of n nodes (actors, such as firms, organizations, individuals) that are connected by edges.

According to Aurenhammer (2016), networks can be theoretically classified broadly into three groups. They can be viewed as independent institutions, as arenas of actors and their interactions, or as instruments of actors. Our vision in this analysis is the second one: that of a construct of actors and their interactions within an arena of policy interest, related to sectoral innovation systems. In particular, as in Podolny and Page (1998), our interest in the network relates to its capacity to facilitate learning and new knowledge creation via the transfer of knowledge from one actor to another.

Firms' knowledge networks might include a wide range of forms, such as intracorporate business units in the case of MNCs, strategic alliances, franchises, R&D consortia, buyer-supplier relationships, government sponsored technology programs, etc. (Inkpen and Tsang, 2005). Our interest is focused in all of them, even though we are not intending to disentangle the links within the firm (for instance between the subsidiary and the headquarter or other subsidiaries).

As a first step to analyse the cooperation between different agents of the forestry innovation system in Uruguay we use microdata from the official Uruguayan Forestry Innovation Survey[4] (Section 4.1). The survey contains data from 64 establishments that are representative of the 773 firms of the sector. We use a Poisson count model to understand whether the cooperation of firms with other agents is related to the intensity of innovation (measured as number of innovation activities carried out by the firm in the period 2007–2009).

The analysis of the Forest Innovation Survey is a valuable starting point to have a general understanding of the innovation networking strategies at the sectoral level. But because the survey is directed only to enterprises, we cannot identify how other actors are interacting between them, and therefore, we cannot find clustering structures, connectedness of the network, influence of different agents, etc.

The second part of the research tries to fill this gap. In Section 4.2 we build a case study around an innovation program carried out by a MNC. First, to choose the case study we conducted interviews with officers from the Ministry of Livestock, Agriculture and Fisheries of Uruguay. We asked to recall an innovative project or program that, to their knowledge, involved several different actors. Second, we interviewed referents from the MNC (our Ego firm or actor) and chose a program of maximization of wood productivity in cold zones. We analysed the innovation program's outcomes as well as the activities required to carry it out. Then we investigated all ties or links with different agents needed for the different activities. To gather data on links among all intervening parties, we used semi-structured interviews, following the strategy that we detail bellow.

Social Network Analysis (SNA) requires a clear delimitation of the scope of the network (at the cost of distorting the ‘real’ network). The empirical strategy followed included two steps. First, an interview with managers of the Ego MNC and the collection of a list of all actors directly involved in the innovation program through different types of knowledge sharing (we call these agents, group A of actors). Some of the questions of the guide for the semi structured interviews can be found at the end of the Appendix. In the second stage, we used the same guide to interview each of the actors in group A to confirm the relationship with the ego-actor (the MNC) and assess whether they had any link with the rest of the actors in group A. They were also asked to name additional actors with whom they generated knowledge links related to the program (group B of actors). B actors were not interviewed but were included at the end of list A to find out whether they had any other connection with the rest of the interviewed actors.

We cannot tell whether B actors interacted among them, because they were not interviewed. We can only describe, for example, if several actors in the A network refer to the same actor in the B network as a relevant agent. In that case, B actor could be part of triangles or more complex structures and not necessarily remain in the periphery. To avoid the potential problem of omitting interactions ought to methodology decisions; we will also perform an analysis of the interactions of only the group A of actors (Section 4.2.2).

Through the semi structured interviews, we collected different information for each node (e.g. the firm's origin, type of organization) to assess the characteristics of actors that take part in the network (see questionnaire in the Appendix). Actors are connected by links or edges that represent interactions between them.[5] Regarding the edges, the

[4] The questionnaire is available in Spanish on the link: http://www.anii.org.uy/upcms/files/listado-documentos/documentos/encuesta-actividades-innovacion-agropecuaria-2007-2009.pdf, pages 379–390 (accessed 08/07/2018).

[5] See Jackson (2010) for an introduction to social network analysis and Aurenhammer (2012) for applications in forestry policy.

Table 1
Links delimitation.

Type of knowledge flow	Types of links
New knowledge	R&D and research contracts
Formal exchange of existing knowledge	Technical assistance/Technology transfer, Experimentation, Capacity building/Academic extension activities
Informal exchange of knowledge	Informal contacts
Knowledge incorporated in goods/services	Other links, (i.e. links with supplier or clients)

questionnaire asks the actors the type of knowledge links they had during the innovation project (column 2 in Table 1). For the analysis, we aggregated the different types of knowledge flows into four types as listed in the first column of Table 1, where the last category, knowledge incorporated in goods and services corresponds to the residual option in the questionnaire, as the answers mostly could be associated to that concept.

Besides the type of link, the questionnaire also asked about the frequency of these links and their perceived importance. As Granovetter (1973) points out, the stronger the ties the bigger the chances for long term commitment and also to generate more complex structures (like transitive relations) which are valuable for knowledge diffusion networks. For the particular case of alliances between firms, Inkpen and Dinur (1998) point out that for knowledge transfer to occur, strong ties between the partners are necessary.

We treat all connections as undirected (with no particular direction). While we acknowledge that this diminishes the explanatory value and applicability for actor-centered analyses (e.g. we cannot tell whether an actor is benefiting by receiving knowledge from neighbours), the computation of some statistics (i.e. centrality, transitivity) is more straightforward with this approach.

In the case that an actor reported a link and the other not, we decided to treat that edge as valid. This is an arbitrary decision. We assume that the difference were ought to the time that has gone since the interaction. The relevance of the interaction which might be different for either actor, or even the fact that the person who was in one of the organizations might not be there anymore can explain this discrepancy. An analogous decision was taken regarding the perceived relevance of the link, selecting the strongest answer when there were differences between the two agents.

In Section 4.2.1 we will approach our case study in the broadest way possible given our data. That means considering all actors (A and B groups) and all types of knowledge flows between them. Later in Section 4.2.2 we will limit our analysis to group A and will split the analysis into four sub-networks, each corresponding to a different knowledge flow according to the definition in Table 1. To characterize the importance of an actor in the network we analyse its centrality. We use the betweenness centrality, proposed by Freeman (1977), as a measure of how well situated an actor is in the shortest paths between other actors, i.e. how important an actor is in terms of connecting other actors (Jackson, 2010). As an actor (node) takes a more central role, it can play the part of a "gatekeeper", controlling the flow of information and bringing together disconnected actors.

The configuration of a network structure determines the pattern of linkages among network members (Inkpen and Tsang, 2005). For instance the density, hierarchy and connectivity affect the flexibility and ease of knowledge exchange through their impact on the extent of contact and accessibility among network members (Krackhardt, 1992). We will concentrate on the density and hierarchy of the network. Density indicates how connected in average the network is; it is measured as the relation between actual and possible links between all dyads. The hierarchy of a network can be associated to the absence of transitive relations (i.e. few actors are in the middle of the passage of information among all other actors). Holland and Leinhardt (1979) pointed out that the lowest level at which there can be found interesting social structures were triadic relations. So we compare the triadic transitivity of sub networks using Wasserman and Faust (1994) definition, which is: the relation between closed triplets and the sum of open and closed triplets.

4. Results and discussion

4.1. Innovation in the forestry sector

The first step of our analysis aims to find a general perspective of the forestry innovation system in Uruguay. With data from the Uruguayan Forestry Innovation Survey we describe firms' behaviour in terms of which are the most innovative ones, whether they engage on cooperation to carry on innovation activities, with whom do they engage, etc. We also want to have a context to validate the results of our case study research, given that the Innovation Survey is representative of the entire forestry sector and of course, this is not the case of the case study.

The analysis of the Forestry Innovation Survey shows that the origin of the firms' capital and their size are important to understand different innovative outcomes. Foreign capital firms have twice the innovative propensity of domestic firms, while large firms are three times more successful in implementing and adapting their innovative ideas/technologies than small firms.[6] As we show later, not only are the bigger firms related to successful achievement of innovation, but also with a higher innovation effort (measured as number of innovation activities carried out).

According to the Forestry Innovation Survey, innovative firms in the forestry sector in Uruguay show higher levels of cooperation with other actors of the system. The main reason to engage with other agents is receiving or exchanging information, while training, technical assistance and experimentation play a secondary role (see Fig. 1).

Given that the Forestry Innovation Survey includes a block of questions regarding the links that firms established with a list of actors from the Uruguayan innovation system. We use that information to analyse more deeply the relationship between these links and the innovation activities performed in the sector. To do this we use a Poisson count model where the dependent variable is the number of innovation activities carried out by firms.

As control variables we use: the firm' size, foreign ownership, human capital and relevance of forest activity in total firms' activity. The rest of the explanatory variables are the ones of more interest for our study and relate to links with firms and other agents of the innovation system (see Table 2). In the survey, links are understood as either formal or informal contacts that enterprises had within the framework of an innovation activity.[7]

In Table 2 we can see that there are three variables that are strongly associated with the number of innovation activities carry out by firms: firm's size, forestry being the main activity of the firm,[8] and the

[6] The indicator of innovation propensity is calculated over groups of enterprises g: $IP_g = {\sum_g IO_g}/{\sum_g IA_g}$, where IO is a dummy variable indicating whether the firm obtained at least one innovative outcome from innovation activities, and IA_g is a dummy variable indicating whether the firm carried out at least one innovation activity. The indicator of innovation propensity is 0.46 and 0.26 for enterprises with and without foreign capital share, respectively. For small, medium and big enterprises is 0.19, 0.42, and 0.49, respectively. On the other hand, this indicator is 0.46 and 0.26 for enterprises with and without foreign capital share, respectively.

[7] In Table A2 in the Appendix we reproduce the question of the Forestry Innovation Survey about the links with other actors of the innovation system.

[8] The Innovation Survey asks: "What were the 3 activities that gave you the highest income during 2009 in order of importance?" from a list of 13 agro activities such as forest, cattle, rice, etc. The variable considered here takes value 1 if the firm answers that forestry is the more important activity and 0

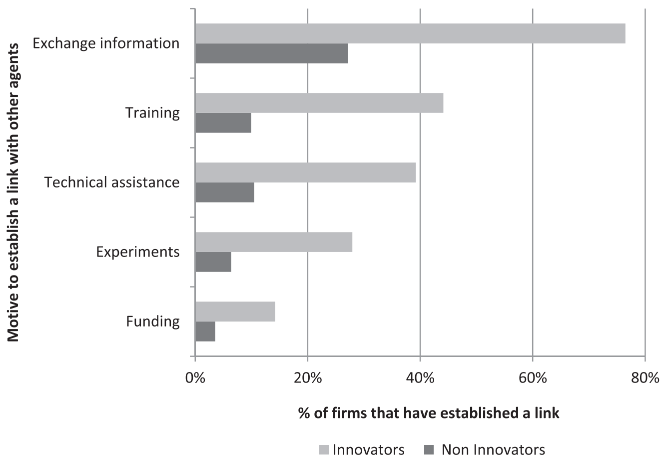

Fig. 1. Propensity to engage with other agents according to motive.
Note: Innovators are those firms that report at least one innovation.
Source: Forestry Innovation Survey.

Table 2
Determinants of the number of innovation activities in forestry firms.

Variables	Estimates
Links for R&D Cooperation	0.455**
	(0.187)
Links with Public Sector	0.191
	(0.145)
Vertical Links	
Links with Suppliers	0.342**
	(0.162)
Links with Clients	−0.113
	(0.184)
Horizontal Links	
Links with Individual Producers	0.259*
	(0.133)
Links with Group of Producers	0.671***
	(0.163)
Links with Scientific Organizations	
Links with INIA	0.0101
	(0.153)
Links with Universities	−0.058
	(0.220)
Links with Laboratories	−0.004
	(0.172)
Size (number of employees)	0.087***
	(0.031)
Foreign Capital	0.110
	(0.195)
Public Funding	−0.122
	(0.246)
Main Activity	0.794***
	(0.301)
Professionals + Technicians/Employees	−0.064
	(0.195)
Professionals/Employees	−0.238
	(0.283)
Technicians / Employees	0.251
	(0.324)
Constant	0.064
	(0.240)
Observations	62

Notes: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The definition of variables can be found in Table A1 in the Appendix.

(*footnote continued*)
otherwise.

cooperation with other actors to perform R&D activities.[9]

When we want to explain the number of innovation activities carried out, instead of the success in achieving innovations, the origin of capital does not seem to be relevant. This can be associated with a higher rate of success of innovation activities carried out by foreign firms.

We find that only horizontal links (with individual or groups of producers), as well as vertical links with suppliers are positively and significantly associated to the number of innovation activities at the firm level.

The links with government, research institutes, and financial institutions are not significantly correlated with innovation activities.

These results suggest the idea of a fragile or immature forestry innovation system in the country. While associations to carry out R&D activities are an important factor to explain firms' innovation activities, there is no evidence pointing to the importance of the cooperation between private firms and academic or public organizations in order to carry out innovation activities.

One limitation of using the Forestry Innovation Survey is that we cannot identify the connections among actors of the innovation system other than from the perspective of forestry firms. For instance, we are not able to identify whether suppliers that are linked to innovative forestry firms are connected to research institutes, and if these are connected to universities, and so on. If this were the case, it is more probable the existence of channels for knowledge diffusion than the case where suppliers act isolated from other actors, or where research institutes not only have few contacts with firms but also few contacts between them.

For this reason, in next section, we build a partial network of knowledge creation and diffusion to analyse with a greater detail how do national and international actors interact in the framework of MNC's innovation program. Through the use of network analysis we will gain insights on the interactions between all agents involved and not only the relations that have a firm as counterpart, as in this section. Of course, by taking the approach of a case study we lose generality of the findings. This is the tradeoff.

4.2. The case study: innovation program to improve forest productivity in cold zones

We build a case study around an innovation program carried out by a MNC with the objective of maximizing the productivity of pulp production in relatively cold zones. The MNC has operated in the country since 2007 in the industrial processing and exporting of wood pulp. It has a subsidiary in the primary stage of production (the Ego of our network) which has been operating in the country for > 20 years and provides the wood for industrial processing. At the time of interviews, near 70% of the wood processed by the industrial plant is originated in its own plantations, and 30% are bought from > 200 farmers associated with the Forest Development Program.[10]

Genetic improvement allows the reproduction of species with high density wood, pulp yield and resistance to weather and diseases. Genetic improvement through hybrids and clones is an important component of the experimentation activities in the case studied (the company has around 500 testing hectares). The process of genetic improvement follows these stages: identifying the species to be tested, establishing breeding populations, identifying the best parent,

[9] This last variable is a dummy that takes value 1 if the firm cooperated with other agents in order to carry out experiments (excluding financial entities). In Table A2 in the Appendix we show all possible variables (columns) of connections with other actors (rows) from the Innovation System.

[10] The Forest Development Program is a public program that since 1980s provides subsidies and tax exemptions with the aim of incentivizing the use of productive land for forest activities.

performing improved crossovers (hybrid), selecting the offspring of these hybrids (candidate clones), identifying those superior trees as clones, and finally, clonal evaluation. In these stages, there is continuous interaction with laboratories to examine the potential and quality of wood.

Once a tree with superior characteristics is selected, early pre-multiplication ensures that there is a reasonable number of mother plants for the process of reproduction by cuttings. In the nursery, the main objective is to generate thousands of seedlings from clones of selected mother plants, making sure the seedlings grow strong roots and are developed enough to be later taken to the company's plantations.

The firm has a **long-term genetic improvement program** that focus on the introduction and improvement (in a profitable way) of a new species in Uruguay: the *Eucalyptus Dunnii* (*E. Dunnii*). This program required the generation and adaptation of knowledge (e.g., in cloning, micro propagation, physiology). In order to be able to reproduce efficiently this new species, the firm had to invest in the building of a new nursery with many particular and innovative characteristics, adapted to the biological specificities of the *E. Dunny*. The new nursery included building new greenhouses, specially designed container technology for seedlings, new machines to handle the new container for seedlings, etc. The new nursery has also involved organizational innovations. For instance, together with a human capital consultancy firm, the Ego developed a specific type of contract for companies that provide outsourced personnel for the nursery, which encourages both productivity and quality of work. Our case study, that we call *innovation program to improve forest productivity in cold zones*, includes both the genetic improvement program and the building of the new nursery.

It is important to highlight that all the relationships that we take into account to build the knowledge networks must have some type of knowledge exchange between actors involved in the transaction (e.g. we discard from the analysis the process of buying a standard product, etc.).

4.2.1. Extended knowledge network (A and B actors)

In this section we analyse the extended network of actors related to the case study. As pointed out in the methodological section, group A of actors are those that had been recalled by the Ego as having direct knowledge flow through any kind of contact in order to carry out the project. They can be called direct collaborators. The Ego firm interacted directly with 22 national and foreign agents.[11] The type of actor, their nationality and the name assigned to each of them can be found in Table 3.

Table 3
Direct collaborators (group A of actors).

Type	Name	Nationality (*F = Extra-regional, R = Regional, U = Uruguayan*)
Forest Firm ego	Ego	F– Operating in UY
Forest Firm ego lab	FE	F – Operating in UY
Forest Firm (MNC Rival)	FE-I	F– Operating in UY
Forest Firm	FE-II	R
Forest Firm	FE-III	R
Consultant	C-I	R
Consultant	C-II	U
Consultant	C-III	U
Consultant	C-IV	U
Consultant	C-V	R
Consultant	C-VI	R
Consultant	C-VII	U
University	RC-I	U
University	RC-II	U
Research centre	RC-III	U
Research centre	RC-IV	F
Research centre	RC-V	R
Research centre	RC-VI	U
Supplier	S-I	F
Supplier	S-II	F
Supplier	S-III	U
Supplier	S-IV	U
Supplier	S-VIII	R

Additionally, the direct collaborators interacted with other agents outside group A. We call these indirect collaborators group B of actors (see Table A3). Overall, the general knowledge network is made up of 64 agents that are linked by 101 links. The graphic representation of this global network is shown in Fig. 2.[12] The size of the nodes (actors) represents their centrality in the network and the shape, the type of actor. Finally, the colour indicates the location of the actor. National actors are those located in Uruguay even if they are MNC, while foreign actors are those located outside of the country, either in the region (e.g. Chile, Brazil or Argentina) or in other extra-regional countries.

The first notable feature of this network is the natural segmentation of international and local actors (foreign-based organizations on the top left of the layout and locally based actors in the bottom right). The Ego and a few other actors are responsible for connecting two geographically distinct areas of knowledge generation.

Second, the network has an uneven distribution of links in which most units have a single link. The average number of links is 3 per node (actor). The organization with the highest level of connections is the regional RC-V (33), followed by the Ego actor (22) and the other MNC, FE-I (22). The national agro research institutions RC-I y RC-VI have 7 and 11 links, respectively, in this network. The existence of hubs—-nodes that have proportionally large number of connections—in the network results in a low overall clustering, i.e., there are many actors that could be linked to each other because they share common neighbours, but they are not.[13]

Third, when considering the centrality (nodes' sizes), the actors with the higher scores are mostly the same as those identified in the previous paragraphs. The most relevant actor in this sense is the regional RC-V because it is the only gateway for most actors in the network to access the Brazilian forest enterprises with which they carry out research activities. This regional forestry research institute is a collective R&D arrangement created as a solution for private forest firms' research needs. It is operated by a Brazilian University (University of Sao Paulo) with funding from the industry. It works as a collaborative venture of firms and local research organizations. Both the Ego and the other MNC surveyed in our case study are partners in this venture, having indirect access to collaborative programs with many Brazilian forest firms and organizations. Furthermore, they are partners in specific research projects with two actors of the network (FE-II and FE-III). The network around RC-V generates a horizontal relationship between forest companies and joint projects that assures the continuity of those links. Under RC-V, research on cloning was partly appropriated by the MNCs in the project being study.

RC-VI has a similar role at the local level, acting as a gatekeeper to access otherwise isolated[14] research organizations (local and regional),

[11] Even though we tried to contact all 22 actors directly linked to the firm for this projects, we could interview only 17 of them.

[12] We used Cytoscape (Shannon et al., 2003) for graphical representation of the networks and R (R Core Team, 2014) for statistical purposes.

[13] While this can be explained partly because we are not capturing the interactions of agents that are not in the primary network (i.e. group B of actors), hub structures are also found among A actors.

[14] If RC-VI was not connected with actors RC-VII to RC-XI, AE-I and AE-II, all the knowledge generated by these actors would be out of the reach of the rest of the actors in the network, particularly the forest enterprises, because they have no direct link to the former. For this reason, the RC-VI has a relevant role because of its potential for knowledge transmission throughout several actors in the network.

universities and agro enterprises. According to interview with RC-VI, these connections are related to genetic improvement programs. The knowledge spillovers works in the following way: RC-VI acquires knowledge on particular species and in vitro techniques, particularly with the species *E. Dunnii* from the contact with both MNCs involved in genetic programs. Given that RC-VI performs technology transfer to local (usually small) companies and cooperatives in other agro activities (like fruit trees), it has a potential role in spreading knowledge to productive activities other than forestry. On the other hand, RC-VI interacts with local institutions (like research institutes at universities with which the forest companies have no direct contact) for research in areas related to genetic improvement programs (soils, water, etc.). Even though this knowledge flow could be potentially useful for the MNCs in the forestry sector, we found no evidence in the interviews.

An important effect in the diffusion of knowledge to local players through RC-VI takes place through the path RC-V, Ego, RC-VI, as this allows the local research centre to attend conferences or workshops held by researchers of the regional RC-V, which otherwise could have been unreachable, according to the interviewed specialist. That is, the economic size of the MNCs, sensibly bigger than that of local research forest organizations, has enabled the latter to connect international research institutions. The connections involve the MNC and no independent relation has grown between the regional and national research institutions.

The central role of the Ego and the other MNC is reflected in the fact that both are at a maximum of two steps of any other node (actor) in the network, which is obvious for the Ego but not necessarily so for the competitor MNC. We find that > 70% of the direct neighbours of the two MNC are shared neighbours. Moreover, in spite of being competitors (each enterprise seeks to improve the quality and quantity of wood plantations) they became partners in some steps of the innovation process. This is also related to the finding of a positive correlation of horizontal links with the number of innovation activities carried out by forestry firms in Section 4.1.

Not only research institutes and MNCs are central players. A regional consultant (C—V), contacted for the construction of the nursery, is the fourth actor in terms of centrality, although it has only five links. This actor allows other agents to access international research institutes and international suppliers.

Finally, in Fig. 2, the perceived importance (for the interviewees) of the link for knowledge creation is represented by straight (important) or dotted (non-important) lines, and the higher frequency of the interaction is shown by darker lines. Links with local suppliers are mostly non-important and discontinued. In the case of international suppliers, there are more important and permanent links.

Summing up, we can say that, at least in the case study, the MNCs (either the Ego or the other MNC) act as bridges between international and local actors. Even though we don't measure how much of the information contained in connections of length one is transmitted to a third party in an additional step, the potential of knowledge transmission between local and foreign actors through the MNCs exists. Besides them, two research institutes (a regional and a national one) have high degree and centrality, meaning that they have also an important role in spreading information through the network; this is because both are linked with private firms and other research institute in their respective regions. The general network is then very heterogeneous and the flow of knowledge through it is highly dependent on these actors. Moreover, only few actors participate in transitive relations and many are in the periphery of the network. These results though can be related to the fact than many of the actors of the general network were not interviewed. For this reason, in the next section we analyse the narrower network of direct collaborators of the Ego (A actors).

4.2.2. First level network (A actors)

While the general network gives us a picture of potential spillovers, we focus here on direct collaborators (group A of actors) to analyse the transitivity and density of the networks associated to different types of knowledge flows. We are interested in this local structure (transitivity) for at least two reasons. First, high transitivity reflects collaborative rather than hierarchical relations when all actors interact as a group (i.e. they all sign cooperation agreement, etc.). Lower hierarchy in the structures of knowledge creation can be associated not only with greater spillover but also with the continuity of relations even when any of the actors gets out of the network. Second, even when the transitivity (let's say triangles in the network) respond to the sum of three bilateral flows,[15] both the assumption of knowledge being a cumulative process and the fact that knowledge in this network is strictly related with the maximization of forest productivity, might have a positive effect on the possibilities of knowledge creation and diffusion. This is important when the closed transitive relation involves actors capable of adding knowledge to the flow. To further transmit knowledge to other parts of the network it is more efficient to use few connections, the so called small world properties (Watts and Strogatz, 1998).

For this reason, in the remainder of this section, we will focus on the main neighbourhood consisting of the 22 actors (group A) directly recalled by the Ego firm.

Also, in this section we will explore whether the different types of knowledge transmitted is related to different typologies of networks. We consider the four types of knowledge flow defined in Table 1: new knowledge, formal exchange of existing knowledge, informal exchange of knowledge and knowledge incorporated in goods/services. Fig. 3 shows the graphic representation of the sub-networks, and Table 4 summarizes some descriptive statistics.

The *formal exchange of existing knowledge* (technology transfer, technical assistance or training) shows the highest degree and displays a denser network. Approximately half (54%) of the connections are very important, and 58% involve continuous contact between actors. Also, it shows a relatively higher presence of local actors, being a possible channel for spillovers to other local agents.

In the case of the *new knowledge* sub-network (joint R&D or research contracts), the ratio of important versus non-important links are significantly higher (85% of links are continuous in time and also important[16]).

Another difference between these two sub-networks relates to average clustering, also called transitivity of the network.[17] Even though both have the same number of triangles, the average clustering of the *new knowledge* sub-network is higher. This means that it is more probable that two actors connected to a third one are also connected between them (in relative terms to the probability of this happening in the case of *formal exchange of existing knowledge*, like technical assistance).

The higher transitivity in the *new knowledge* sub-network favor the emergence of synergies among actors and stronger ties, which can be related to the higher value assigned by the actors to their neighbours in this sub network.

In both sub-networks, most of the triangles are conformed by local organizations. Only two regional actors participate in the *new knowledge* sub-network, and a few international suppliers interact in triangles in the *formal exchange of existing knowledge* sub-network. In the last case, the transitive pattern involves the MNCs, which is a reflection of the cooperation between the two MNCs in some non-sensitive areas.

Finally, we can see that the actors with greater dissemination capacities (larger centrality) are in both cases the two forestry companies, the Ego MNC and its MNC competitor.

[15] Instead of a joint three part agreement, which is often the case here.

[16] For at least one of the interviewed actors in each dyad.

[17] Transitivity between three nodes i, j, and z means that if i and j are connected to z, then i and j are also connected between them. The clustering coefficient of a network measures the presence of these triangles in relation to all adjacent vertices.

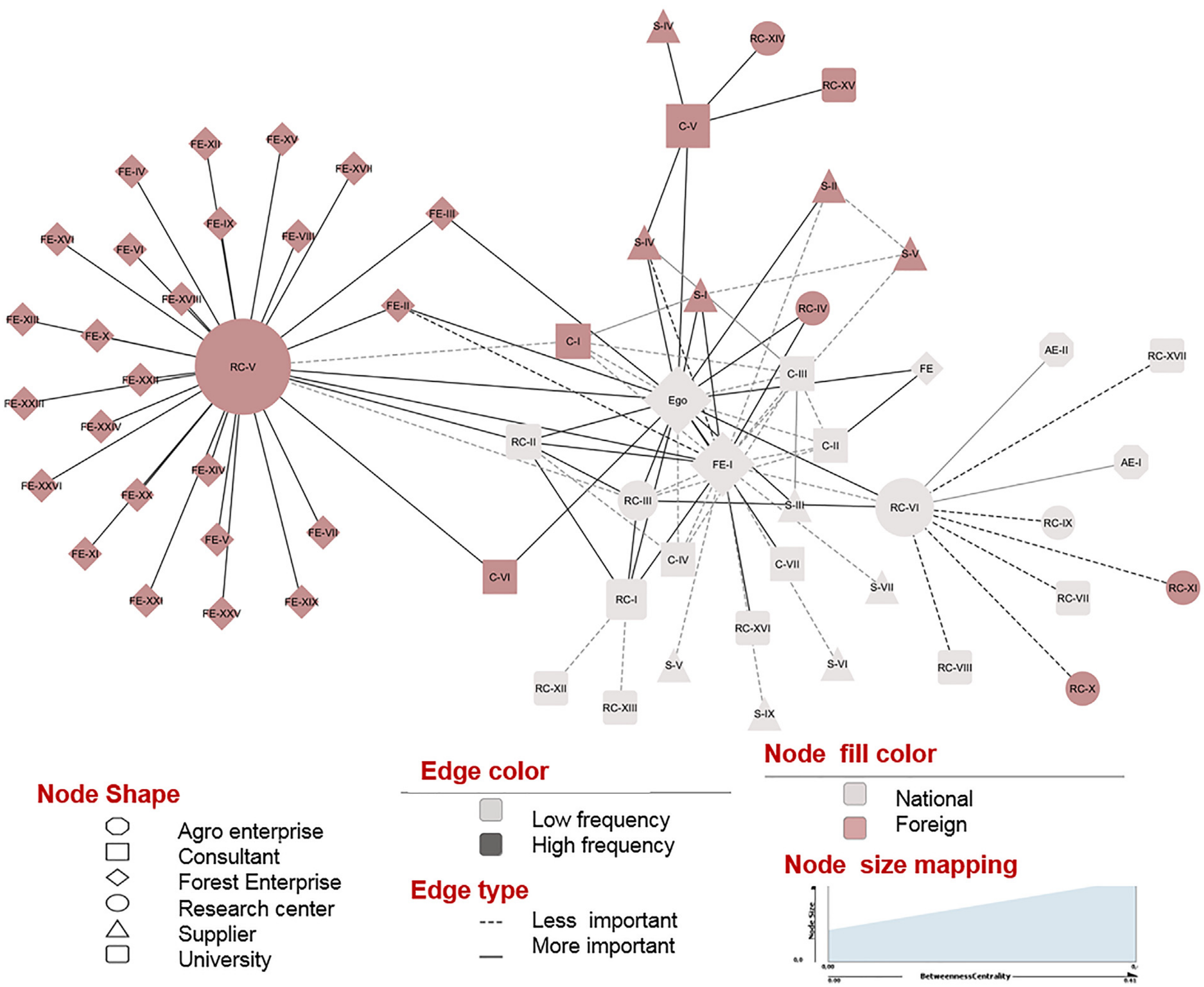

Fig. 2. General network.

In the *new knowledge* and *formal exchange of existing knowledge* sub-networks, related to creation and transmission of existing knowledge respectively, the Ego actor is present in 42% of all dyadic relationships, while in the *informal exchange of existing knowledge* sub-network, it is in 26%. Thus, it seems that informal communications involve relationships that are more independent from the Ego compared to other types of knowledge transmission. In particular, it is through informal communication channels that local regional organizations and consultants communicate with international organizations, consultants and suppliers without the intermediation of the MNCs.

The *knowledge incorporated in goods/services* sub-network reflects the cooperation between the two MNCs with international suppliers, with the aims of developing new products to the respective breeding houses (cycles of length four). The commercial contracts involved in these relations -forest MNCs in Uruguay have developed R&D ventures with leader technology suppliers abroad- imply that this knowledge will not be spread throughout the network.

The position of actors in each sub-network is linked to their organizational capacity and participation in the genetic improvement program and the construction of the new nursery. In the case of *new knowledge* transmission, links with research institutes, both at national and regional level (particularly with Argentina and Brazil) predominate. In general, the interactions are stable, and they occur both through research contracts and other formal agreements. In many cases, the new information is shared through research working papers, academic journal articles or extension works.

In the activities more closely related to the introduction of new technology for the new nursery such as adaptation of inputs, protocols, systems, infrastructure or machinery, the dominant channels are existing formal and informal knowledge transmission and commercial contracts for the exchange of goods and services. The MNCs are central agents. In fact, the knowledge embodied in inputs and services transmitted through commercial links are developed to suit Ego's needs. These types of knowledge transmission channels have the potential to shorten the distance between the country and the global technological frontier. Also important for this kind of discrete change in technology are the horizontal and local partnerships with competitors (particularly the link between Ego firm and its MNC competitor) and the transmission of existing knowledge with consulting firms.

5. Conclusions

Our paper contributes to the scarce literature that studies the international dimension of innovation networks in the forestry sector in developing countries and that analyses the knowledge exchange and collaboration for innovation in this context. More generally, we expect to contribute to an open academic controversy on what is the actual role that MNC can play for the technological dynamisms of developing countries.

The Uruguayan forestry sector has been growing rapidly in the last two decades. Notwithstanding, it has not yet consolidated a sectoral innovation system as this research shows.

While a macro sectoral analysis of the sector shows that innovative firms in the sector do engage with other agents to generate or diffuse

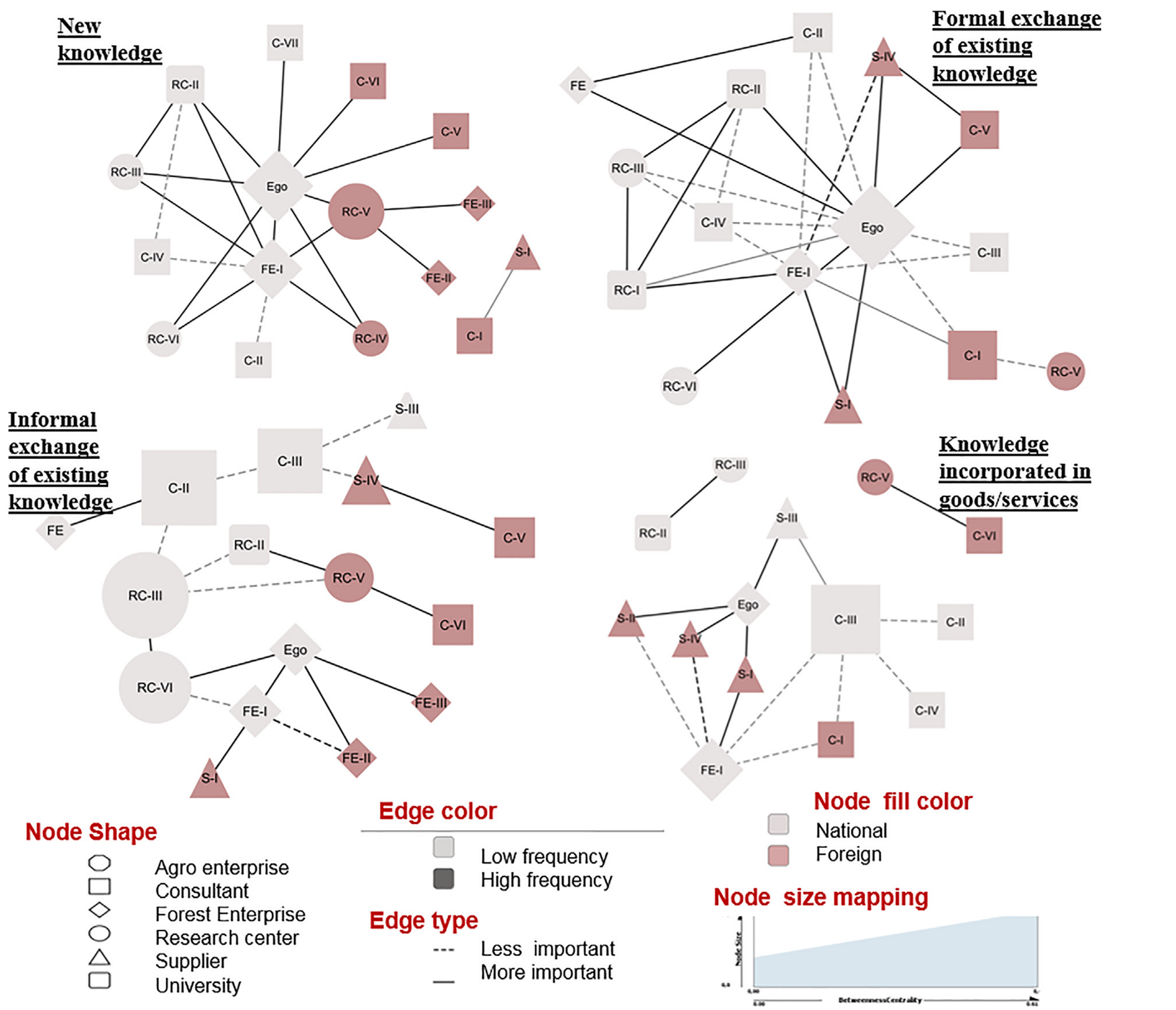

Fig. 3. Knowledge creation and diffusion sub-networks.

Table 4
Network statistics by type of knowledge.

Sub-networks or Networks	Size*	Links	Average degree	Density	Global clustering
New knowledge	16	21	2.63	0.18	0.29
Formal exchange of existing knowledge	15	26	3.47	0.25	0.20
Informal exchange of existing knowledge	16	18	2.25	0.15	0.27
Knowledge incorporated in goods/services	14	15	2.27	0.16	0.07
First level network (all types of knowledge)	22	55	4.96	0.23	0.31

Note: * statistics are computed without considering isolated nodes.

knowledge or to adapt new technologies, the interactions seem to be restricted to enterprises (with suppliers and other producers). Links with universities, laboratories, research centres and the public sector are not significant in explaining the number of firms' innovation activities. This is showing that key players of the local forestry innovation system are not playing an important role for the innovation in the sector. This is a phenomenon that has been identified in other countries as well (Jarský, 2015; Živojinović et al., 2017). In part, the disconnection between firm's needs and academia can be explained by the different structure of incentives. While academia rewards peer-review articles, presentation at conferences, etc., forest firms are governed by problem solving incentives (Klenk and Wyatt, 2015).

The case study shows the strategies that MNCs follow to cope with the limitations of the local innovation system when carrying out an innovation program. In order to accumulate strategic resources for innovation in immature innovation systems, MNCs need to develop channels to absorb information, codified technical knowledge and know-how.

MNCs in Uruguay follow three main cooperation strategies in order to innovate. First, they cooperate with other MNCs. This cooperation includes sharing contacts of relevant agents for the innovation process. Seventy percent of the direct neighbours of the two MNC are shared neighbours. This is a relatively new finding in the literature. Narula and Zanfei (2005) point out that, while the academic world has a long tradition in the cooperative generation and diffusion of knowledge, private firms have more recently increased the cooperation with competitors, suppliers and customers. Živojinović et al. (2017) report the importance of inter-firm collaboration for innovation in non-timber forest products in southeast European countries.

A second strategy that MNCs follow in order to obtain knowledge that is not readily available in the local innovation system is to establish links of cooperation with regional research institutes. Moreover, we find that this strategy has potentially important consequences in terms of knowledge spillovers from the regional research centres to the local ones. The regional research centre has an important centrality in the network. This implies that they are key for the long term generation and transmission of knowledge among agents. They represent a stable source of knowledge and links.

MNCs can be considered gatekeepers of the network as they facilitate indirect channels between local and international actors. This finding sheds some light on the potential role of MNCs in opening the national innovation system or helping the system to get internationally involved. However, as Marin and Giuliani (2008) point out, for developing countries to get an actual benefit, the subsidiaries of MNC need not only to be internationally connected, which gives them access to superior sources of knowledge, but also they need to have initiative to promote local linkages. In our case study, the local linkages with other firms are indirect, with an important role of a local specialized research institute.

Finally, the third source of knowledge for MNCs comes from international suppliers. Important and permanent links are established with them.

When we focus on the type of knowledge that is created or diffused some additional conclusions emerge.

The interactions that involve new knowledge connect regional and local agents and give place to a greater degree of interaction between the actors. Also, more stable relationships among actors seem to facilitate the generation of transitive communication between agents. All these facilitate knowledge spillovers.

In the case of transmission of existing knowledge through technical assistance, experimentation or capacity building, suppliers and consultant firms have a stronger role. In these cases, the networks serve specific purposes, and alliances end once the problem is solved. These networks involve private firms that cooperate through horizontal and vertical links. In our case study, some of these are companies providing knowledge-intensive services. Also, these types of links with suppliers and consultants have a global—rather than regional—geographic reach, with developments segmented in specialized companies through several countries. Contacts between actors are only for the specific purpose instead of based in continuous relationships. The non-persistence of contacts might make spillovers difficult.

While our findings seem to be partially aligned with the previous literature on MNCs that asserts that local subsidiaries have access to international knowledge and facilitate the knowledge transfer across national boundaries (e.g., Frenkel, 2008), it is not clear whether this is enough to generate actual spillovers in all cases.

First, other local forestry firms do not participate in any of the subnetworks, besides the two MNCs. Given that the local research institutes and universities do share information with different agents in the network, the knowledge accumulation could have greater spillovers if other local forest firms cooperate with those actors. But this is not usually the case, according to data of the innovation survey.

Second, we found low synergies among actors in the network. Although triadic relationships were found in a few cases between research institutes, consultants and firms, no triadic relationship involved at the same time local and foreign organizations. Furthermore, suppliers generally made contact with the Ego and do not establish links with each other or with other forestry firms different from the MNC.

Finally, the potential risk of 'hollowing out' effect should be addressed in further research. This risk appears when the domestic innovation system does not meet the needs of firms in certain industries, leading firms to seek alternative innovation systems in which to embed (Narula and Zanfei, 2005). This risk is particularly important to small open economies highly specialized and with the lead of a few large MNCs firms, such as the case of Uruguay.

Appendix A. Appendix

A.1. Part of the questionnaire applied to build the case study in semi-structured interviews

Q1. Name, Name of the organization, Type of organization, Year of creation, Location.

Q2. Regarding this innovation process (explain the program under study), did you have any type of relationship with the following agents?

Q3. Did you have any type of relationship with other agents? (If so, list them).

Q4. For all of the agents with whom you interacted evaluate the importance of the relation, in terms of frequency (continuous /discontinuous) and importance (high/ low) for you.

Table A1
Definition of variables

Variables	Definition
Links for R&D Cooperation	Established a link with other organization with the purpose of R&D activities (We use a proxy for definition of R&D the last column of table A1: carry out experiments). Takes value 1 if yes, 0 otherwise.
Links with Public Sector	Established a link with public sector to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with Scientific Organizations	Established a link with scientific organizations (INIA, universities, laboratories) to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Vertical Links	Established a link with clients or suppliers to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Horizontal Links	Established a link with individual or group of producers to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with Financial Sector	Established a link with financial sector to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with individual producers	Established a link with individual producers to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with group of producers	Established a link with group of producers to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with suppliers	Established a link with suppliers to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with clients	Established a link with clients to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with INIA	Established a link with INIA to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with Universities	Established a link with universities to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Links with Laboratories	Established a link with laboratories to carry out innovation activities. Takes value 1 if yes, 0 otherwise.
Size (number of employees)	Number of employees of the firm.
Foreign capital	The firm has foreign capital participation. Takes value 1 if yes, 0 otherwise.
Public Funding	The firm has received public funding for innovation activities. Takes value 1 if yes, 0 otherwise.
Main activity	Forestry activities are the main activity of the firm. Takes value 1 if yes, 0 otherwise.
Professionals and Technicians/Employees	Ratio of professionals and technicians to total employees
Professionals/Employees	Ratio of professionals to total employees
Technicians /Employees	Ratio of technicians to total employees

Table A2
Questions about cooperation in the Forestry Innovation Survey.

Between 2007 and 2009, within the framework of innovation activities: Have you established a link with any of the following agents?

Agent	Did you linked?		The link with … (row agent) was aiming to…					
	Y	N	Receive/exchange information	Training	Receive technical assistance	Receive funding	Experimentation	Other motives (specify which)
Individual producers								
Groups of producers (CREA)								
Agro associations, development companies, others								
Other group of producers								
Suppliers								
Buyers								
INIA								
Universities								
Public or private laboratories								
Financial institutions								
Others (specify with whom)								

Table A3
List of indirect collaborators (Actors B).

Type	Name	Nationality
Agro Firm	AE-I	U
Agro Firm	AE-II	U
Forest Firm	FE-IX	R
Forest Firm	FE-V	R
Forest Firm	FE-VI	R
Forest Firm	FE-VII	R
Forest Firm	FE-VIII	R
Forest Firm	FE-X	R
Forest Firm	FE-XI	R
Forest Firm	FE-XII	R
Forest Firm	FE-XIII	R
Forest Firm	FE-XIV	R
Forest Firm	FE-XIX	R
Forest Firm	FE-XV	R
Forest Firm	FE-XVI	R
Forest Firm	FE-XVII	R
Forest Firm	FE-XVIII	R
Forest Firm	FE-XX	R
Forest Firm	FE-XXI	R
Forest Firm	FE-XXII	R
Forest Firm	FE-XXIII	R
Forest Firm	FE-XXIV	R
Forest Firm	FE-XXV	R
Forest Firm	FE-XXVI	R
Research centre V	RC-IX	U
University III	RC-VI	U
University IV	RC-VII	U
University V	RC-VIII	U
Research Centre VI	RC-X	R
Research Centre VII	RC-XI	R
University VI	RC-XII	U
University VII	RC-XIII	U
Research Centre VIII	RC-XIV	F
University VIII	RC-XV	R
University IX	RC-XVI	U
Supplier	S-IV	F
Supplier	S-IX	U
Supplier	S-V	F
Supplier	S-V	U
Supplier	S-VI	U
Supplier	S-VII	U
Supplier	S-VIII	Y

	With agent X	Importance	Frequency
Joint R&D			
Research Contract			
Technical assistance/Technology transfer			
Experimentation			
Capacity building/Academic extension activities			
Informal Exchange of knowledge			
Other knowledge links (eg: with suppliers)			

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