Knowledge networks associated with the production of natural resources in Latin America: a comparative analysis[1]

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Abstract

The opportunities for innovation that arise from natural-resource production are associated with the formation of knowledge networks that facilitate learning both within and outside the sectors in question. This article identifies the types of knowledge networks associated with innovation activities in the natural-resource domain using four case studies from the region: the livestock sector in Argentina, the mining sector in Chile, agriculture in Paraguay and forestry in Uruguay. The results show that, in all four cases, natural-resource producers form networks in which scientific knowledge is exchanged. While these have heterogeneous characteristics in terms of the capabilities of the participants, their structure and degree of openness, all display potential to disseminate and create knowledge.

Keywords

Natural resources, innovations, knowledge management, scientific and technical information, case studies, Latin America, Argentina, Chile, Paraguay, Uruguay

JEL classification

D83, Q16, L2

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I. Introduction

Until very recently, natural-resource-based activities were viewed as having little potential for economic growth and poor technological dynamism. In the 1950s, this was blamed on the following: deteriorating terms of trade for natural-resource-based products (Prebisch, 1962; Singer, 1950); fluctuations in the prices of commodities based on these resources (Levin, 1960; Nurkse, 1958); the low potential for technical progress in these sectors relative to manufacturing (Prebisch, 1962); and the lack of capacity in industries that work with natural resources to forge linkages with the rest of the economy (Singer, 1950; Hirschman, 1958; Singer, 1975). In the 1960s, the Dutch disease phenomenon, along with a number of subsequent empirical studies, provided additional evidence for the existence of a "natural-resource curse" (Auty, 1993 and 1997; Gelb, 1988; Gylfason, Herbertsson and Zoega, 1999; Nankani, 1980; Sachs and Warner, 1995; Wheeler, 1984). In this context, it became conventional wisdom that natural resources could help overcome the external constraint by exploiting static comparative advantages in the short run; but, in the medium and long terms, they did not foster the creation of dynamic advantages because they offered few opportunities for innovation, and their linkages with other actors in the economy were weak. Thus, natural-resource-rich countries needed to generate a structural change towards other more dynamic activities, such as manufacturing.

In recent decades, however, this view has been changing, as major economic, technological, institutional and social transformations have started to create new opportunities to innovate and add value in natural-resource-related activities (Marín, Stubrin and Da Silva, 2015; Pérez, 2010). These include the following: changing patterns of demand, characterized by greater demand for natural resources, its greater segmentation and the appearance of dynamic niches in the sectors in question; the diffusion of new knowledge-intensive technologies, such as biotechnology, nanotechnology and information and communication technologies (ICTs), which make it possible to diversify and develop new natural-resource-based products; and institutional changes, such as the possibility of patenting living material (Marín, Stubrin and Da Silva, 2015; Pérez, 2010). Along with these changes, there is growing recognition that natural-resource-related activities generate various increasingly important opportunities for value creation (Andersen, 2015; Andersen and others, 2015; Dantas, 2011; Marín, Navas-Alemán and Pérez, 2015; Marin and Stubrin, 2015; Smith, 2007; Ville and Wicken, 2012).

The empirical literature on new opportunities for innovation associated with natural resources is growing but is still limited (Crespi, Katz and Olivari, 2016; Dantas, 2011; Figueiredo, 2010; Iizuka and Katz, 2015; Marín, Stubrin and Da Silva, 2015; Morris, Kaplinsky and Kaplan, 2012). This article contributes to this emerging literature by exploring innovation opportunities associated with four natural-resource-related activities that are important in Latin America. In particular, it focuses on a growing phenomenon: the opportunities that natural-resource-related activities are creating to generate value "upstream", through networks that emerge to provide the knowledge that the sector needs to innovate.

Expanding the base of scientific knowledge and its applications forms a key element of any economic-development process. In natural-resource production, scientific knowledge is increasingly harnessed to create new products and make the extraction and processing of these resources more efficient and environmentally safe (Marín, Navas-Alemán and Pérez, 2015; Pérez, 2010). The development and application of new knowledge in production activities generally require knowledge networks that involve different types of players from both the production and scientific domains. This type of network facilitates the acquisition and exchange of dispersed knowledge and fosters innovation (Etzkowitz and Leydesdorff, 2000; Lundvall and others, 2002; Mazzoleni and Nelson, 2007).

If natural-resource-related activities enable new knowledge networks to arise or existing ones to expand, there will be an opportunity for firms in the network to scale up towards activities with more value added. There will also be opportunities for participation by other actors that subsequently relate to one of the existing members of this network and, more generally, for expansion of the knowledge base, which would galvanize the system as a whole. With the aim of analysing the new value creation opportunities that the natural resource sectors are generating, this study makes an in-depth analysis of the collaboration networks that have been established, based on biotechnological scientific knowledge requirements in four selected natural-resource sectors: livestock in Argentina; mining in Chile; agriculture in Paraguay and forestry in Uruguay. The chosen sectors are major players in the four economies studied, and also have a very significant tradition of innovation in the region. Biotechnology was chosen as an area of knowledge and technology that is present in the four sectors, since this will occupy a central place in future growth phases in the global economy (Pérez, 2010) and it has a very fertile field of application in natural-resource production.

To understand the potential value-creation impact of the development of natural-resource knowledge networks, the study characterizes the different networks chosen according to a set of dimensions that the literature identifies as important for explaining their capabilities to innovate and disseminate knowledge. The results show that networks for the exchange and creation of scientific knowledge associated with innovation activities in the natural-resource domain do indeed exist. In all cases studied, these networks show some of the characteristics, in terms of the capabilities of the players and structure, which the literature have identified as promising for the diffusion and creation of scientific knowledge.

The article is divided into six sections including this introduction. Section II reviews the conceptual framework of the research and the criteria that will guide the empirical work. More specifically, it identifies the characteristics that the literature considers favourable for knowledge creation and diffusion. Section III describes the production sectors chosen in each country, in terms of their recent evolution and the basic features of innovation in each case; and section IV describes the methodology used to collect and analyse the data. Section V analyses the networks and their potential to create and disseminate knowledge, evaluating the capabilities of the players, the structure of the network and its degree of openness. Lastly, section VI draws conclusions and identifies policy implications.

II. Which networks are most favourable for knowledge creation and diffusion?

Innovative activity often develops within knowledge networks, particularly in the course of overcoming complex problems that firms are unable to resolve individually, so they draw on knowledge that can be provided by a multiplicity of players (Mazzoleni and Nelson, 2007). The creation and application of new knowledge in production is generally a costly activity with uncertain results. For that reason, private firms cooperate with other enterprises to spread the costs and risks; and they engage in partnerships with the scientific community to access knowledge not found in the industrial sphere (Lundvall and others, 2002).

The literature has identified numerous examples of knowledge networks that have created learning opportunities for their participants, in developed and developing countries alike (Bell and Giuliani, 2007; Cabral, 1998; Etzkowitz, Carvalho de Mello and Almeida, 2005; Giuliani, 2013; Schmitz and Nadvi, 1999; Stubrin, 2013).[2] Nonetheless, the benefits derived from knowledge networks are not confined to their participants, since the new knowledge generated to address innovation problems within the network can also be used in other networks and production activities, which stimulates the system as a whole. In other words, the knowledge and technologies that are created in a specific context, such as natural-resource production, could be useful for other production activities, in a process that Lorentzen (2005) has dubbed “lateral migration”.

[2] For example, the literature has documented how, in the case of the South African coal industry, the need to wash the extracted coal (owing to its poor quality) stimulated the development of capabilities and products that migrated to other areas —such as the washing of spirals in the Canadian tar sands (Morris, Kaplinsky and Kaplan, 2012)— through the production and knowledge networks that were created in that activity.

Not all networks give rise to the same opportunities to innovate and disseminate knowledge, however. Networks can be differentiated by the types of players (the nodes) that compose them, or else by their capabilities, the distribution of those capabilities in the network and the type of knowledge that is exchanged. Moreover, the links between the nodes produce networks with a variety of structures (hierarchical, centralized, highly embedded, disperse and others) that affect individual performance and that of the network as a whole.

The literature has generally found that the capabilities of network participants are crucial both for generating innovations and for disseminating knowledge inside and outside the network (Giuliani, 2013; Giuliani and Bell, 2005). For example, knowledge exchanges are more likely to occur, and the evolution over time is likely to be positive, in networks that involve firms with higher capabilities. This is because firms endowed with greater capabilities have resources to share, and they generally seek to complement their capabilities with others existing in the network. In the case of firms with more limited capabilities, the opposite effect occurs. Altenburg and Meyer-Stamer (1999) note that, in low-capacity environments, the imitation culture makes entrepreneurs reluctant to share information of any kind and gives rise to opportunistic or even predatory behaviour (p. 1697). Moreover, firms with greater capabilities are more likely to be invited to collaborate on different projects, and they have a greater chance of absorbing and reusing the knowledge that flows across the network in a way that is profitable for themselves and for the network as a whole (Giuliani and Arza, 2009). It could be said, then, that it is particularly important that the central players in the network, which have more opportunities to disseminate knowledge within it, have greater capabilities.

The degree of similarity between the players in terms of knowledge levels has also been identified as an important variable explaining the creation of links and the sharing of knowledge (Giuliani, 2013; Giuliani and Bell, 2005). When firms possess an advanced level of knowledge, they prefer to establish knowledge links with others that have a similar level of technology or knowledge. This is because they only have incentives to establish links if they foresee benefits from the interaction in question (Giuliani, 2007). If the knowledge bases are too different, cooperating and knowledge-sharing will be less likely. Thus, networks need to have a relatively high minimum capacity.

The literature also notes the need to complement knowledge, since firms search outside for knowledge and skills that are not available internally. In the most technologically dynamic industries, the complexity and extension of the knowledge base needed to compete encourages firms to set up alliances with other agents to gain access to new knowledge. These links are not established between two firms at random, but, above all, between those that share a common knowledge base, but also have some differential knowledge that justifies collaboration (Ahuja and Katila, 2001; Duysters and Schoenmakers, 2006; Gulati and Gargiulo, 1999; Mowery, Oxley and Silverman, 1996).

In terms of structure, networks in which all participants tend to be interconnected (clustering) seem to favour the diffusion and creation of new knowledge within the network (Cowan, 2005). Some authors argue that cooperative networks involving participants with common contacts (a phenomenon known as "structural embedding") are generally rich in social capital (Coleman, 1988). In this type of network, opportunistic behaviour tends to be minimized, since firms have incentives to preserve their reputation in the network and thus maintain their chances of collaborating and participating. Part of the literature also considers that these characteristics help foster the circulation and exchange of knowledge among network members, which can thus strengthen the capacity of firms to innovate. From an empirical perspective, it has been found that structural embedding is a significant factor explaining the innovation and learning capacity of firms in industries such as textiles (Uzzi, 1996) and biotechnology (Ahuja, 2000; Powell and others, 1999), and in information and communication technologies (ICT) (Hagedoorn and Duysters, 2000).

The literature has also underscored the value of reciprocity (Ahuja, Soda and Zaheer, 2012; Giuliani, 2013), which exists when each firm both gives and receives. This characteristic is seen as fostering the development of links and the sharing of knowledge, since it reduces imbalances and power relations. It also counteracts opportunism, since a reputation for opportunistic behaviour does not encourage the sharing or circulation of knowledge. In contrast, reciprocity fosters the spreading of knowledge and the establishment of new links.

Links with agents outside the network are also critical for promoting and sustaining enterprise competitiveness, since they can renew and expand the knowledge base (Breschi and Malerba, 2001). External links can be particularly important in new and dynamic activities that are subject to major technological changes, since forging links with agents outside the network (with which there is neither a prior relationship nor an indirect connection) can give access to new and diverse knowledge, as well as to resources that make it possible to gain an advantage in the market or simply avoid technological lock-in. For example, in the biotechnology industry (Rees, 2005) and also in the semiconductor industry (Rosenkopf and Almeida, 2003), alliances with agents located in other regions were found to be valuable for renewing the knowledge base among local players.

In short, the literature highlights several dimensions of knowledge networks, in terms of both the characteristics of the nodes and the links, to enable them to successfully generate innovations and disseminate knowledge. These notions suggest that networks will tend to be more effective when the following criteria are met.

In relation to capabilities:

(1) The average capacity of the players is high.

(2) All the players have a high minimum capacity level.

(3) Players occupying a central place in the network as emitters of knowledge have high capabilities.

In terms of cohesion:

(4) The network has a high level of clustering.

(5) There is a high level of reciprocity in the network.

(6) There is a high level of structural embeddedness (transitivity).

Relative to network openness:

(7) Links are set up outside the central core of the network.

(8) External players have high capabilities relative to those at the core.

In the following paragraphs, after presenting the cases (section III) and the methodology (section IV), this article analyses the networks (section V) in terms of the capabilities of the players, cohesion and degree of openness.

III. The sectors studied and their knowledge networks for innovation

Innovative activities and knowledge networks are studied in four natural-resource sectors in four countries: the livestock sector in Argentina; mining in Chile; agriculture in Paraguay, and forestry in Uruguay. Recently, each of these sectors has made major innovations to meet new challenges, as briefly described below.

1. The livestock sector in Argentina

Historically, the livestock sector has accounted for a large share of Argentina's agricultural production and in its exports; but, since the 1990s it has faced difficulties associated with land disputes, owing to the spread of agricultural activities, especially those related to soybeans, as well as conflicts with national public policies aimed at guaranteeing the supply of meat to the domestic market at affordable prices.[3] Despite these challenges, cattle stocks have remained relatively stable in Argentina (around 50 million head), owing to a process of production intensification to boost efficiency and enhance meat quality through genetic improvement. Biotechnological tools, such as artificial insemination, in-vivo and in-vitro fertilization and the sexing of embryos and semen, have been central elements in this process.[4] These tools are used to modify the animal's genetic profile; and the genetic improvements introduced are then transmitted, along with the ownership of the breeding animal, or else through the sale of semen or embryos of selected breeders. This study chose a network of knowledge on bovine genetic improvement.

2. The mining sector in Chile

The mining industry has been key to economic growth in Chile, which is the world's leading copper producer (34% of world production) and owns nearly 30% of the world's copper reserves.[5] Currently, however, the sector faces numerous challenges, such as declining ore grades and rising energy and water costs. To address these challenges, innovative suppliers are increasingly being used (Fundación Chile, 2012 and 2014), including those that provide services based on scientific knowledge. A key example has been the development of "bioleaching" —a biotechnological process to separate the mineral from the rock that requires less water and energy than other traditional methods. Currently, over 500,000 tons of fine copper (about 10% of all copper production in Chile) is obtained through this new technology; and its use is expected to increase as mineral sources become depleted. In 2009, there were seven bioleaching operations controlled by five different mining groups (COCHILCO, 2009). This study selected a knowledge network associated with biotechnological solutions that are used in mining.

3. The wheat sector in Paraguay

Wheat production is a strategic activity in Paraguay, since this grain has a high priority in the food basket. In the late 1980s, thanks to the use of higher-yielding varieties and more efficient production technologies (use of fertilizers, chemical disease control and cultivation at appropriate times, among others), Paraguay managed to supply its domestic market and even export wheat. Today, wheat ranks fifth among the cereal crops produced by the country, with over 600,000 hectares planted. Nonetheless, the major expansion of soybeans nationwide has created the need to maintain wheat production, which functions as an alternate crop in winter. As a result, efficiency has had to be increased and production adapted to areas that are not naturally suited to it.[6] With this aim, the wheat sector is implementing major innovations based on the diffusion of new and better agronomic practices and the genetic improvement of seeds. The case study chose a knowledge network associated with both types of activities.

[3] To that end, in 2006 the national government started to introduce a series of policies, such as restrictions on meat exports, an increase in withholding rates, control of prices at different stages of the production chain and the establishment of minimum slaughter weights.

[4] Quantitative genetics has provided another tool, which is used to evaluate certain characteristics of the animals which are of economic interest (for example, birth weight, weaning weight, meat tenderness, quantity and location of fat, and level of milk production, among others). These measurements are then used in the selection process performed by the firms that "produce" breeding animals ("breeders" or "*cabañas*").

[5] In 2012, the value of mining production in Chile represented 12% of gross domestic product (GDP), mining exports were equivalent to 60% of total exports, and the sector's contribution to the public treasury represented 14% of all tax revenues.

[6] According to data from the Paraguayan Chamber of Grain and Oilseed Exporters and Marketers (CAPECO), between the 2002/2003 season and 2013/2014, the soybean production area more than doubled from 1.5 million to 3.5 million hectares.

4. The forestry sector in Uruguay

In Uruguay, forestry activity has grown vigorously in recent decades, to become the country's third most important export sector (after meat and soya). This has been associated with the expansion of the forested area and production. The former went from 650,000 to 1 million hectares between 2000 and 2012, and the latter more than tripled in 2000–2011, from roughly 3 million m^3 in 2000 to 10 million m^3 in 2011. Innovation activity and the introduction of technological advances have been central to this growth (Bervejillo, Mila and Bertamini, 2011). Innovation aims at introducing genetic changes in the species used for production and reduce the time that elapses between the selection of a tree and its commercial exploitation. The case study focuses on the second of these innovation activities, which is done in two stages. The first takes place in micropropagation laboratories, where plant tissues are cultured aseptically, and the volume of microplants grows exponentially in a small time and space. The second occurs in the nursery, where the final propagation is carried out by vegetative reproduction (using grafts) from mother plants.

IV. Methodology

1. Design of the research

The main objective of this study is to reconstruct and characterize the networks associated with the knowledge needs of four natural-resource sectors in four of the region's countries. In each country a key player was selected for knowledge development aimed at solving the problems of the natural-resource suppliers. This key player was identified as the "network ego" and was used to reconstruct the knowledge network, including other players with which the "ego" interacted to exchange knowledge.

In Argentina, the natural-resource firms studied are the *cabañas* or entities that develop and sell bovine genetics. To reconstruct the *cabañas'* knowledge network, a player was identified that was central for the exchange of knowledge on the use of biotechnology for bovine improvement,[7] namely the IRAC-BIOGEN enterprise, ego of the livestock network. This firm undertakes two types of activity: research, training and product development (IRAC); and transfer and marketing (BIOGEN). IRAC does research in the field of in-vivo and in-vitro reproduction, the freezing of semen and embryos, superovulation and the sexing of embryos and spermatozoids, among other biotechnological techniques. It also formulates work protocols enabling local producers to apply highly complex techniques. Its milestones include the development of in-vitro bovine reproduction technologies, which were applied for the first time in Argentina in 2012. BIOGEN, the commercial pillar of the institution, provides technology transfer services, advice and tailor-made solutions to meet the demands of livestock producers. The export of genetics is another of the firm's regular activities.

In Chile, the natural-resource producers studied are the large mining companies. The knowledge network was reconstructed around Aguamarina S.A., a firm that provides biotechnological services to mining companies and represents the ego of the mining network. It is a firm based on national capital, providing solutions for medium- and large-scale mining based on the use of microorganisms. One of its key products consists of a biotechnological solution to reduce the amount of particulate matter in suspension. The firm also develops solutions and services in the field of bacterial bioleaching and applications in which bacteria are used to combat pollution (tailings).

[7] As noted above, genetic improvement uses two tools: quantitative genetics and biotechnology. In this study, the network was constructed around the second of these, although some entities use the first tool.

In Paraguay, the players selected to represent the natural-resource sector are wheat producers, which can be classified into three types: (i) large firms, which produce and market cereals and oilseeds; (ii) medium-sized agricultural cooperatives that undertake activities related to the commercial production of cereals and oilseeds, and also produce agribusiness products (flours, oils and dairy products) and agricultural inputs (fertilizers and agrochemicals); and (iii) independent farmers that are not members of cooperatives. The network studied for this research was formed around a consortium of players that implemented a project entitled "Strengthening Research and Dissemination of Wheat Cropping in Paraguay", consisting of the Paraguayan Chamber of Grain and Oilseed Exporters and Marketers (CAPECO), the Paraguayan Institute of Agrarian Technology (IPTA) and the Institute of Agricultural Biotechnology (INBIO). This project aims to develop innovations and form technological capabilities in the wheat sector. Its specific goal is the genetic improvement of wheat and the identification of best agronomic practices taking account of local conditions in the country's various agricultural areas (Kolhi, Cubilla and Viedma, 2009). The project's ultimate objective is to increase wheat production and enhance its industrial quality. The consortium is the ego of the wheat network.

Lastly, in Uruguay, the firm UPM Forestal Oriental is used to represent the natural resource sector since it encompasses different links in pulp production, and the forestry sector is quite concentrated. The study focuses on the activity of the firm responsible for optimizing forest productivity, specifically through the genetic improvement of varieties. As an integrated multinational, this firm uses its own nurseries and laboratories as its main knowledge source. Therefore, unlike the other networks, the ego of the forest network is part of the same firm that produces natural resources: the Santana nursery and the micropropagation laboratory.

Table 1 summarizes the main characteristics of the knowledge possessed by each network ego, as well as the type of knowledge produced and disseminated within them.

Table 1

Players that constitute the ego of each network and the type of knowledge produced and disseminated

Country	Network knowledge	Ego	Activity	Area of specialization	Knowledge produced	Knowledge milestones
Argentina	Genetic improvement used in bovine reproduction; network built around a firm that provides genetic services	IRAC-BIOGEN	Sale of services Training Research	Development and application of advanced animal reproduction technologies	Creation of new scientific knowledge and recombination of existing technical knowledge to facilitate its diffusion and transfer	Development of in-vitro embryo production technology in Argentina
Chile	Biotechnological solutions in which microorganisms are used to solve mining problems	Aguamarina S. A.	Sale of services	Development and application of technologies for mining based on the use of microorganisms	Scientific knowledge and recombination of technical knowledge	Biotechnological solution to reduce the amount of particulate matter in suspension. Bacterial bioleaching
Paraguay	Genetic improvement and capacity-building in wheat handling techniques; network built around a specific project	Paraguayan Chamber of Grain and Oilseed Exporters and Marketers (CAPECO)	Trade organization		Organizational	Creation of new wheat varieties by region; and improvements in wheat quality
		Paraguayan Institute of Agrarian Technology (IPTA), scientific advisor	Research, technology transfer, extension and training	Development and application of technologies for the genetic improvement and the agronomic management of agricultural varieties	Recombination of technical knowledge	
		Institute of Agricultural Biotechnology (INBIO)	Research and project management	Lobbying, diffusion and promotion of biotechnology in Paraguay	Organizational, political	

Table 1 (concluded)

Country	Network knowledge	Ego	Activity	Area of specialization	Knowledge produced	Knowledge milestones
Uruguay	Genetic improvement network to increase forest productivity in cool areas; network created around part of the multinational company UPM Forestal Oriental	UPM Forestal Oriental: Micropropagation laboratory and the Santana nursery	The laboratory multiplies provisional clones. The nursery performs the vegetative propagation of selected clones of *E. dunnii*. Both the laboratory and the nursery are part of UPM	Application of micropropagation and vegetative propagation technologies	Standardization of technical knowledge	Adaptation of the E. dunnii variety to cold weather. The nursery was built with an innovative technology that, for the first time in the country, allowed to adopt vegetative propagation (by stakes) of the species *E. dunnii* in cold zones

Source: Prepared by the authors.

2. Information sources

Fieldwork in the four countries was undertaken between December 2013 and April 2014, and included structured and in-depth interviews. Table 2 shows the number of interviews held in each country, by type of player. The in-depth interviews made it possible to build the initial list of the participants in each network, specify the path for the subsequent work —especially in terms of the selection of the players to be interviewed— and contextualize each case study.

Table 2
Players interviewed in each country[a]

Country	No. of in-depth interviews	No. of semi-structured interviews	Ego firm	Type of player interviewed	No. of players	Period of field-work
Argentina	4	16	IRAC-BIOGEN	Private firm	8	From the last week of December 2013 through February and March 2014
				Public research organization	2	
				University	6	
Chile	4	8	Aguamarina S. A.	Private firm	4	February and March 2014
				Multinational firm	1	
				Private laboratory	1	
				Association	1	
				Other	1	
Paraguay	12	12	CAPECO-IPTA-INBIO[b]	Private firm	5	March and April 2014
				Public research organization	1	
				Non-governmental Organization (NGO)	1	
				Others (cooperatives)	5	
Uruguay	3	17	UPM Forestal Oriental	Private company	6	From January to April 2014
				Multinational firm	4	
				Public research organization	2	
				University	2	
				NGO	1	
				Other	2	

Source: Prepared by the authors.

[a] Annex A1 contains an exhaustive list of the entities interviewed in each country.

[b] CAPECO is the Paraguayan Chamber of Grain and Oilseed Exporters and Marketers; IPTA is the Paraguayan Institute of Agricultural Technology, and INBIO is the Institute of Agricultural Biotechnology.

The questionnaire was designed to capture the different types of knowledge links that each node had with other actors in the list that had been prepared. The interviewees were allowed to point out other nodes that were not on the list, with which they had knowledge links. In Argentina, 135 entities were recognized as network participants; in Chile, 66; in Paraguay, 26, and in Uruguay, 68.[8]

3. Methods of analysis

The following paragraphs describe a set of indicators used to evaluate the empirical propositions defined in section II. As also noted in that section, the indicators are grouped into three types, associated with: (i) the capabilities of the players (linked to criteria 1 to 3); (ii) the cohesion of the network (linked to criteria 4 to 6); and (iii) the openness of the network (linked to criteria 7 and 8).

Table 3 describes the statistics to be used in the analysis and associates them with the empirical propositions that each one illustrates, either individually or jointly.[9]

Table 3
Indicators and statistics

Indicator number	Description of indicator	Criteria				Definition and comments	Comparability between countries	Notes on comparability
		Capabilities	Cohesion	Openness	Number			
1	Number of players interviewed						High	
2	Average proportion of knowledge outcomes per player	X		X	1, 2, 3 and 7	From a standard list of six possible outcomes: (i) products, (ii) patents, (iii) other intellectual property rights, (iv) disclosure reports, (v) extension and (vi) others, which includes publications, research and development projects with external financing and others not included. Weighted average according to the total number of players present by type in each network.	Medium	In the case of the wheat network, a different survey was made of the results of the research, which made it necessary to group the categories to make the indicators comparable.
3	Average ratio of professionals per player	X		X	1, 2, 3 and 8	Average participation of professionals among those employed in each player, weighted according to the total number of players present by type in each network.	High	
4	Capabilities in the links: relationship between exploration and diffusion	X			1	Dyads (links between two players) with new knowledge flows and dyads with existing knowledge flows.	Medium	The activities of the central player were taken into account in the mining network, but not those focused solely on mining activity.
5	Centrality (output proximity)	X			3	Minimum number of steps needed to get from each player to all the others.	Medium	
6	Density		X		4	Existing links on the total of possible links.	Medium	The wheat network was associated with a specific project, while in the rest of the countries, the networks were built around an player in a research field.
7	Transitivity		X		6	Probability that two players connected to a third party are connected to each other.	Medium	

[8] In Paraguay, the total number of players identified is much smaller because they are linked exclusively to a specific project.

[9] The empirical analysis of the networks used the "igraph" package (Csardi and Nepusz, 2006), implemented in the "R" language (R Development Core Team, 2014).

Table 3 (concluded)

Indicator number	Description of indicator	Criteria				Definition and comments	Comparability between countries	Notes on comparability
		Capabilities	Cohesion	Openness	Number			
8	Reciprocity: percentage of bidirectional dyads		X		5	Dyads (links between two players) with mutual or bidirectional knowledge flows, as a proportion of the total existing (mutual and asymmetric) dyads.	Medium	
9	Reciprocity: percentage of unidirectional dyads		X		5	Dyads (links between two players) with asymmetric or unidirectional knowledge flows, as a proportion of the total number of existing (mutual and asymmetric) dyads.	Medium	
10	Openness			X	7 and 8	In each network there is a group of "core" players made up of natural resource producers and other players who link with them directly, frequently and importantly. With the opening indicator, the proportion of players (per type) that are outside the core is evaluated, in relation to those that remain inside it.	Medium	In the case of the mining network, the interviews focused on players that were not the producers of natural resources, so the resulting opening values will be high.

Source: Prepared by the authors.

(a) Indicators associated with capabilities

To evaluate the capabilities of network participants, two key indicators are used: firstly, the number of knowledge outcomes produced by each participant (indicator 2); and, secondly, the endowment of qualified (professional) human resources (indicator 3). To construct these indicators, values are imputed to players who were identified in the network but not interviewed. This was done according to the type of player, using data provided by those who were interviewed.

These two capacity indicators were then calculated with respect to different groups. Firstly, the capabilities of players in the twenty-fifth percentile were measured (based on indicator 3), since the literature finds that knowledge-sharing and diffusion require most of the network participants to have a relatively high minimum capacity.

The literature also reports that the capabilities of players occupying a central place in the network are particularly important. To evaluate this characteristic, data on capabilities (indicators 2 and 3) and centrality (output proximity) are combined (indicator 5). Output proximity measures the minimum number of steps needed to get from each player to all others, considering the directionality of the knowledge flow (output only). The measure is based on the idea that the participants that can interact more quickly with the rest are more central (Wasserman and Faust, 1998). Thus defined, this indicator, which could only be calculated in relation to the players interviewed (there were no imputations), was divided into three groups to identify players of high, medium and low centrality, considering percentile (1/3) and percentile (2/3) as cut-off points in each case study.[10] This made it possible to evaluate the capabilities of each of these groups, in the expectation that the central players were of particularly high capacity.

Another measure used in relation to the capabilities of the players is linked to the type of knowledge that is disseminated among them. An indicator is proposed that measures whether the links between the players are based on the diffusion of existing knowledge or on the exploration of new knowledge (indicator 4). Knowledge creation links include exchanges made under research and development agreements or research contracts; those of existing knowledge are exchanges made through agreements for the provision of services, technical assistance, technology transfer, testing and experimentation, training

[10] As the output proximity values are repeated among each country's players, the distribution of players by category is not necessarily uniform.

and extension. In contrast, links that involve the creation of new knowledge require more sophisticated capabilities. This measure complements the previous ones effectively, since it captures capabilities that are not formalized in university degrees or materialized in research and development products.[11]

(b) Cohesion-related indicators

According to the literature, a high level of clustering guarantees broad and rapid knowledge diffusion. The networks' level of clustering is measured with a network density indicator (indicator 6), defined as the proportion of links that actually exist in the network (regardless of their directionality) with respect to the total number of possible links (if n is the number of nodes in the network, the maximum number of possible links is the pairwise combinatorial of n, equal to $n\ (n\text{-}1)/2)$.

The clustering measure is complemented by one of structural embeddedness based on a transitivity index, defined as the probability that two players that are linked to a third are themselves connected (indicator 7). This indicator measures the emergence of "triangles" in the network.

An indicator of the reciprocity of exchanges is also included through a dyad census. Dyads are "mutual" where the exchange is bidirectional, "asymmetric" where the exchange is unidirectional and "null" where there is no exchange (Wasserman and Faust, 1998). The dyad census counts all types of dyads. On this basis, the proportion of mutual and asymmetric links is calculated as a percentage of the total bidirectional and unidirectional links present (indicators 8 and 9).

Lastly, cohesion indicators are calculated for sub-networks defined according to the type of knowledge that circulates across them, whether new or existing, as explained in relation to the capacity indicators.

All the cohesion indicators, and also those of openness explained below, were constructed from the data obtained from the interviews held (that is, no imputations were made).

(c) Openness-related indicators

To analyse the degree of openness of each network, an indicator referred to as "migration" was constructed. This entailed defining a core of players from each network, consisting of the group of natural-resource producers and the entities that have the most frequent, important and direct links with them; then an evaluation was made of how the network expanded beyond the area of influence of the natural-resource production in each case (indicator 10). This calculation could not be performed for the mining network, because no interviews were held with the mining companies. In the other networks, the proportion of players inside and outside the core was evaluated, along with their composition by type.

V. Empirical results

This section makes a joint analysis of the four natural-resource networks studied: the livestock network in Argentina; the mining network in Chile; the wheat network in Paraguay and the forestry network in Uruguay. The objective of the section is to explore the extent to which these networks, which originate in response to the knowledge needs of natural-resource producers, have the potential to create and disseminate knowledge and, eventually, extend applications of that knowledge to other production activities. The section is organized following the order of the criteria mentioned in section II: capabilities, cohesion and, lastly, openness.

[11] Field days were also incorporated into the existing knowledge network of the wheat sector in the "Other" category.

1. The capabilities of network participants

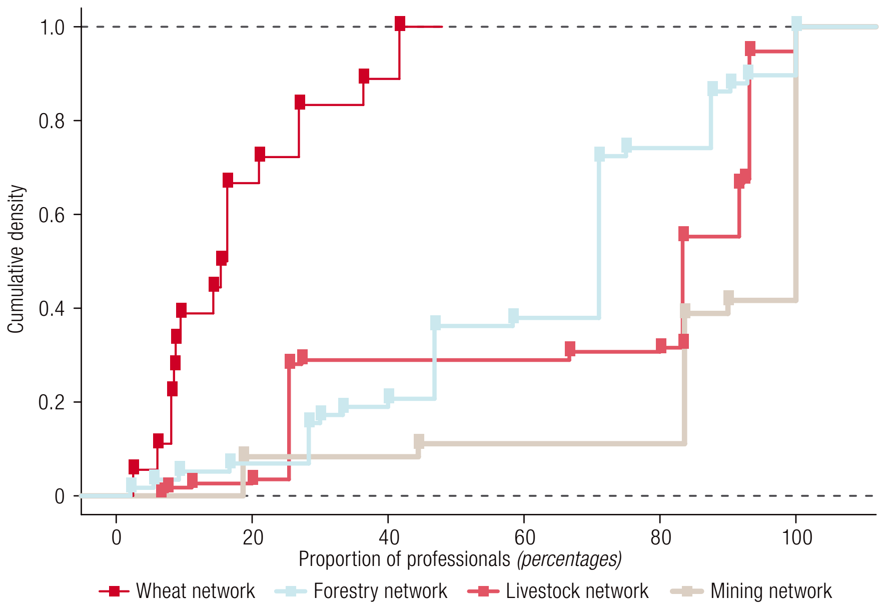
The different indicators used to measure capabilities show that networks have varied characteristics. In the mining network, most of the players interviewed are private firms that have commercial links with a firm that provides biotechnological services for mining. As can be seen in table 4, the selected indicators show that the individual players in this network generally have high capabilities. Moreover, the distribution of capabilities seems quite equitable, and the minimum capabilities of all the participants is high: in 25% of the players with the least capabilities, professional workers account for more than 83% of the total number of employees (see figure 1). This means it is a network which, in terms of capabilities, has very good potential for knowledge diffusion and creation.

Table 4
Average capacity of each network based on the participants interviewed
(Percentages)

	No. of participants interviewed	Average proportion of knowledge outcomes per participant[a b]	Professionals			
			Proportion in each network interviewed	Proportion per participant		
				Average	Percentile 25	Coefficient of variation
Livestock network	16	59.3	53.2	70.3	25.4	43.3
Mining network	8	58.6	59.4	86.8	83.6	27.2
Wheat network[c]	12	53.0	15.6	18.0	8.4	67.0
Forestry network	17	42.3	31.3	62.9	46.8	41.3

Source: Prepared by the authors.
[a] Average expanded by type of player: in the livestock network, to 114 nodes; in the mining network, to 36; in the wheat network, to 18, and, in the forest network, to 58, using the measurements obtained from the interviewees in each case.
[b] Six categories of knowledge outcomes are considered.
[c] Information on the human resources of 11 of the interviewees is available in the wheat network.

Figure 1
Distribution of the proportion of professionals in the different networks



Source: Prepared by the authors.

The livestock network has highly trained human resources: on average, 70% of those employed in each player are professionals. Nonetheless, the coefficient of variation is 43%, so there is quite a wide dispersion of capabilities within the network. This also means that the minimum capacity in the network is relatively low. Thus, in the 25% of players with the least capacity, the ratio between the number of professionals and the number of employed persons is barely 25%. Although it is impossible to establish the minimum capacity threshold, these two latter characteristics could reduce the potential of the network to disseminate knowledge internally.

In the forestry network, the proportion of professionals in the total number employed per player is high (63%) and the minimum capabilities tend also to be high: in the 25% of players with the least capabilities, professionals account for 47% of all employees. This means that there is a critical mass of knowledge in the network, sufficient for scientific knowledge to circulate easily. Nonetheless, capabilities within the network are not well distributed.

Lastly, the wheat network displays relatively low capacity indicators, especially in terms of the percentage of professionals among the employees of each player; and the distribution of capabilities is poor. Figure 1 shows that, among the human resources of more than 60% of the players interviewed, fewer than 20% are professionals. These characteristics are unlikely to favour the diffusion of knowledge, whether inside the network or outside it.

Table 5 shows the same capacity indicators, but in relation to the players that have a central role in the diffusion of the network's knowledge. The higher the capabilities of this group, the better will be the potential for knowledge diffusion and creation. The direct relationship between centrality and capabilities would seem to be present in all networks except forestry. This suggests that the livestock, mining and wheat networks offer high potential for knowledge circulation, since the central players have high capabilities in all three cases.

It is also interesting that, except in the case of forestry, the networks' ego players are among the most central. While this partly reflects the network's own reconstruction, since it was the ego itself that originally identified the participants, the fact of measuring centrality as output centrality reduces the bias of centrality by methodological design, since it is measured in terms of the emission of knowledge.

The forestry network ego is the subsidiary of a multinational and is a net knowledge recipient. As was verified during the fieldwork, this player has adopted a cautious approach to prevent the knowledge on genetic improvement that it sees as its main competitive advantage from spreading.

Lastly, table 6 shows the type of link that corresponds to each dyad. The fourth column shows that in none of the networks is the relationship between exploration and diffusion greater than 100%, which means that the main activity in all cases is the diffusion of existing knowledge. Nonetheless, there are differences between the individual networks.

Table 5
Capabilities of the players that play a central role in network knowledge diffusion

Output proximity	Indicator	Livestock network		Mining network		Wheat network		Forestry network	
		Value	Players	Value	Players	Value	Players	Value	Players
High	Average proportion of professionals *(percentages)*	87.5	Ego 1 public research organization 1 *cabaña*	95.0	Ego 1 association	26.0	Ego 1 NGO 1 cooperative	68.3	2 private 1 public research organization 1 other
	Average proportion of knowledge outcomes *(percentages)*	66.7		83.3		55.6		33.3	
	No. of participants	4.0		2.0		3.0		4.0	
Medium	Average proportion of professionals *(percentages)*	64.2	3 *cabañas* 3 universities	72.9	1 private 1 laboratory 1 other	23.9	1 private 2 cooperatives	72.1	2 private 2 multinational companies 1 university
	Average proportion of knowledge outcomes *(percentages)*	58.3		50.0		55.6		46.7	
	No. of participants	6.0		3.0		3.0		5.0	
Low	Average proportion of professionals *(percentages)*	54.4	3 *cabañas* 1 private 1 public research organization 1 university	81.5	2 private 1 multinational firm	8.2	4 private 2 cooperatives	52.5	Ego 2 private 1 multinational company 1 public research organization 1 university 1 NGO 1 other
	Average proportion of knowledge outcomes *(percentages)*	47.2		38.9		50.7		45.8	
	No. of participants	6.0		3.0		6.0		8.0	

Source: Prepared by the authors.
Note: The shaded cells indicate the position in which the network ego is located in each country.

Table 6
Distribution of new and existing knowledge links by network

		Links			Ratio between exploration and diffusion
		Totals	New knowledge	Existing knowledge	
Livestock network	Number	52	15	37	40.5
	Percentege of total	100.0	28.8	71.2	
Mining network	Number	19	9	10	90.0
	Percentege of total	100.0	47.4	52.6	
Wheat network	Number	36	1	35	2.9
	Percentege of total	100.0	2.8	97.2	
Forestry network	Number	42	16	26	61.5
	Percentege of total	100.0	38.1	61.9	

Source: Prepared by the authors.

In short, the analysis of capabilities seems to indicate good potential for knowledge diffusion in all networks, albeit for different reasons. Although in the wheat network the capabilities are scarce in absolute terms and are less explored, capacity is well distributed within the network and the central players have greater capabilities than the rest.

2. Network cohesion

Table 7 shows the cohesion indicators for all the networks and also the sub-networks defined by the type of knowledge that circulates across them. The wheat network is one of high density, reciprocity and transitivity, in which all existing knowledge is exchanged. As can be seen in the second column, there are only two participants in the new knowledge creation network. This suggests a high potential for knowledge diffusion among network participants, although the low capacity level present in it makes this potential somewhat relative.

Table 7
Network structure: density, transitivity and reciprocity
(Percentages)

		Complete network	New knowledge network	Existing knowledge network
Livestock network	Density	40.0	19.2	30.8
	Transitivity	43.9	25.0	39.6
	Reciprocity (bidirectional)	83.3	93.3	64.9
	Reciprocity (unidirectional)	16.7	6.7	35.1
	Number of players	16	13	16
Mining network	Density	39.3	32.1	35.7
	Transitivity	44.1	27.3	40.0
	Reciprocity (bidirectional)	100.0	100.0	90.0
	Reciprocity (unidirectional)	0.0	0.0	10.0
	Number of players	8	8	8
Wheat network	Density	65.2	100.0	53.0
	Transitivity	75.7	0.0	62.3
	Reciprocity (bidirectional)	93.0	100.0	82.9
	Reciprocity (unidirectional)	7.0	0.0	17.1
	Number of players	12	2	12
Forestry network	Density	32.4	24.2	24.8
	Transitivity	44.0	38.9	20.2
	Reciprocity (bidirectional)	54.5	68.8	19.2
	Reciprocity (unidirectional)	45.5	31.3	80.8
	Number of players	17	12	15

Source: Prepared by the authors.
Note: When the network has a large number of participants, the indicators used take extreme values and their interpretation is not totally reliable. This happens in the case of the new knowledge network in the wheat network.

The livestock, mining and forestry networks are in the opposite situation, with a high capacity level, but reduced cohesion with respect to all the indicators used (except for the reciprocity indicator in the case of the mining network). The reciprocity indicators of the forestry network are particularly low.

In the livestock network, the existing knowledge sub-network is considerably denser than the new knowledge sub-network. There is less of a difference between the forestry and mining sub-networks.

In short, contrary to the findings of the capabilities analysis in the preceding section, the wheat network is the one that has a structure favourable to knowledge creation and diffusion. An example of the opposite is the forestry network, since reciprocity and density are extremely low. This is not entirely surprising, since, while the wheat network was created from a consortium of players with a specific purpose, the forestry network was constructed from the subsidiary of a multinational enterprise, a type of entity that tends to be less inclined to share knowledge.

3. Network openness

According to the literature, networks with a higher level of openness are more likely to access a diversity of knowledge, enhance their capabilities and speed up their creativity to generate new knowledge. The results of the analysis are shown in tables 8, 9 and 10.

The livestock network is the only one with a high level of openness: over 50% of the players studied are not natural-resource-producing firms or have direct links with them, of the frequent and important type such as those evaluated in this indicator. The total migration in this network (the growth of the number of players) is 120%. In the wheat network, the equivalent measurement is 8% and, in the forestry network, 9%.

Table 8
Migration in the livestock network

	Livestock network		
	Core	Migration	Ratio between the size of the migration and the size of the core *(percentages)*
	Number	Number	
Cabañas	23	0	-
Other private	4	12	300
Public research organizations	3	7	233
Universities	5	22	440
Government agencies	1	0	0
Associations	4	7	175
Total	40	48	120

Source: Prepared by the authors.

Table 9
Migration in the wheat network

	Wheat network		
	Core	Migration	Ratio between the size of the migration and the size of the core *(percentages)*
	Number	Number	
Agricultural producers	10	0	-
Other private	0	1	-
Public research organizations	1	0	0
Non-governmental organizations	1	0	0
Total	12	1	8

Source: Prepared by the authors.

Table 10
Forestry in the wheat network

	Forestry network		
	Core	Migration	Ratio between the size of the migration and the size of the core *(percentages)*
	Number	Number	
Forestry enterprises	27	0	-
Other private	6	2	33
Multinational companies	3	0	0
Public research organizations	3	1	33
Universities	3	1	33
Non-governmental organizations	1	0	0
Total	43	4	9

Source: Prepared by the authors.

This indicates that the livestock network has, in principle, a high capacity to gather knowledge from beyond its core (natural-resource-producers and their direct links), and to spread knowledge from the network outward. Conversely, in the forestry and wheat networks, it appears unusual for knowledge to be received and disseminated outside the core. In the case of the wheat network, this situation of poor openness might require attention, because it is a network with relatively low capabilities which, without openness, could face a greater risk of technological lock-in. Nonetheless, this network, unlike the other three, was studied in relation to a specific project, which necessarily biases the openness indicator downward. It is therefore highly likely that the network participants have links with other players in other research projects that were not analysed.

In terms of network openness, effective knowledge creation and diffusion also seems to be associated with the fact that participants that do not belong to the core have relatively higher capabilities. To evaluate this characteristic, the proportion of professionals and the proportion of knowledge outcomes (indicators 2 and 3 of table 3) were estimated in relation to the groups of core players and those of the migration; the results are shown in table 11. The livestock network displays strong indicators in this regard, with an average proportion of professionals outside the core almost double the number within it. There is also a higher average proportion of knowledge outcomes among participants pertaining to the migration.

Table 11
Capabilities of the core and migration players
(Percentages)

	Estimation of capabilities	Core	Migration
Livestock network	Proportion of professionals	46.9	90.5
	Proportion of knowledge outcomes	49.1	67.3
Wheat network	Proportion of professionals	16.5	8.5
	Proportion of knowledge outcomes	54.5	33.3
Forestry network	Proportion of professionals	60.0	55.0
	Proportion of knowledge outcomes	40.9	47.3

Source: Prepared by the authors.
Note: The estimate is made by expanding the data obtained from the interviewees, by type of player, to the rest of the node, using the average proportion of professionals and knowledge outcomes. In some cases, certain types of players may belong to the core or to the migration but were not interviewed; in those cases, the data on capabilities are missing.

In the wheat network, the estimates yield diametrically opposing results: capacity in the migration is considerably less than within the core. In this particular case, however, there is only one player outside the core, and it should be remembered that the network was built around a specific project, so the considerations mentioned above must again be taken into account.

Lastly, in the case of the forestry network, the average capacity of the players inside and outside the core is similar. This supports the interpretation of a network that is closed partly because of jealousy over the knowledge outcomes and the desire to protect them as a source of competitiveness. In this sense, both the core and the migration players have high capabilities.

VI. Conclusions and policy implications

Natural-resource-related activities have been and remain controversial. Some authors claim that they are harmful to countries, because they create environmental, institutional and economic problems. Many others, however, maintain that the effect of these activities on countries' development depends largely on the set of institutions that are used to organize them inside each country. An argument that has gained importance recently looks beyond this discussion to note that current technological and market conditions have changed, and there are new opportunities to take advantage of natural resources as these activities become more knowledge-intensive, have greater potential to encourage other knowledge activities and are less likely to affect the environment.

This article made an in-depth study of four collaborative networks that have been established on the basis of the scientific knowledge requirements of four natural-resource sectors chosen in four countries. The sectors are important for each of the economies studied: the livestock sector in Argentina; mining in Chile; agriculture in Paraguay, and forestry in Uruguay. The cases were also chosen with the aim of embracing a diversity of players that occupy the central place in each network. Thus, in the case of Argentina, the central player is a domestic firm providing biotechnology services for livestock breeders; and, in Chile, it is a firm that provides services for mining. In Paraguay, in contrast, the central player is a public-private consortium and, in Uruguay, it is a laboratory and a nursery integrated into a multinational enterprise.

The study is exploratory in nature. The literature has few studies of scientific knowledge networks associated with natural-resource production; and the authors are unaware of any comparative studies in Latin America. In all the networks chosen, biotechnology plays a key role as a domain of scientific research that has the potential to nurture innovations; although in the wheat network the effective role of biotechnology is, thus far, more incipient. The empirical evidence collected was not exhaustive, since only a group of players from each network was interviewed. Accordingly, the conclusions should be considered in the light of the difficulties of comparing case studies of various kinds and shortcomings in the representativeness of the data collected for each case.

Nonetheless, the empirical analysis reveals some interesting insights that enable an initial approach to be made to the research topic. It also raises some new questions of relevance for future research.

This study found that scientific knowledge is indeed used in natural-resource-related activities, that this is important in their operation and that the need for scientific knowledge fosters the development of knowledge networks of various types. A variety of participants are identified in each network: universities, public research organizations, private entities, private research institutes and others. Different types of knowledge-exchange agreement were also identified (research and development, training, technical assistance, testing and experimentation, among others).

The knowledge networks studied display a number of clearly differentiated characteristics that admit reflection on their potential importance for knowledge creation and diffusion.

Firstly, the analysis of the capabilities of the participants shows that, although the networks are all different, each one has indicators that highlight some potential to spread or create new knowledge. Drawing on the analysis of the literature, three empirical propositions were formulated for capabilities that, if fulfilled, would help the network to function effectively in terms of knowledge creation and diffusion:

(i) the average of the capabilities should be high; (ii) the minimum of the capabilities should also be high; and (iii) the capabilities of entities that play a central role in the network should also be high. Although the average and minimum capabilities of the wheat network are very low, the central player in this network has greater capabilities and can, therefore, contribute to the diffusion of knowledge among the other players. In the other three networks, the average capabilities of the participants are moderately high, at least. In the livestock network, the condition that the minimum is high is not fulfilled, but the central player has higher capabilities. In the forestry network, the reverse situation prevails and in the mining network all the conditions associated with capabilities are met.

Secondly, the cohesion level of the natural resource networks was assessed through indicators of density, transitivity and reciprocity. The results show that the networks are heterogeneous, but each has characteristics which the literature indicates as promising. The livestock, mining and wheat networks display a very high level of reciprocity, and this indicator is also moderately high in the forestry network. On the other hand, the wheat network alone also has a high level of transitivity and density. This indicates that, although exchange between the connected players tends to be symmetrical, which undoubtedly favours cohesion and trust between them, the networks overall still have a way to go in this regard.

Third and last, the study analysed the openness of the networks. The livestock network showed a high level of openness, extending by 120% outside the natural resource core. In the other networks, however, the level of openness is low: 8% in the wheat network (owing partly to the design of the study), and 9% in forestry. The calculation could not be made for the mining network, because no mining firms were interviewed.

In short, the study found solid evidence that there are networks associated with innovation in the field of natural resources, in which a diversity of players with different capabilities participate. These networks can create new knowledge or disseminate pre-existing knowledge or new applications from it. In these networks, the indicators used show that the players that produce natural resources have lower capabilities than other participants and do not usually play a central role in knowledge diffusion or creation. The level of cohesion in the networks is diverse: only one of them displays relatively high values in the three indicators used to assess cohesion. On the other hand, only one network also has a high level of openness outside the natural-resource core, although this is oriented more towards teaching and research than towards other production activities.

Apart from anecdotal reports, no hard evidence was found that these networks are creating knowledge that is used in other sectors of economic activity, although other studies have reported such effects (see Lengyel and Bottino, 2011; Kuramoto and Sagasti, 2008; Velho and Velho, 2008).

Nonetheless, the fact that this study failed to find such evidence may be the result of the design of the research, since the study of the networks will probably need to consider longer time periods and include a multiplicity of players to capture the effects in question. The empirical analysis of social networks is not without weaknesses and has points that could clearly be improved. First, as noted above, the networks reconstructed for each country are not strictly comparable with each other. The last two columns of table 3 show differences in data collection in the various networks and the impact of these differences on comparability between the indicators. In view of this, caution has prevailed and greater weight has been given to the analysis of each network itself than to the comparison between them. Moreover, each of the networks presented is a minimal reconstruction of the true underlying network, which is sure to include more knowledge links, a larger number of participants, and greater diversity in both.

These methodological shortcomings obscure the impact that the use or creation of scientific knowledge pertinent to natural-resource production has on innovation by other entities that are not necessarily part of the same value chain and, therefore, not directly linked to natural-resource producers. Future research needs to explore this issue in greater depth.

Analytical classifications and simplifications, compounded by resource constraints for exploring each case in greater depth, mean that only an incomplete knowledge of the network can be obtained; but, nonetheless, this has produced interesting lessons.

To conclude, several elements emerged during the research that are important for the design of sector policies. Firstly, the study identified an area of intervention (industrial policy, and science and technology policy) that is not usually considered when thinking about policies for the natural-resource sectors: the knowledge networks that are generated in association with those sectors. The study established that these networks do exist, and they involve private-sector agents in conjunction with academic entities and policy-makers. Moreover, to meet the requirements of the natural-resource sectors, these agents and players apply and disseminate existing scientific knowledge and, to some extent, create new knowledge.

When thinking about policies to exploit the opportunities that arise from natural-resource-based activities, the latter are usually considered as sources of foreign currency or taxes. Yet, insofar as scientific knowledge is used and networks are developed in these sectors, they represent a new potential area of intervention that cannot be ignored.

Policies can be designed to support the construction of knowledge networks related to production and innovation in natural resources. This should be done not only because this study has shown that knowledge networks foster innovation in the natural-resource sector, but also because the literature shows that the more developed and open the networks are, and the greater the capacity of the participants, the better the results in terms of innovation and knowledge creation in innovation systems generally.

Secondly, the participants' capabilities are related to the role they play in the network. The study found that those with greater capabilities generally play a central role in knowledge diffusion across the network. This finding has implications for the design of intervention tools, since it would be advisable to attract nodes with high-levels of capabilities to participate in the networks that are being promoted.

Thirdly, the study shows that, in general, in the identified networks there is a tendency to use existing knowledge rather than to create new knowledge. The lack of evidence that this new knowledge is migrating to other sectors would be a potential area of policy intervention. Both the natural-resource sector and other activities with which its knowledge matrix could be linked would benefit from intensifying the practices and linkages that foster new knowledge creation. Interventions could encourage cooperative research agreements between firms and the scientific sector, or between firms themselves, or else by promoting the openness of networks and the inclusion of entities with different types of knowledge.

Lastly, there is some indication that the type of players involved seems to affect the structural characteristics of the networks. For example, the only network centred around the subsidiary of a multinational has specific features: the player in question does not occupy a central place in knowledge diffusion, and the network it forms is relatively closed. Thus, the specific characteristics of the participants can condition the potential for knowledge diffusion and creation; and they need to be taken into account when considering policies aimed at encouraging network development.

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Annex A1

Table A1.1
Players interviewed in each network

Network		Player interviewed	Player that produces natural resources	Type of player
Livestock network	1	IRAC-BIOGEN		Private firm (ego)
	2	Cabaña Sierras Chicas	X	Private firm (ranch)
	3	Tambo Don Antonio	X	Private firm (dairy farm)
	4	Cabaña La Sultana	X	Private firm (ranch)
	5	Cabaña Los Socavones	X	Private firm *(cabaña)*
	6	Cabaña Las Pencas	X	Private firm *(cabaña)*
	7	Cabaña La Lilia	X	Private firm *(cabaña)*
	8	Instituto Veterinario Chamical		Private firm
	9	Centro de Excelencia en Productos y Procesos de Córdoba (CEPROCOR)		Public research organization
	10	National Institute of Agricultural Technology (INTA) Castelar, Centre for Research in Veterinary and Agronomic Sciences (CICVYA)		Public research organization
	11	National University of Córdoba (Agricultural sciences)		University
	12	National University of Villa María (Veterinary)		University
	13	National University of Río Cuarto (Veterinary)		University
	14	University of Buenos Aires (Agronomy)		University
	15	National University of San Martín (Biotechnology)		University
	16	National University of la Plata (Veterinary)		University
Miming network	1	Aguamarina S. A.		Private firm – Ego
	2	Essbio		Private firm
	3	VialCorp		Private firm
	4	Aplik		Private firm
	5	Harsco		Multinational firm
	6	NTC		Private laboratory
	7	Mining cluster		Association
	8	Fundación Chile		Other (public-private foundation)
Wheat network	1	Sem-Agro	X	Private firm
	2	Hilagro		Private firm
	3	Agro Santa Rosa	X	Private firm
	4	Dekalpar	X	Private firm
	5	Semillas Criciuma	X	Private firm
	6	Paraguayan Institute of Agrarian Technology (IPTA), Paraguayan Chamber of Grain and Oilseed Exporters (CAPECO) and Institute of Agricultural Biotechnology (INBIO)		Public research organization
	7	Paraguayan Agricultural Technology Centre (CETAPAR)		NGO
	8	Cooperativa Pindo	X	Cooperative
	9	Colonias Unidas	X	Cooperative
	10	Cooperativa La Paz	X	Cooperative
	11	Cooperativa de Producción Agroindustrial Santa María Ltda. (COOPASAM)	X	Cooperative
	12	Sociedad Cooperativa Pirapó Agricola Ltda.	X	Cooperative

Table A1.1 (concluded)

Network		Player interviewed	Player that produces natural resources	Type of player
Forestry network	1	Theobaldus Jauken		Private firm
	2	Ing. Agrim. Eduardo Guerra de Geofly		Private firm
	3	CSI Ingenieros		Private firm
	4	GeoAmbiente		Private firm
	5	SPT Consultores		Private firm
	6	Turboflow		Private firm
	7	Xternum		Private firm
	8	Technical dept. of UPM in Fray Bentos, Uruguay		Multinational firm
	9	Montes del Plata	X	Multinational firm
	10	Ellegaard		Multinational firm
	11	Netafim		Multinational firm
	12	Vivero Santana	X	Multinational firm
	13	National Institute of Agricultural Research (INIA), Forestry Department		Public research organization
	14	INIA, Micropropagación		Public research organization
	15	Universidad del Trabajo del Uruguay (UTU)		University
	16	Department of Forestry Production and Wood Technology, and Soil and Water Department of the Agronomy Faculty (FAGRO) of the University of the Republic (UDELAR)		University
	17	Forestry Research and Studies Institute (IPEF)		NGO

Source: Prepared by the authors.