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The network effects of NGOs on social capital and innovation of smallholder farmers. A case study in Peru

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Abstract: The impact of Non-Government Organizations (NGOs) on the local development of rural areas has rarely been explored empirically. Here we employ methods from network science to evaluate the impact of an NGO's activities on the social capital and innovation of three Peruvian farming communities between 2003 and 2018. Data was collected from in-depth interviews with farmers, including information about the farmers' socioeconomic characteristics, types of interactions with the NGO, and innovations in processes, products, marketing, and organization. Our findings show that the NGO had a significant impact on the local social cohesion and innovation performance of the farmers. The NGO helped to connect farmers from different villages, provided access to external knowledge, and facilitated the establishment of a local productive organization. Yet, the NGO also changed the local power structure by becoming the most central agent in the local innovation system. The NGO's centrality declined, though, at later stages of the development project as local agents took over the role of the NGO. Moreover, econometric results show that having a link with the NGO is associated with a significantly more central role of the farmers in the local network. However, only close cooperation with the NGO, such as membership in the local productive organization or active participation in technical training workshops was associated with a significantly higher innovation performance. Finally, our study demonstrates that methods from network science can help to empirically evaluate and monitor the effects of NGOs on local development at different stages of their development interventions.

Keywords: NGO; smallholders; innovation; social capital; network analysis; local development

JEL: D8, L3, O31, Q1, R11

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1 Introduction

In recent years, a substantial body of research has analyzed the impact of Non-Government Organizations (NGOs) on the living standards of the poor (Macdonald, 2016). In that context, several frameworks have been proposed to evaluate the social and economic impact of development projects (Friedmann, 1992; Farrington et al., 2003; Fowler, 1995; Bebbington, 1999; 2004; Hoefer, 2000; Esquivel et al., 2006; Conley et al., 2010; Hartmann et al., 2011; Kú et al., 2013; Marshall et al., 2014; Hermans et al., 2017; Dick et al., 2018). Yet, research on the impact of NGOs on the social structures and innovation capabilities of smallholder farmers in developing countries is still rather limited. This is a major shortcoming, considering that around 2 billion people (IFAD, 2013) live in smallholder households, many of which rely on NGOs' local development projects. Here, we show how methods from network science can be used to evaluate the impact of NGOs on the social cohesion and local innovation performance of smallholder farmers.

While smallholder farmers usually do not engage in cutting edge global innovation, they do introduce, create, adopt, adapt, and diffuse local innovations. Local innovations are those that (in their essence) are not necessarily new in the global context, but they are new to a particular region and typically require adaptation of existing knowledge and technologies to the region's unique conditions (Cassiolato et al., 1999). Indeed, innovative activities can be found in local agricultural communities all over the world (e.g. Mytelka 2000, Srinivas and Sutz 2008). Key factors for the diffusion of local innovations (as they are also for global innovation) are both intra-regional learning through local innovation networks as well as access to new technical information through external sources (Bathelt et al., 2004).

Arguably, the innovation performance of farmers in small communities is linked with two key forms of social capital: one stems from their ability to establish strong social bonds at local level, that is, within productive organizations or frequent information exchange with other local farmers; and a second is related to their capability to create bridges to external knowledge sources. Yet rural regions in developing countries often face significant constraints, such as lack of regional communication, trust, and access to external knowledge. In that context, NGOs can play a key role by providing access to external technical knowledge and in promoting local initiatives that foster cooperation and knowledge exchange. However, NGOs' activities can also reshape the power and socio-technical structures in local regions to the point where the communities become too dependent on their presence. This is problematic, as it goes against the goal of an NGO, which in this case is to help farmers to help themselves.

Methods from network science can help in understanding the social clustering, power structures, information flow, and cohesion of local communities, and thus provide a valuable methodology to evaluate the impact of NGOs on local development. Indeed, early approaches in social network analysis have been applied to study the diffusion of innovation in rural areas (Rogers, 1962). Moreover, recent approaches in applied development projects and economics have used social network analysis to map existing influence and power structures (Schiffer and Hauck, 2010). However, social network analysis has rarely been used to study how NGOs impact the local socio-technical and innovation performance of smallholder farmers (Hartmann et al., 2011; Hartmann, 2014; Hermans et al., 2017).

The majority of literature concerning NGOs activities is rather of an argumentative nature and lack empirical evidence (Lecy et al., 2012). A look at most academic works on effectiveness/impact of NGOs shows that authors tend to focus on adding theory, or analytical frameworks, to the research agenda. Data driven studies that test those frameworks are rare (Lecy et al., 2012).

In this article, we make use of methods from network science and econometrics to analyze the effects of an NGO's development project on the social cohesion and innovation of smallholder farmers in an agricultural community in Peru between 2003 and 2018. To that end, we made in-depth interviews with 48 fruit and wine farmers on their socioeconomic characteristics, main sources of technical information, and different types of innovation they introduced to their production and distribution processes.

The remainder of this paper is structured as follows. Section 2 reviews the literature on the impact evaluation of NGOs local development projects on social capital and innovation of smallholder farmers in rural areas of developing countries. Section 3 introduces methods from network science and survey data on the social capital and innovation performance of fruits and wine farmers in Chaparra, an agricultural valley in southern Peru. Section 4 presents empirical results on the effects of an external NGO's local development projects on the evolution of the social cohesion, network centrality and innovation performance of Chaparra's farmers in the period 2003 to 2018. The findings show that the NGO had significant effects on the social cohesion and network centrality of the farmers, though, the effect on the innovation performance of the famers also depended on the type and strength of interaction of the farmers with the NGO. Section 5 provides concluding remarks.

2 Literature review

A review of the literature on the effectiveness of NGOs highlights the existence of a wide range of perspectives about how to evaluate the impact of NGOs. This is mainly due to a wide range of definitions of what is an NGO and, thus, possible evaluation criteria (Rodriguez Sosa et al., 2007; Lecy et al, 2012). For instance, studies that define NGOs as non-profit organizations or social entrepreneurship tend to use economic growth or human development indicators as evaluation methods for an NGO's effectiveness. Other approaches use the concept of transnational advocacy networks to measure NGO's ability to mobilize resources and public opinion to influence politicians at the national and international level (Embrahim et al, 2010; Lecy et al, 2012; Marshall et al., 2014. Contributions from social sciences, in contrast, tend to apply qualitative multi-criteria analysis of the social sustainability of development projects, e.g. existence of participatory approaches for decision making, mechanisms for conflict resolution, social leadership, and communication methods (Esquivel et al., 2006) or measure organizational variables, such as management, fiscal health, and mission orientation (Embrahim et al., 2010). Finally, agronomic sciences frequently evaluate the sustainability of agricultural and livestock production, such as production yield, genotypes, input efficiency, cost-benefit analysis, or dependence of temporary employees (Kú et al., 2013). Despite the many different approaches in evaluating the role and effectiveness of NGOs' interventions in the development of poor regions, the use of quantitative methods and empirical evidence about an NGO's impact is relatively scarce (Lecy et al, 2012)

The study of NGOs' impact in poor regions started to receive special attention in the 1980s and 1990s. Many scholars were motivated to understand and improve social learning processes in small farming communities, while considering the role of NGOs in such process (e.g. Korten 1980, 1987; Clark, 1991, Carroll, 1992, Friedman, 1992, Farrington and Lewis, 1993, Wellard and Copestake, 1993, Foster and Rosenzweig 1995). These studies emphasized how NGOs, by helping small farmers to acquire new managerial knowledge and technical capabilities, improved the living standards in poor rural areas. As a result, a more people-centered approach was presented as an alternative to traditional development policies, which focused on capital transfer from the wealthy economies to poor ones, which failed to result in significant poverty reduction (Korten, 1980; Kanbur, 2000). When the emphasis changed to acquisition and generation of new knowledge by the poor, NGOs became the most common type of organization to assist in the development of small communities of farmers in developing countries (Carroll, 1992), and were recognized by their ability to support empowerment of the rural poor (Friedman, 1992). Several studies showed that NGOs can play an effective role as facilitator in the emergence of local initiatives (Farrington and Lewis 1993; Fisher, 1993 and

1998; Hermans, 2017). This being said, the recent use of methods from network science (e.g. Valente, 2012; Schiffer and Hauck, 2010) to analyze the effects of NGOs on local knowledge diffusion, connecting farmers to external sources, and improving the innovation performance is still scarce.

There are, though, several works that have made progress in measuring rural innovation networks. These works have explored the relationship between social capital and innovation, and studied the capacity of smallholders in less developed regions to introducing novelties into their local agricultural production systems (Monge et al. 2008, Spielman et al. 2011). It has been shown that driven by scarcity, access to microcredits, and external interventions (e.g. by development projects), many novelties are introduced by farmers into local agricultural systems, leading to new products, processes, inputs and new forms of organizing productive activities. Analyses of technology diffusion in small farmers communities has also shown that farmers incorporate information from more successful neighbors in their decision to adopt new agricultural technologies (Conley and Udry 2010). Through social interactions individuals exchange information, communicate with each other over their network channels, and create new knowledge that can culminate into innovation (Hermans et al., 2017). Another study used network science methods to analyze how the interactions among members of a rural community in Ethiopia improved their ability to innovate, but the participation of NGOs in this process was not considered (Spielman et al., 2011). Similar studies were also conducted in Bolivia (Monge et al., 2008) and in Vietnam (Hoang et al., 2006), where network analysis was employed to analyze the impact of social networks in the innovation ability of small farmers. What is clear is that social networks profoundly affect the type and direction of local farmers' learning activities and their capacity to engage in entrepreneurial action and introduce novelties into their local innovation system (Rogers 1962, Mytelka 2000, Bebington, 2004, Giuliani and Bell 2005, Giuliani et al. 2018). In this regard, methods from network science allow for a better distinction and analysis of the importance of local and international network relationships and the feedbacks between them (e.g. Giuliani and Bell 2005).

A central point is that knowledge is not evenly distributed or freely available within clusters and regional innovation systems, but highly dependent on individuals and their specific skills (human capital) and social relationships (Breschi and Lissoni 2001, Grebel et al. 2003, Giuliani and Bell 2005). Other studies have demonstrated that community survival and success are dependent on their linkages within communities (Monge et al, 2008). The degree of cohesiveness of the community – the number of connections within the community – determines how successful they will be. Therefore, external interventions aiming at developing communities of small farmers should focus on the creation of linkages among individuals

within the community, which will increase interaction and communication and consequently increase the innovation rate.

Previous research on sociotechnical networks in rural areas has also emphasized that geographic conditions and the surrounding infrastructure do have an impact in the network characteristics, facilitating or hampering the communication within the network or between networks of people (Bebbington, 2004). The location of a community constrains, for instance, the presence of external agents in a region. Places that are difficult to reach by conventional transports system and roads tend to receive less direct development interventions. Moreover, geographic characteristics and transportation systems affect not only the activities of external agents (such as NGOs), but also the interactions among individuals within a rural community.

One of the few studies using network analysis to analyze the impact of NGOs in poor rural areas is found in Hermans et al. (2017). They analyzed the impact of multi-stakeholder platforms (in which NGOs are only one type of element) on the rate of innovation and development of rural communities in Congo. The study shows that facilitating the development of new network ties among members of poor rural community and strengthening the existing ones can be an effective development approach for NGOs.

In conclusion, to the best of our knowledge, research using methods from network science to directly evaluate the effect of an NGO on the local socio-technical networks and innovation performance of farmers is still scarce. Existing studies have not analyzed to which extent different type of linkages between farmers and NGOs (e.g. simple technical advice, training workshops or participation in local initiatives) have a statistically significant effect on the local farmers' innovation performance, or the effects of NGOs on the local social cohesion and innovation performance over the entire period of their development intervention in a given region.

3 The case region and the purpose of the projects of the NGO

Here, we use methods from network science to analyze the effect of the NGO DESCO on the structure of the local technical information network and in the innovation performance of smallholder farmers of the Chaparra community. Chaparra is a narrow agricultural valley that is located in the province of Caraveli in a dry region of Southern Peru. The most important economic activities in the valley are artisanal mining activities, followed by agriculture, and commerce (Arata et al., 2010). The valley has a small river and relatively fertile soil that allow for agricultural and small-scale food industry activities, such as the production and distribution

of fruits, grape, wine, and related products. Wine production has been of importance to the local economy for centuries (Raimondi, 1929; Arata et al., 2005)

There are several reasons why the Chaparra valley is a relevant case. Firstly, because it shares some features typical to many poor agricultural communities around the world, such as: (a) the dominance of smallholder farmers; (b) the scarcity of key resources, such as water; (c) small-scale production; (d) a significant amount of artisanal economic activities (e) strong exposure to fluctuations in commodity prices, (f) lack of trust, which negatively affects the existing social relationships; and (g) the presence of external agents who hold considerable influence over the local system.

During the 1980s and 1990s, the region suffered from violent conflicts in connections with the terrorist organization Shining Path. After the end of violent conflict in early 2000s, Chaparra gained access to a limited number of fixed public telephones and in 2011 to the national electricity grid. Subsequently the mobile phone usage and Internet coverage expanded, yet remains limited. Moreover, a rapid increase of the gold prices has attracted a significant number of migrant workers to the artisanal mining sector of the valley, especially between 2008 and 2013. This led to an increase in the valley's population size and the demand for agricultural production in the region (Arata et al., 2005; Arata et al, 2010; INEI, 2017).

In the early 2000s, The Center for Studies and Promotion of Development (DESCO) started development projects in Chaparra. Founded in 1965, DESCO, the second oldest NGO of Peru and its program DESCOSUR, has accumulated experience in local development projects in southern Peru since 1985. The development projects in Chaparra began in May 2000 with a medium-to-long-term perspective of its presence in the region (Arata et al., 2005), and is expected to complete the projects by March 2019. Financed by national and international cooperation funds, the initial goal of the development projects in the region were (1) to increase social cohesion and cooperation of the population and (2) help the local farmers to increase their local production of fruits, wines and related products. According to senior project managers, it was difficult at the beginning of the project to improve the communication and socio-technical cooperation between the farmers from the three villages, namely Achanizo (located at an altitude of 596 meters above sea level), Caramba (791 m), and Chaparra (1092 m) (see Figure 1-A). There were several reasons for the lack of communication and cooperation, such as the physical constraints (due as the lack of telephones, bad roads and the spatial distance between the farmers), trust problems between farmers, and the lack of formal productive organizations and associations (Arata et al, 2005; Arata et al, 2010) After an initial period of getting acquainted with farmers, the NGO became quickly the main source of technical information in the region.

The gradual introduction of agricultural technologies in the 2000s and 2010s, such as drip irrigation systems, fertilizers or storage techniques, helped the farmers to expand and improve their agricultural production (See Figure 1-B). Moreover, interactive learning between the NGO and the farmers facilitated diversification into new durable products (such as jam or pear liquor) and helped in the creation and establishment of a production organization. This organization latter evolved into a company of 14 farmers who use and run a processing plant together, while producing a variety of products, including different types of wines and liquors. Continuous dialogue between members and the transparent use of goods and financial resources created trust between its members and contributed to increase the incomes for all members (Arata and Farfan, 2015). The NGO continuously helped this local productive organization in its professionalization and expansion process. Moreover, it offered frequent training workshops in agricultural and agri-business technologies, as well as direct technical advice to all farmers in the region.

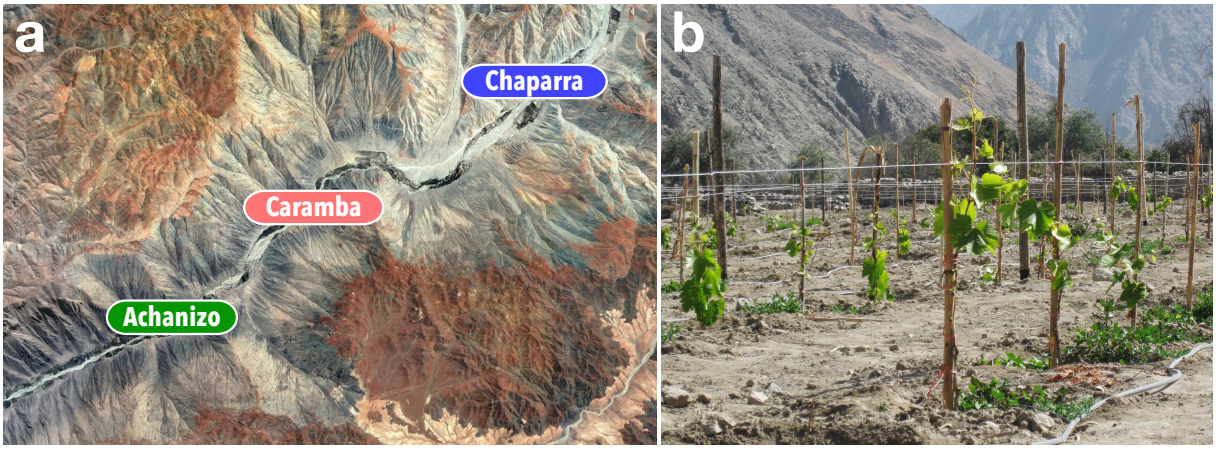

Figure 1-A: Map of the narrow agricultural valley and the case villages Achanizo, Caramba, and Chaparra. Source: Google Earth Pro, Image 2018 Digital Globe. Pointers to the villages added by the authors, based on Google Earth latitudes and longitudes information of the three villages. 1-B Expanding agricultural production through vineyard trellis and drip irrigation in the dry, but fertile soil of Chaparra. Source: DESCOSUR (2013), p.9

Nevertheless, we do not yet know if the effect of the NGO on the innovative behavior of the farmers was statistically significant, or if farmers that did not frequently interacted with the NGO saw a similar increase in their innovation performance. Moreover, we do not know the quantitative effect of the NGO on the social cohesion and socio-technical networks of the region. This is important, as development interventions from external agents should aim to finish their projects in a socially and economically sustainable manner.

4 Data and Methods

In order to analyze the effect of the NGO on the social cohesion and innovation performance of the smallholders, we elaborated an in-depth questionnaire on the socioeconomic characteristics, different types of local innovations, and access to technical information of the farmers in three time periods: 2003-2007, 2008-2013, and 2014-2018. Due to the relative ease in defining the spatial and social boundaries, we could interview all 48 smallholder farmers that not only sell fruits, but also wines and related products. The questionnaires were distributed and collected between 6th of August to 7th of October 2018. The sample size of 48 farmers is relatively small, but allowed us to perform a comprehensive in-depth data-based case study on the innovation performance and access to technical information of the farmers. The three different time periods (2003-2007, 2008-2013, and 2014-2018) were chosen, because they mark significantly different socioeconomic periods for the farmers (before, during, and after the boom of the gold price), and thus represent three different time periods the farmers can easily distinguish and remember main changes in their innovations, main partners and socioeconomic characteristics. The precise questions draw on previous work about social capital and innovation in developing countries (Cassiolato, 1999; Jaramillo et al. 2001; Grootaert et al. 2004; Hartmann and Arata, 2011; Bezerra, 2013; Hartmann, 2014), as well as insights from local experts about the innovation activities in the agricultural valley. The result was a comprehensive set of indicators on innovation, access to technical information, and other socioeconomic characteristics of the local wine farmers, that we will explain below.

4.1 Operationalization of variables

Regarding the innovation performance, we asked the farmers for the variety of products they sell, including fruits, grapes, wines and related products, as well as for innovations in organization, process and marketing they introduced in the three time periods. This measurement draws on suggestions from the Oslo Manual (OECD, 2005) and Bogota Manual (Jaramillo et al. 2001) for the measurement of innovation, as well as research highlighting the importance of product diversity (e.g. Teece, et al., 1994; Saviotti, 1996). In order to create a measure of the total innovation performance *Log_Inno* of the farmers, we summed up the product diversity and the innovations in processes, marketing, and organization.

The socioeconomic characteristics include age, gender, formal education, region (dummies Caramba, Chaparra, and Achanizo), as well as working time spent in agriculture (*WTimeAgri*) vs. mining or commercial activities. Moreover, we asked three external experts about the technical capabilities of the farmers (*Tech_Cap*).

Regarding the farmer's interactions with the NGO, we asked to which extent the farmers participated in technical training workshops or not *(Info_Training*) and if they participate in a productive organization initiated by the NGO (*Prod_Org*).

Moreover, to measure the technical information network of the farmers, we asked them about the people with whom they exchanged most frequently technical information about activities related to their fruit and wine farming activities, in each of the three time periods 2003-2007, 2008-2013, and 2014-2018. We asked about strong ties with frequent interactions because high levels of trust are necessary for fine-grained information exchanges (Coleman 1988). This is arguably the case in local settings which suffered from severe social conflicts and institutional crises in the past, as was the case of Chaparra. Moreover, frequent interaction is necessary to exchange and build up tacit knowledge (Polanyi, 2009). The resulting data allowed us to measure whether the farmer mentioned the NGO DESCO as a frequent partner of technical information exchange or not, and to calculate the closeness centrality of the farmers in the local technical information network. The closeness centrality (C_i) of a node i is calculated as the reciprocal of the sum of the distances between every pair of nodes in the network, that is:

$$C_i = \frac{1}{\sum_j d(n_i, n_j)} \tag{1}$$

Hence, closeness centrality is a measure of proximity and implies that the most central nodes (farmers) are the ones that have the lowest distance to all the other nodes (farmers) in the network. In our case, a farmer with high closeness centrality will be better situated to learn technical information from all other farmers of the local socio-technical network and its external partners.

4.2 Regression models

To inspect whether the engagement and contact with the NGO is a contributing factor to explain the farmers' centrality in their socio-technological network, we regress the closeness centrality (C_{ij}) of the farmers against different types of links with the NGO, as well as several socio-economic indicators. Hence, consider the following model:

$$C_{ij} = \alpha_0 + \alpha_1 ORGPROD_{ij} + \alpha_2 DESCO_{ij} + \alpha_3 INFOTRAIN_{ij} + \beta_{ij} X_{ij} + P_j + \epsilon \tag{2}$$

where the dependent variable C_{ij} is the closeness centrality of farmer i in period j. This variable is regressed against $ORGPROD_{ij}$ a dummy variable that indicates whether the farmer is member of the productive organization start-up; $DESCO_{ij}$ a dummy variable that indicates whether the farmer mentioned the NGO as a key source of technical information; $INFOTRAIN_{ij}$ measure the participation of the farmers to training workshops of the NGO; X_{ij} a vector of farmer socio-

economic indicators such as Technical Capabilities (TCap), Age, Gender, Location (Caramba, Chaparra, or Achanizo), Education, and Working Time in Agriculture (W.T.A.); P_j controls for time period fixed effects; and ϵ is the error term.

Likewise, we used the obtained data to assess the statistical significance of the effects of the links with the NGO, closeness centrality, and a vector of socioeconomic characteristics on the innovation performance of the farmers. Hence, we explore a second regression model of the form:

$$\begin{aligned} LogINNO_{ij} = \; & \alpha_0 + \alpha_1 ORGPROD_{ij} + \alpha_2 DESCO_{ij} + \\ & \alpha_3 INFOTRAIN_{ij} + \alpha_4 \widehat{C_{ij}} + \beta_{ij} X_{ij} + P_j + \epsilon \end{aligned} \tag{3}$$

where the dependent variable $LogINNO_{ij}$ represents the logarithm of the innovation output of farmer i in period j. In this model we also consider the residuals from model (1) $\widehat{C_{ij}}$ as an independent variable, which indicates whether a farmer was more/less central in the network than predicted from the indicators available.

4.3 Network cohesion

Finally, we analyzed the social cohesion/fragmentation of the local community and how fast new technical information can reach all farmers. For this purpose, we calculated the average path length, diameter, and modularity of the network.

The diameter of a network graph corresponds to the maximum shortest distance between a pair of nodes in the network (Barabasi, 2016). In our case, the diameter of the farmers network captures the longest potential path a new technical information would need to "travel" between the two farmers that are furthest apart / disconnected from each other.

The average path length (APL) of a network is defined as the average distance (measured as the minimum number of links necessary to transverse to go from one node to another) between all pairs of nodes in the network (e.g. Albert and Barabasi, 2002). Formally, this measure can be computed as

$$APL = \frac{1}{N(N-1)} \sum_{i \neq j} d(n_i, n_j) \tag{4}$$

where N is the number of nodes in the network, and $d(n_i, n_j)$ the shortest distance connecting between a pair of n_i and n_j. In our case, and since the network represents social links between farmers, the average path length can be understood as an average social distance between the 48 farmers.

Modularity (Q) is a measure of the quality of a network partition, which is also called groups, clusters or communities (Newman, 2006). Formally modularity is computed as

$$Q = \frac{1}{2m}\sum_{i,j}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j) \quad (5)$$

where m is the total number of links the network; A_{ij} is the adjancency matrix whose entries are one if nodes n_i and n_j are connected; k_i is the degree of node n_i and corresponds to the number of links node i participates; c_i is the partition/cluster/community in which node n_i is placed; and finally $\delta(X, Y)$ is the Kronecker delta which equals one if $X = Y$ being zero otherwise. Networks with high modularity exhibit clusters of nodes with a very dense connection pattern among nodes of the same clusters, while being sparsely connected with nodes of different clusters. In our case, a lower level of modularity is desirable, as this would mean that the farmers do cluster less into small fragmented groups, but exchange technical information with each other and thus cooperate and help each other improving their fruit and wine farming activity. To find the best partition that maximizes the modularity of our network we used the Louvain algorithm (Blondel et al., 2008)

5 Results

5.1 Evolution of the social cohesion of the technical information network

First, we analyzed the structure and evolution of the technical information network of the 48 smallholder farmers in 2003-2007, 2008-2013, and 2014-2018. This network illustrates which farmers most frequently exchanged technical information about activities related to their fruit and wine farming activities. Figure 1 shows the evolution of the network linkages between the 47 farmers from the valley (47, because one of the 48 respondents did not have any direct contact with the other farmers.) The nodes are colored according to the home village of the respective farmers. We can observe a strong spatial clustering of the network ties of the farmers in all three periods studied. This means that the farmers tend to more frequently exchange technical information with their neighbors from the same village than with farmers from other villages in the region.

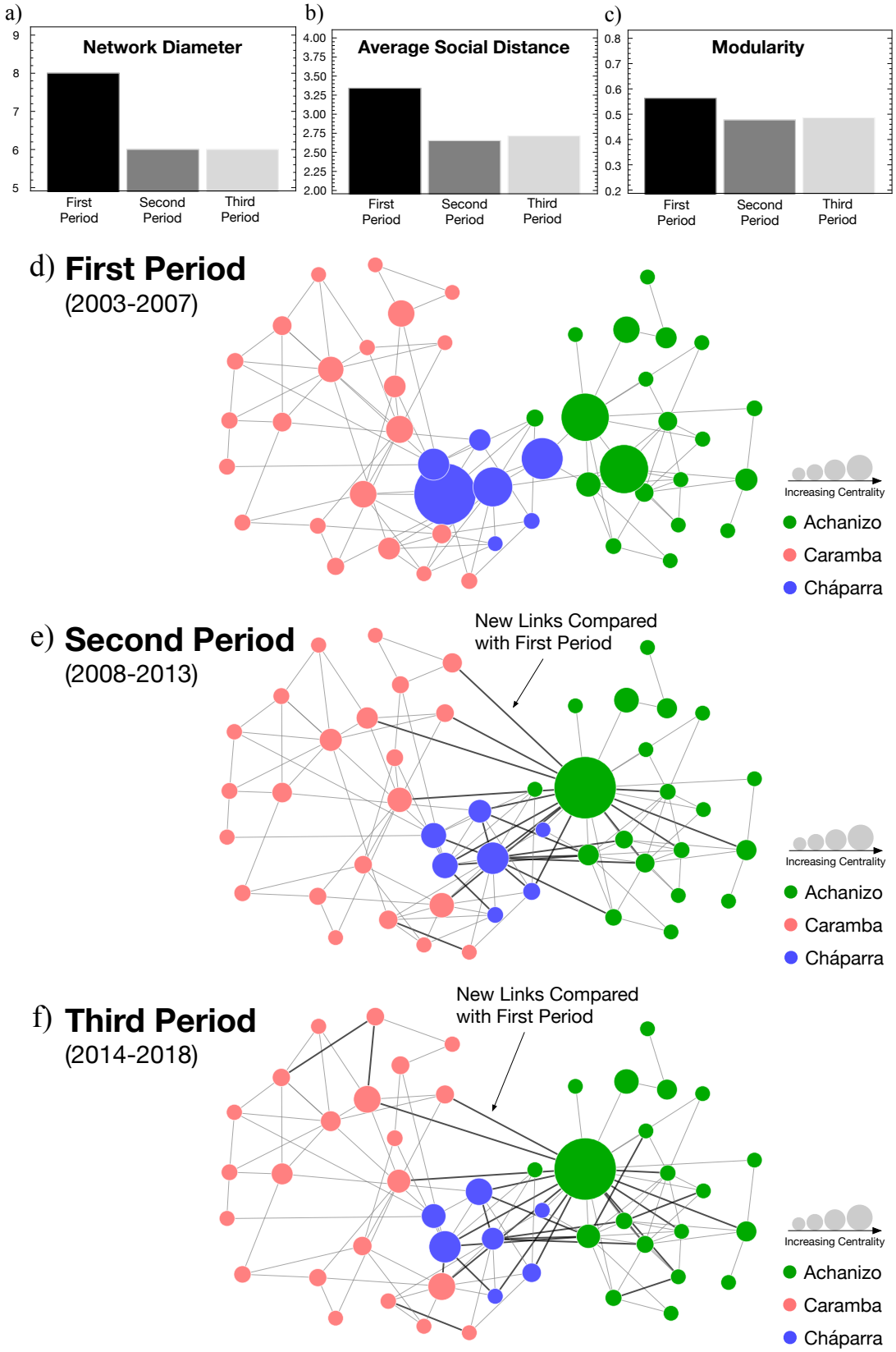

Figure 2. Evolution of the technical information network between the interviewed farmers. The first three panels measure the **a)** network diameter, **b)** average social distance and **c)** modularity of the network between the farmer in the time periods 2003-2007, 2008-2013, and 2014-2018. The panels **d)**, **e)** and **f)** illustrate the networks in the three periods. Each node is a farmer, links indicate whether they exchange frequently technical information, node size indicates the closeness centrality of the node in the respective period, node color indicates the farmers' region: green nodes are farmers from Achanizo, red from Caramba, and blue from Chaparra.

Moreover, we can observe that in the first time period there were no direct links of farmers from Achanizo to farmers in Caramba and very few links from Achanizo to Chaparra. Consequently, the communication between farmers from different villages about technical information regarding the agricultural activities was limited. In the second and third period, several new links were created between farmers from the three villages. As a consequence, there was an increase in communication and social cohesion between the farmers. The network diameter, average social distance (i.e. average path lengths), and modularity significantly declined from the first period to the second period and then remained stable on the lower level in the time period three (see Figure 2a)-c)). Thus, the network became less fragmented and technical information was able to flow more quickly through the local network. We can observe that one farmer from Achanizo in particular created several bridging links with farmers from Caramba. This farmer became a key boundary spanner between the villages and in consequence also became the most central agent. This farmer worked closely together with the NGO and took a leading role in the productive organization. Additionally, several further links were created between other farmers from Achanizo and Chaparra, facilitating social cooperation and a faster diffusion of technical information across the valley.

5.2 The effects of the NGO on the closeness centrality of the farmers

Next we analyze whether frequent interaction and active engagement with the NGO had a significant impact on the closeness centrality of the farmers in the network of all local and external partners that the farmers mentioned. Regression Table 1 shows that (i) having a link to the NGO, (ii) working in the productive organization, and (iii) participating in the technical training workshop are all positively and significantly associated with the closeness centrality in the technical information network. Thus, working with the NGO reduced the distance of the respective farmer to the entire technical information of the socio-technical network of the three villages and its external partners. Besides the linkages with the NGO, another significant factor for closeness centrality is also the technical competence of the farmers. Moreover, it appears that the farmers from Chaparra are on average significantly more central than the farmers from Achanizo and Caramba. One reason for this is that Chaparra has been a commercial, mining, and social hub for several decades. Thus, most farmers tend to be frequently in Chaparra and many of them interact frequently with the local farmers. Moreover, three of the interviewed farmers from Chaparra also have commercial, social and political leadership roles in the valley.

Table 1- The effects of the NGO and other socioeconomic variables on the closeness centrality of the farmers in the technical information network

	Dependent variable: Closeness Centrality									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ORGPROD	0.045***								0.011*	0.012**
	(0.008)								(0.006)	(0.006)
DESCO		0.065***							0.042***	0.042***
		(0.005)							(0.006)	(0.006)
INFOTRAIN			0.041***						0.016***	0.015***
			(0.007)						(0.005)	(0.005)
TCap				0.056***					0.031***	0.029***
				(0.007)					(0.006)	(0.006)
Education					0.0002				-0.0003	0.0001
					(0.001)				(0.001)	(0.001)
W.T.A.						0.017				0.002
						(0.011)				(0.008)
Age							0.0004			0.0001
							(0.0003)			(0.0002)
Gender							0.011			0.006
							(0.008)			(0.005)
Caramba								0.0004		0.005
								(0.008)		(0.005)
Chaparra								0.026**		0.014**
								(0.011)		(0.007)
Constant	0.377***	0.342***	0.369***	0.266***	0.383***	0.374***	0.355***	0.381***	0.285***	0.272***
	(0.006)	(0.006)	(0.006)	(0.015)	(0.011)	(0.009)	(0.018)	(0.008)	(0.012)	(0.020)
Observations	144	143	144	144	144	144	144	144	143	143
R^2	0.223	0.516	0.234	0.366	0.035	0.052	0.064	0.076	0.661	0.676
Adjusted R^2	0.206	0.505	0.218	0.353	0.015	0.032	0.037	0.049	0.643	0.646
F Statistic	13.360***	49.299***	14.291***	26.973***	1.711	2.565*	2.357*	2.847**	37.541***	22.580***

Notes: *p<0.1; **p<0.05; ***p<0.01
All Models consider Year/Period Fixed Effects

5.3 The social sustainability of the NGOs development interventions and its dominance in the local information network

Next, we analyze to what extent the NGO itself may have become an overly dominant player of the local technical information network, which can potentially undermine the social sustainability of the projects. To understand the effects of the NGO and its network position in more detail, we analyzed the network of all technical information partners that the farmers mentioned, including the non-wine farmers, the NGOs, governmental organizations and other external agents. It is clear that the NGO is the most central agent in all three time periods, and has situated itself as a boundary spanner between the three villages (see Figure 3). While, the NGO has a dominant role in period 1, in period 2 several further ties are formed between the different network groups, and in period 3 a significantly denser network can be observed than in period 1. In the last period, some farmers partially substituted the role of the NGO, created

network ties between different groups, and thus increased the likelihood of a positive social impact on technical cooperation between the farmers of the regions.

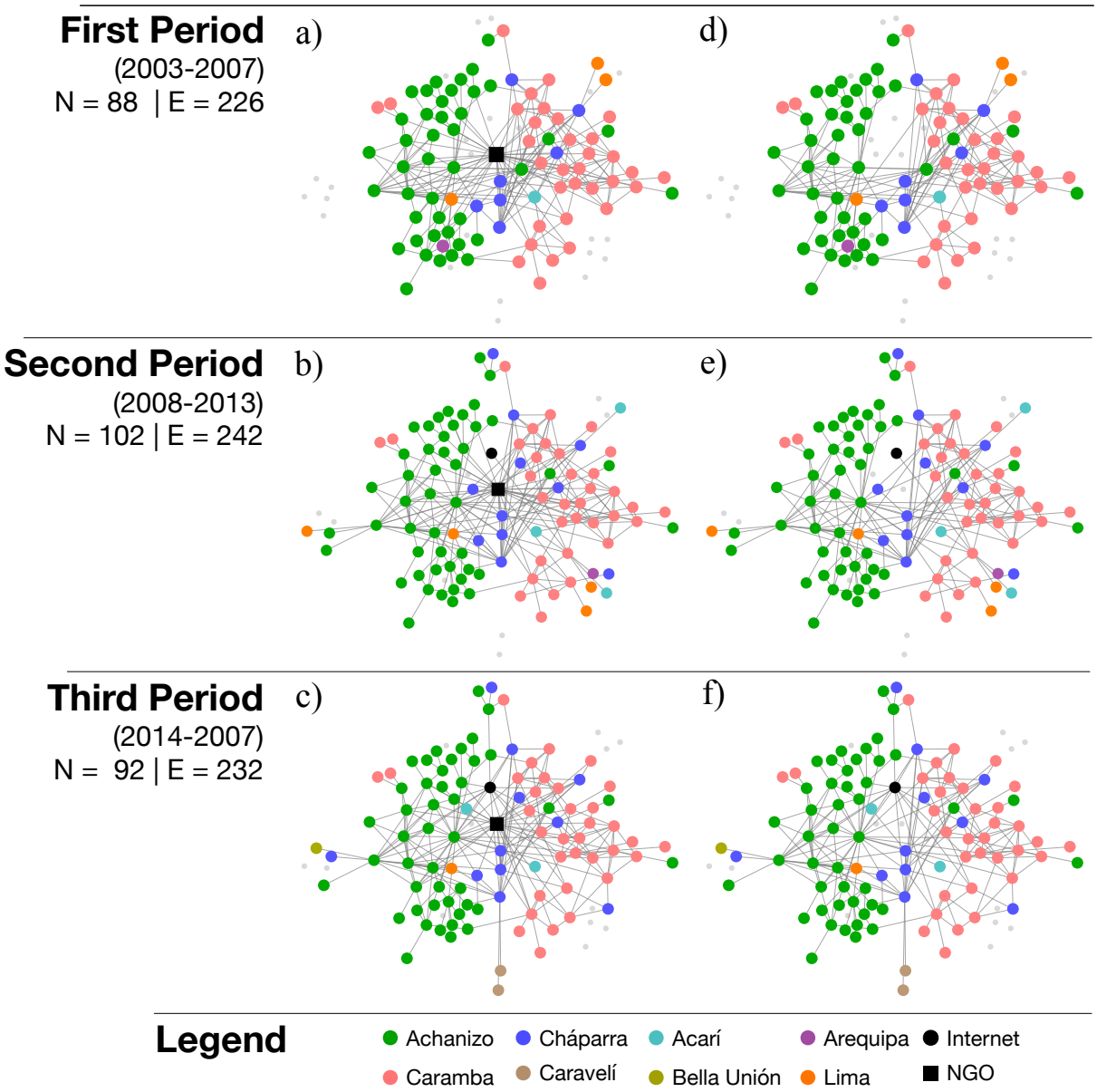

Figure 3. Evolution of the main local and external technical information partners of the farmers. The panels **a)**, **b)**, and **c)** illustrate the full network in the time periods 2003-2007, 2008-2013, 2014-2018, **d)**, **e)**, **f)** illustrate the same networks without the NGO.

While the NGO helped to create linkages between different farmers / villages, the NGO also significantly changed the network centrality of the farmers (Fig 4). If we compare the closeness centrality ranking of the farmers with and without the NGO, some farmers gain up to 25 positions or lose up to 22 positions in the ranking due to the presence of the NGO (Fig 4-B). This implies that not all farmers benefitted equally from the NGO's presence and the NGO greatly changed the power over the information flow in the region. The impact of the NGO is especially pronounced during the first time period, in which the ranking with and without the NGO have a relatively low Kendall Tau correlation (Fig4-A). Yet we can also observe a

decrease in upwards and downwards movement in the network centrality of the farmers in the second and third time periods and thus a slightly less pronounced impact of the NGO in the later phases of its development interventions. In these periods some of the local farmers, with whom the NGO worked, took over social and technical leadership roles and function today as boundary spanners between different groups / villages and thus partially can substitute the role of the NGO.

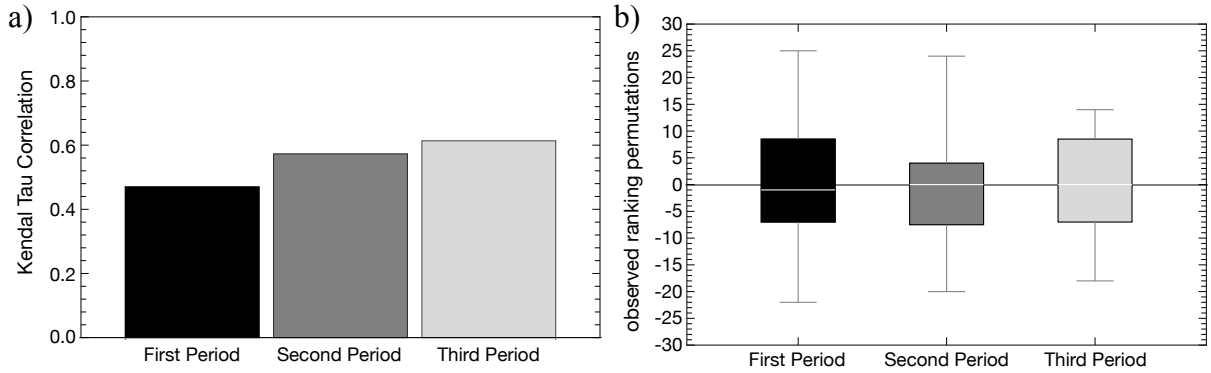

Figure 4. Changes in the farmers' centrality ranking positions due to the NGO's presence. A) Correlation between centrality ranking with and without the NGO. B) Boxplots on the distribution of upward and downward movements in the ranking positions of the farmers if the NGO is considered or not.

Our analysis shows that social network analysis can help the impact of an NGO's presence on the local information flow and power structure of smallholder villages. Arguably taking this impact into account could help to design social sensitive intervention and understand potential impact on local social hierarchies and power structures. Moreover, it also shows that there is probably an optimal time for NGOs to finish a development intervention, when local agents are empowered and the dependence of the local network from the NGO declines again. A significant impact on the local social structures is partially even desired in the first stages of local development projects to promote the local technical information flows, yet arguably in the later phases, local agents should take over the role of the external agents and ensure the increased information flow after the NGO leaves the region.

5.4 The effects of the NGO on the innovation performance of the farmers

Next, we analyzed to what extent the NGO was able to increase the innovation performance of the farmers in the region. A clear positive trend can be observed regarding the innovation performance of the farmers (see Figure 5). When the NGO entered the region in the first period, several small innovations were introduced. Yet the number of innovations significantly increased in the second and third time period, when the NGO consolidated its presence and the farmers became more disposed to introduce changes into their production and distribution processes.

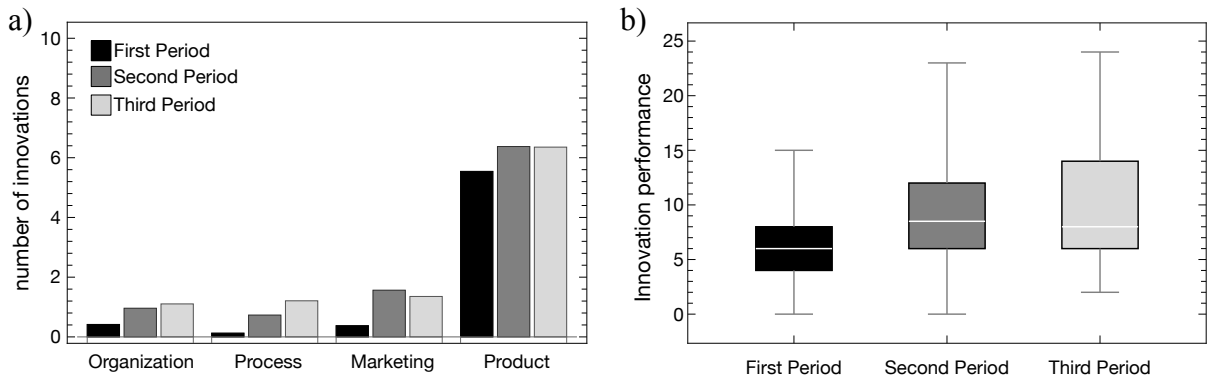

Figure 5: Evolution of the product diversity and number of innovations in organization, process and marketing. A) Bar chart on total number of products and innovations. B) Boxplots on the differences in the total innovation performance across farmers

But to which extent in the interaction with the NGO a significant predictor of the innovation performance of the farmers? It results that active participation in the training workshops and membership in the productive organization promoted by the NGO is positively and significantly associated with a higher innovation performance of the farmers (see Table 2). In contrast, simply being connected to the NGO (i.e. a farmer considering it an important information source, but not participating neither in the productive organization nor frequently in the training workshops of the NGO) is not significantly associated with a higher innovation performance. Thus it seems that active participation and in-depth interaction seems to be necessary to fully gain from the knowledge of the NGO and increase the innovation performance. Other positive and significant predictors of innovation performance are, as expected, the farmer's technical capabilities as well as the closeness centrality of the farmer. Instead, the localization of the farmers in Chaparra, Caramba, or Achanizo is not a significant predictor of the innovation performance when controlling for other factors.

Table 2 - The effects of the NGO and other socioeconomic characteristics on the farmers' innovation performance

	Dependent variable: Log Innovation										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
ORGPROD	0.279***									0.165***	0.159***
	(0.047)									(0.048)	(0.050)
DESCO		0.177***								0.007	-0.007
		(0.046)								(0.046)	(0.048)
INFOTRAIN			0.237***							0.156***	0.141***
			(0.042)							(0.042)	(0.043)
Closeness Res.				1.456						1.456**	1.456**
				(0.893)						(0.734)	(0.727)
TCap					0.222***					0.145***	0.154***
					(0.046)					(0.046)	(0.048)
Education						-0.005				-0.008	-0.004
						(0.006)				(0.005)	(0.007)
W.T.A.							0.114*				0.066
							(0.068)				(0.069)
Age								0.003			0.001
								(0.002)			(0.002)
Gender								-0.033			-0.064
								(0.050)			(0.043)
Caramba									-0.004		0.018
									(0.048)		(0.044)
Chaparra									0.185***		0.117**
									(0.068)		(0.058)
Constant	0.698***	0.632***	0.656***	0.750***	0.274***	0.794***	0.678***	0.636***	0.725***	0.414***	0.295*
	(0.036)	(0.048)	(0.039)	(0.039)	(0.104)	(0.069)	(0.058)	(0.108)	(0.047)	(0.103)	(0.165)
Observations	144	143	144	144	144	144	144	144	144	143	143
R^2	0.263	0.168	0.249	0.094	0.210	0.081	0.095	0.091	0.132	0.414	0.447
Adjusted R^2	0.247	0.150	0.232	0.075	0.193	0.061	0.076	0.065	0.107	0.379	0.391
F Statistic	16.674***	9.334***	15.434***	4.844***	12.434***	4.105***	4.907***	3.490***	5.300***	11.836***	8.023***

Notes: *p<0.1; **p<0.05; ***p<0.01
All Models include year/period fixed effects

6 Conclusions

In this article we used methods from network science to analyze and evaluate the network effect of NGOs on social capital and innovation performance of rural farmers. The NGO in the case study had a significant impact on the local technical information network and in the innovation performance of the participating farmers. The NGO contributed to increasing the social cohesion and technical communication between the farmers, yet it also became a dominant agent in the region and changed the power of different local farmers over the information flow. The dominance of the NGO, though declined, in later periods of the development project as it was able to train some of the farmers to play a more active role, assume technical and social leadership, and facilitate the communication between different villages. This also implies that methods from network science can help to evaluate the social sustainability of the project at different time steps. This, in turn, can also help to identify the appropriate time for an NGO to finish their development intervention.

Moreover, the results indicate that the NGO had a positive effect on the innovative behavior of the farmers. However the results also suggest that this effect may depend on the strength and types of the interaction between the farmers and the NGO. Whereas active participation in training workshops and active participation in the productive association were associated with a significantly higher innovation performance, mere contact with the NGO, and thus a more passive behavior was not significantly associated with a better innovation performance. These results show that the effects of the NGO depend on the active engagement/participation of the local population. Furthermore, our results showed that empirical analysis on the types of the socio-technical relationships and innovation performance of the farmer can provide important information for the factors driving or hampering the success of an NGO's productive development interventions.

Of course, there are several shortcomings of this work that require further inquiry in subsequent research. Firstly, the main goal of this work was to illustrate the effect of the NGO on the social network structure and innovation performance of the farmers. Yet a promising line of future research also involves disentangling the causal relationship between the closeness centrality and innovation performance of smallholder farmers, using larger datasets and more sophisticated econometric models, such as structural equation models. Moreover, other regions may have more external development agents present in the region and thus the competition and/or cooperation between different NGOs and other external agents may play an important role in the social cohesion and innovation performance of the region. Finally, the appropriate level of network heterogeneity, cooperation and clustering could be explored and provide insights on successful network interventions (Valente, 2012; Pinheiro and Hartmann, 2017)

Despite of its limitations, our study showed that empirical methods from network science can help to provide important information on the effect of NGOs on local development in less advanced regions. The development of interventions can be more effective and socially sustainable if supported by joint methods from network science and econometrics. We believe these should be part of the tool-box to monitor, design, and evolution processes of development interventions by NGOs. It is important to note that while big data may facilitate the analysis of large-scale metadata, readily available datasets can lack information about the interpersonal networks and related factors driving the social cohesion and innovation performance in remote areas. Naturally, it is not realistic to expect that all development aid workers have expertise in methods from data science. Nonetheless as programming and data analysis skills are becoming increasingly available, thus a greater emphasis on empirical methods is certainly feasible and can contribute to the transparency, monitoring and success of development interventions. The methodology chosen in this work provided interesting results, albeit is relatively simple and not costly. In conclusion, as we have illustrated in this article, methods from network science and econometric can arguably enrich and complement existing evaluations on the social impact of NGOs on local development in rural communities.

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