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The role of the social network structure on the spread of intensive agriculture: An example from Navarre, Europe.

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The role of the social network structure on the spread of intensive agriculture: An example from Navarre, Europe.

Abstract

Social structures underpin land management decision-making in agricultural landscapes by influencing how farmers access knowledge and resources. We explored the role of social networks in decision-making among farmers in Navarre (Spain) to understand how and why some practices spread among farming communities. Social network analysis allows us to understand how farmers in this region share both knowledge and resources, and the potential implications of this sharing for the landscape. We find that large-scale farmers undertaking intensive land management are at the core of the network in this region, controlling the flow of knowledge and resources related to farm management, policy, technology, and finance. The central position of these farmers in the social network, and their reputation, are key to the spread of intensive farming practices in the region, which ultimately may lead to homogenization of local agricultural landscapes. Understanding farmer network structures in a context of agricultural intensification can help tease out the social mechanisms behind the spread of agricultural practices.

Keywords: social network structure, knowledge-sharing, resources, land management, sustainability, agriculture, agrarian landscapes

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1. Introduction

The integration of rural economies into global commodity markets has led to a restructuring of rural agrarian sectors worldwide (Kay, 2002; Cramb, 2007) accelerating agricultural intensification processes (Tilman et al., 2011). Such restructuring is normally accompanied by an increased area of monocultures and the use of new technologies such as improved seed varieties and large-scale irrigation (Zarrilli, 2010; Andreas and Zhan, 2016). While intensification may favor yield increases it can also lead to habitat and biodiversity loss (Díaz et al., 2020), increased greenhouse gas emissions (Shukla, et al., 2019) and other environmental problems (Foley et al., 2011).

Farmers' land management decision, including the level of agricultural intensification of their farm, is influenced by their interactions with fellow farmers and other community members, including agronomic specialists and seed and fertilizer salespeople (Pahl-Wostl et al., 2008). It is important to understand how farmers' position within their social networks affect knowledge and resource acquisition as this may influence their current and future land management decision-making (Crona et al., 2011; Inman et al., 2018), which ultimately can shape the structure of landscapes over time.

Access to knowledge and resources related to farm management directly affects farmer livelihoods (Scoones, 1998; Ribot and Peluso, 2003; Baumgart-Getz et al., 2012). Knowledge and resources are key assets (Barnes et al., 2017) that can contribute to accumulating other necessary benefits (Bennett et al., 2018). For example, knowing who to ask for agrarian related subsidies often facilitates access to key resources, such as land or technology. The capacity to access resources and knowledge in rural areas can also affect the adoption of environmentally friendly farming practices, such as those associated with agro-environmental policy schemes (Burton and Paragahawewa, 2011; Alló et al., 2015; Inman et al., 2018).

Knowledge sharing depends to a large extent on how farmers are connected to local farmer networks; these networks also shape the distribution of control over farming resources at the local level (De Haan and Zoomers, 2005). This means that such networks can have direct effects on farmers' livelihood outcomes (e.g. their income level and stability), and indirectly on local environmental outcomes, such as on soil and water quality, and agrobiodiversity (Scoones, 1998; Allison and Ellis, 2001; Hahn et al., 2009).

Control of knowledge and its distribution can reinforce power relations among actors. Uneven access to resources and knowledge within a social network is both a result and a source of asymmetric power relations (Carlsson and Berkes, 2005). Likewise, the uneven distribution of resources is also a direct source of power asymmetry (Carlsson and Berkes, 2005). It is therefore important to understand how uneven distribution of knowledge and resources can shape farmers' livelihood strategies and their effects on landscapes in the context of uneven power among farmers. We hypothesize that the more central some farmers are, in a social network and in terms of access to knowledge and resources, the more power they have over local land-use decisions and the more they can thus affect the decision making of more peripheral farmers in the network. Ultimately, such a situation leads to restructuring the landscape in ways that favor the interests and preferences of those farmers at the core of the network.

Social networks link organizations and individuals across space and time, through the sharing of information or resources, creating different kinds of knowledge and resource flow structures (Guerrero et al., 2013). The literature on formal and informal social networks suggests a variety of ways in which networks influence individuals' thoughts, values, and behaviors (Reyers et al., 2015; Colloff et al., 2017; Inman et al., 2018) including the adoption and spread of new technologies and farming practices in agriculture (Warriner and Moul, 1992; Foster and Rosenzweig, 1995; Conley and Udry, 2001). Farmers who are very central in networks may play a critical role in the introduction, transfer, and implementation of new farming techniques (Isaac et al., 2007, 2014). Additionally, whereas local networks can directly impact local land-use change, external bridging ties can also drive local land-use change via the introduction of new technologies (Isaac and Matous, 2017). Kiptot et al., (2006) and Isaac (2012) show how the role of information networks affects the innovative land-use practices in agricultural systems and their effects on agrobiodiversity. Moreover, farmers who are central in social networks can leverage their control of resources to maintain their social position within the network, which may exacerbate the unequal dissemination of agricultural inputs, such as seeds (Ricciardi, 2015). Finally, the literature also points to the idea that social networks exhibit structural features related to multiple social processes (Levy and Lubell, 2018).

Understanding rural communities' social network structures and how they can influence farming decision-making by different types of farmers can contribute to policy decision making about how to best use incentives to encourage sustainable agricultural practices within a landscape. For example, understanding farmers’ social networks can help identify which types of farmers incentive programs should target first to help disseminate more sustainable land management practices (Isaac et al., 2007, 2014). This information can also help policymakers improve the cost-effectiveness of the dissemination of information and the design of self-monitoring instruments.

Here, we focus on a village in Navarre, Spain, as a model system in which processes of agricultural intensification are accelerating to explore the role of social networks in shaping the land intensification process happening in this region and in many places around the world (Grafton et al., 2018). We use network analysis to understand a) how different types of farmers are connected to each another; b) what types of farmers are located at the core of the social network, thus potentially having relatively more capacity to control resource and knowledge flows within the network, and c) what the social network structure may imply for the structure of the landscape, e.g., the likelihood of increased landscape homogenization. Our underlying assumption is that core farmers in the network can influence other members of the network to adopt farming practices that suit those central farmers’ interests (Isaac and Matous, 2017).

2. Social networks and land-use decisions

Changes in land management decisions can result from social processes (activities that involve interactions between people or organizations), which are influenced by, and serve to form, the structure of a social network (Groce et al., 2019). Two network members who share a tie will influence each other over time, potentially leading to an increased similarity between them (Crona et al., 2011). Relational ties for the exchange of some specific kind of knowledge can evolve into deeper social relationships, which can aid the development of common norms and values or even trigger behavioral change (Bodin and Crona, 2009).

In the context of agricultural land management, we assume that a) members with similar farming practices tend to obtain similar information and behave similarly within their respective circles, and b) shared knowledge by farmers can influence farmers’ decisions about land management and affect the structure of agroecosystems (Villanueva et al., 2017).

Social Network Analysis (SNA) can be used to understand the structure of social networks, and to identify those members of the network who are most relevant in terms of *influence and control* over resource flows within a community (Crona et al., 2011). SNA can be used to analyze connections among individuals based on the number of ties they have to other network members. By occupying central positions in the social network, some network members are better situated to access valuable knowledge, which can put them at an advantage (Bodin and Crona, 2009) because their position in the network means they have higher levels of agency (Brown and Westaway, 2011). In SNA, the number of ties reflects the degree of centrality in a network and is typically associated with that member's influence over other network members ("out-degree"), or the influence he or she receives from others ("in-degree") (Bodin and Crona, 2009). Betweenness centrality is another metric that refers to the degree to which a network member indirectly connects other members (Granovetter, 1977; Bodin and Crona, 2009). This type of centrality of the network can be associated with the level of *bridging and bonding* social capital (Bodin and Crona, 2011).

Bonding ties promote trust, reciprocity, and cohesion within communities, which is generally seen as beneficial for consensus building and conflict resolution (Bodin and Crona, 2009). Bonding ties are also frequently required for tacit knowledge transfer. However, homogeneity can also hinder problem resolution or uptake of innovative management strategies, which require diverse knowledge and perspectives (Lyon, 2000; Prell et al., 2010). Bridging ties, on the other hand, connect otherwise disconnected actors (Siciliano and Wukich, 2017), providing access to external resources and helping actors initiate or support collective action (Bodin and Crona, 2009). Members with bridging ties outside the central network can act as 'brokers' for change (Bebbington, 1997). *Brokerage* in this way refers to when an actor connects otherwise unconnected actors (Gould and Fernandez, 1989). Members who can balance bonding with brokerage tend to be in a better position to perceive and access knowledge and resources, balancing the tendency to work with similar network members with the benefits of coordinated action across diverse network members (Wukich and Robinson, 2013; Siciliano and Wukich, 2017).

While the importance of central actors who use bridging and bonding ties to benefit other network members is often assumed (e.g., Hahn et al. 2006), being in a favorable (central) position in a social network does not necessarily imply being the only members having important influence over others. There can also be network members who occupy marginal positions but retain influence through a formal level of authority (Bodin and Crona, 2009).

Social network structures, distinguished by their density of connections, influence the way that information spreads through a network (Janssen et al., 2006). Density and centralization are indicators that show the potential of power exertion by central members —i.e. the capacity or ability to direct or influence the behavior of others (Bodin and Crona, 2009).

Some networks are defined by having a core-periphery structure, which consists of two classes of network members, one core group densely connected and another periphery group only loosely connected to this core (Mascia et al., 2013). This structure has implications for information diffusion and access to diverse types of knowledge (Bodin and Crona, 2009). Core members can frame the discourse and the decision-making agenda, through their central position, effectively channeling and exerting influence over other members (Ernstson et al., 2010). Isaac et al., (2007) found this kind of structure in farmers' advice networks in Ghana, where the core members were significantly more engaged in the acquisition of new information and knowledge than periphery members, acquiring information from external sources and peripheral farmers. Core farmers acted as bridges, bringing new information and knowledge to the village, and disseminating this new information. Further, high status individuals tend to occupy central/core positions in the social network and they are thus more likely to receive valuable knowledge within information exchange networks (Lu et al., 2017).

In summary, core members within a network, who have a high level of out-degree ties and brokerage positions, are enabled by the network structure to channel and control knowledge and resources flows. As a result, such core members influence other members' farming strategies and land-use decisions (Ernstson et al., 2010; Isaac et al., 2007). The aggregated effect of these decisions can change the structure of the landscape, ultimately leading to landscape homogeneity due to the spread of similar land management strategies (Isaac and Matous, 2017).

3. Case study and methods

3.1. Study area

Our study area is Artajona village in the region of Navarre, Spain, in the Ebro River watershed. Navarre, which features both small-scale family farms (0 - 5 Ha), and large-scale farms (50->100 ha), and which remains as one of the few autonomous communities in Spain noted for still its large communal land area (Aguas, 2010). This means that farmers can access more arable lands than those that they own privately. Navarre has undergone rapid agriculture intensification fueled by the development of a large-scale irrigation project, by the governments of Spain and Navarre, known as *Itoiz Canal de Navarra,* that irrigates 37,445 ha (Albizua et al., 2019a, 2019b). This large-scale irrigation transformation affected around 22 villages in the region. Our study focuses on Artajona village with a population of around 1,600 inhabitants.

The large-scale irrigation project has led to a homogenization of the landscape of Navarre (Albizua et al., 2019a, 2019b), in part due to a process of grouping small plots of land into holdings of at least five hectares (De Vries & Garcia 2012). Farmers who owned land in the areas affected by the irrigation project had three options: they could adopt modern irrigation, collaborating with other farmers if they owned less than five hectares; they could switch to lands in other areas under rainfed systems, or they could simply sell or rent out their lands. Some farmers, unwilling to invest in the new irrigation technology, left their land to the local rural cooperative[1], rented to other farmers, or sold their land. This has led to a concentration of land in fewer hands and a decline in small-scale farming in the region. These landholders are nevertheless still influential in some land management decisions by deciding who is going to farm their land and, sometimes, by deciding the type of farm management in the lands they own.

The irrigation project has led to land management changes. These include the increased cultivation of corn and forage and increased use of pesticides and fertilizers (Albizua et al., 2019a, 2019c).

The irrigation project has been strongly subsidized by the government of Navarre, and other funding has followed suit. Some examples include funding available for farmers to create farm cooperatives to share the heavy machinery necessary (Gil and Bonis,

[1] There is a strong culture of agrarian cooperatives in this region around which farmers normally organize themselves.

1986). There are also other kinds of local cooperatives, which help with crop storage, farming advice, and selling fertilizers and other inputs. In the village we studied, the local cooperative is one of the oldest and most important in the region, having started in 1904 (Gran Enciclopedia de Navarra, 1990). After the large-scale irrigation project started, this local organization has taken on a new role as the mediator between irrigators (with the labor and the machinery) and landholders who are often renting out their lands. The access to communal land has also been altered, since some municipalities in the region have prioritized allocation of communal land to full-time and young farmers, who are the main adopters of modern irrigation technology (Albizua et al., 2019a).

3.2. Sampling strategy

We selected a sample of farmers by triangulating various approaches. First, we obtained a list of farmers and landholders in Artajona from the Navarre government. We added to this list all farmers that belonged to the local cooperative and others registered in the Ecological Agriculture Council of Navarre. We then asked key farmers and community members to check the list and add missing members, using snowball sampling until the addition and mention of new farmers' names were minimal which indicated that our list had reached saturation. We tried to talk to every farmer and landholder in the village so that our sampling was an accurate reflection of the farming practices and network structure of the village.

We collected information to characterize the social networks in our study site that influence the exchange of several types of knowledge and resources through surveys administered in-person to heads of households during June-August 2017. During the survey, we explained that our aim was "to explore the surveyed person's social network to understand who influences him or her when making decisions about land management and his or her farm performance". We performed a name generator with free recall (Alexander et al., 2018) and invited farmers to mention people who might influence their land-use decisions. We told them that "we'd like you to begin by identifying up to five people with whom you exchange knowledge/information or from whom you receive advice about farming, and then we'd like to learn a little more about each of them. You could start with the person you probably talk to the most and we can go on from there". We asked the same question regarding resource exchanges among the farmer being interviewed and the other five farmers. For both, knowledge and resources, we made an open question followed later by a list of topics generated in the trail. We then aggregated all different types of knowledge and resources being exchanged into manageable categories. Knowledge categories included a high variety of topics (see **Table 1**). Resource categories consist of labor, land, machinery, crops, money, seeds, fertilizers and subsidies.

Farmers and landholders nominated other farmers and landholders, agriculture/farmer organizations, extension service agents or consulting firms (from in or outside the village) as those with whom they shared resources and knowledge. We also inquired about 1) the frequency of knowledge and resource exchanges, 2) the importance attached to relationships with each of the persons mentioned, and the reasons behind those exchanges and 3) if and how they thought that connections to the mentioned people influenced their farming practices. All participants mentioned that knowledge and resource exchanges influenced their farming decisions. However, they did not normally specify exactly in which particular ways. Nevertheless, how such interactions influence their farming practices is, to some extent, revealed by the data collected regarding the management they performed (see **Table 2**).

We approached a total of 106 people, of whom 81 completed the survey (a response rate of 77%). Farmers nominated 80 additional people leading to a total network of 161 people. The total network included *intensive* farmers (N=48): generally, young farmers owning and renting land to cultivate agro-industrial commodity crops including biofuels, maize and other cereals in large plots (50->100 ha) and applying relatively high doses of inputs (fertilizers, pesticides, and irrigation); *small-scale diversified* farmers (N=44): part-time farmers or retired farmers owning the land and cultivating for self-consumption or small-scale trade; *landholders* (N=29), who were mainly old retired farmers who rented out their land; *farming-related organizations* (N=27) including agrarian cooperatives, agrarian unions, seed and food companies, land cultivation service companies and the Council of Organic Agricultural Production of Navarra (CPAEN);[2] and *others,* which included other farmers as family members (N=13) (see **Table 2**). We also carried out 32 face-to-face semi-structured interviews with organization representatives and key informants related to the regional agrarian sector.

[2] Most surveyed organizations were included as part of the initial fieldwork design, following the main author own criteria due to her familiarity with the context, and some few were included as suggested by surveyed farmers.

These were normally outsiders to the local farming community. The information was useful to get a better sense of the main actors influencing farmers' decisions at the regional level (see supplementary material).

3.3. Statistical and social network analysis

We first performed a hierarchical cluster analysis (HCA) to classify farmers and landholders in different groups (García-Llorente et al., 2008) based on the decisions they made about land management. Some of the key variables included were plot area (ha), type of fertilizers and irrigation used, and types of crops grown. This analysis indicated the farming strategy of each group of farmers. We then carried out a 'multiplex network' analysis. That is, we focused simultaneously on multiple graphical representations of networks, each of them in turn representing a unique resource or knowledge exchange relationship and where each node represents a member of the farming community, and where every node appears in each of these graphical representations (Bodin and Crona, 2009; Rathwell and Peterson, 2012; Baggio et al., 2016). By comparing the multiple graphs, we assessed the structural differences at several levels.

At the individual level, we calculated two individual centrality network measures: *centrality degree* and *betweenness centrality*. We measured the *centrality degree* to understand the level of involvement each network member had (how active they were) in terms of exchanging knowledge and resources with others. The centrality degree indicator represents the level of activity of the members of the network—i.e. the number of ties entering or coming from an individual—with larger nodes representing more ties. Also, we assessed *betweenness centrality* to understanding each network member's position in terms of connecting different types of members' subgroups (for example, to determine if who used more similar farming practices were closer to each other within the network) (Prell et al., 2010). We carried out the Gould-Fernandez Brokerage Analysis for the two knowledge and resource exchange networks to understand the roles played by network members based on where they are positioned in the network and with whom they exchanged information. Brokerage is the only mechanism that permits isolated or unconnected actors to share knowledge and resources. It is assumed that a broker's connections to and control over knowledge and resources being exchanged between unconnected network members gives them greater access to information and resources compared to those who are not brokers. Together these network analyses provide information about who is more central in the rural community, for every type of knowledge and resource exchange.

At the group level, we calculated mean module-to-module knowledge exchange-correlation scores among different groups of network members to understand the degree of homogeneity of those groups for each of the different types of knowledge networks (Sayles and Baggio, 2017). The mean module-to-module calculation aims to understand the extent to which farmers of one group exchanged knowledge with other groups of farmers (Sayles and Baggio, 2017). This analysis shows whether there is an asymmetry in the knowledge flows between different groups of farmers (Doreian et al., 2004). In our case, the groups are intensive farmers, small-scale farmers, and landholders, all being differentiated by their different land management decisions given the information obtained from the HCA (organizations and ‘others’ were removed from the analysis.

Finally, at the level of the whole farming community, we describe the network structure for each type of knowledge or resources exchanged (e.g. core-periphery vs loose and open structures), and we measured cohesion indicators such as *density*, *reciprocity*, *centralization*, *diameter* and *average path length* (Prell et al., 2009). *Cohesion* represents the minimal number of members in a social network who need to be removed to disconnect[3] the group (Moody and White, 2003). *Density* refers to the proportion of ties that are present out of all possible ties in the network. *Reciprocity* refers to the proportion of ties that are reciprocated. *Centralization* refers to the central position of individuals regarding their betweenness for the overall network cohesion. This is a position of strategic significance in the overall structure of the network. *Diameter* expresses the longest minimum distance between any pair of individuals. *Average path-length* refers to the mean of the shortest distance between each pair of nodes in the network. These measures complement individual level calculations and reinforce the answer to the question of which group of farmers is more central and whether the shared knowledge or resource is reciprocal or not. The analysis is also geared to compare the multiple types of knowledge and resource exchanges. For example, some types of knowledge flows may be more frequent but the ties may not be reciprocal; by contrast, the network may have a lower density for other kinds of knowledge exchange but with a

[3] Disconnection of the groups refers to make such community dysfunctional –i.e. not useful for farming related decision-making, in this case.

higher level of reciprocity. Similarly, we compare other interactions regarding the number of "intermediary" people between two actors.

4. Results

4.1. Well-integrated active intensive farmers versus weakly integrated passive small-scale farmers

At the individual level, we found that intensive farmers were the most active in exchanging all types of knowledge and resources, except for crop exchanges (see **Table 4**). Likewise, intensive farmers were the closest to all other farmers in all the networks analyzed, as shown by their higher score of *betweenness* centrality. This central position allows these farmers to serve as brokers of knowledge and resource flows in the community, thereby having the capacity to influence the spread of knowledge and resources to other farmers in the network. Interviews also revealed that intensive farmers had a privileged position to access policy-related knowledge (such as how to obtain subsidies to access machinery and adapt to the new irrigation requirements) due to their connection to farming organizations. This puts them in a privileged position viz-a-viz other farmers who also require this type of information.

Small-scale farmers were less active in exchanging knowledge and resources (i.e., lower *degree* centrality) and occupied a peripheral position in terms of knowledge and resource exchange networks, indicating that they were less able to connect to other farmers. The cohesiveness measures (centralization and diameter, **Table 3**), the low value of individual measures (mean values of *degree* and *betweenness centralities*, **Table 4**), and small-scale farmers' peripheral position (**Figure 1)** suggest that they are more likely to rely on brokers, such as intensive farmers and formal organizations, for knowledge and resources. There were also few examples of younger small-scale diversified farmers whose networks seemed to be external to the community, but these farmers represented a minority among the surveyed small-scale farmers.

4.2. Asymmetric knowledge exchange among farmer groups

Farmers exchanged a variety of types of knowledge with other farmers who generally shared common farming practices (**Figure 2**). In addition, there appears to be asymmetry in knowledge sharing between different groups of farmers and landholders. Although small-scale farmers mainly mentioned landholders when asked with whom they exchanged knowledge and resources, landholders did not always mention small-scale farmers when asked the same question. This reveals that landholders did not attach the level of importance to such interactions, as did small-scale farmers (**Figure 2**). We also see a relatively strong alignment[4] between intensive farmers, formal organizations and landholders, who tend to exchange key resources such as land, labor, and machinery, as well as management-related knowledge. Key informants provided further information about the type of advice/knowledge intensive farmers shared: mostly related to newly introduced crops (maize, grass, and biofuels), the rotations that suited such crops, sprinkling irrigation, and other technologically related management options, and about the required fertilizers and pesticides. Interviews also revealed that landholders hired in intensive farmers' labor and gave them responsibility for all farming practice decision-making.

Intensive farmers play many roles, including acting as representatives, coordinators, gatekeepers, and mediators of knowledge exchange **(Table 5** shows the multiple roles comparable across farming groups**)**. Local organizations act as mediators when knowledge exchange is assessed in an aggregated way (**Table 5**) and, particularly, in the exchange of land resources (**Table 6**), where such organizations mediate the transfer of land from landholders to intensive farmers and the transfer of labor in the opposite direction. Although intensive farmers and landholders are the most active agents, other actors, typically family members, play a role as mediators for groups of similar farmers (known as itinerant broker role) and among different groups of farmers (known as liaison broker role) in the network. This reveals the importance of those "other" actors in land plot exchange networks (**Table 6**), despite their low activity when the network is assessed at the whole community or individual levels. Intensive farmers are representatives, coordinators, and gatekeepers of labor (see **Table 7**) whereas landholders, and, to a lower extent, organizations, are the gatekeepers and representatives for land and machinery exchange networks (**Tables 6** and **8** respectively).

[4] With strong alignment, we refer to the fact that intensive farmers, landholders and some local organizations always mentioned each other for land, labour and machinery exchanges (see Figure 2). Fieldwork revealed that intensive farmers laboured landholders' lands, and local organizations helped this to happen and helped intensive farmers organize to share machinery among themselves.

4.3. Core-periphery, and loose and open community network structures

At the community level, we found that the networks about land management and finance-related knowledge exchange have a strong core-periphery structure. This implies that a small number of intensive farmers, who are primarily transmitting such knowledge to other farmers, occupy central positions in these knowledge exchange networks (**Figure 1-A-b,c)**. The data shows that farmers who share land management knowledge hold less reciprocal exchange of information (reciprocity: 0.69) compared to those sharing knowledge about technology (0.81), policy (0.78) or finance (0.76). Interestingly, while fewer farmers talk about technology, policy or finance, when they do, there is normally a mutual sharing of knowledge. With technology and policy-related knowledge sharing, there are two distinguishable subgroups. When they share information about technology, the subgroups are interconnected via a formal organization—the local rural cooperative—whereas when they share information about policy the farmer groups do not seem to be connected (**Table 3** and **Figure 1-A-d.e**).

The land (resource) exchange network is more open and less dense, meaning that fewer people are involved in land exchanges. The structure is not a core-periphery one, with few farmers providing lands to the rest; instead, some landholders provide lands to intensive farmers who are connected among other intensive farmers, creating a linear structure (see **Figure 1-B-c**). Machinery and labor exchange networks are more reciprocal than land exchange networks. The distance between two individuals in labor networks is the highest of any of the networks, which implies that there are normally broker persons in such exchanges (e.g. local cooperative acting as a mediator).

5. Discussion

We pose that the social structure of a farming community, which determines the flow of resources and knowledge exchanges within the community, can affect individual farmers' land-use decisions and land management behavior. Further, when aggregated, these decisions can impact land use and landscape configuration. Because of the strong influence of central farmers, the landscape may be reconfigured over time in ways that are associated with the interests and preferences of those farmers who are central to the social network of the farming community. Here, we analyzed the main network characteristics as regards knowledge and resource exchanges of a representative farming region in Navarra, Spain, with the objective of predict how the farming landscape may evolve shortly based on the social structure of the community.

Bridging ties between different types of farmers, and between farmers and other local organizations, can increase information dissemination and adoption of farming techniques (Bodin and Crona 2009). Promoting external bridging ties can also contribute to land use diversification when there is a strong local network to implement that change (Isaac and Matous 2017). In our case study, we show that intensive farmers are the ones who mostly disseminate knowledge about farm management and serve as gatekeepers of such knowledge within a core-periphery network. Their core position and the role they play allows them to determine the main ways that knowledge is disseminated in the network, and by so doing we believe that this allows them to maintain the status quo that promotes their farming strategies and interests. In a different context, Ernstson et al., (2010) also demonstrated the ability of key network members to block transformational change. The multi-level network structural differences found in the access to knowledge and resources puts intensive farmers in a position of power influencing other farmers' land-use decisions. Intensive farmers' central position and their capacity to control not only the flow of knowledge about farm management, but also about policy, technology, and financial aspects, as well as key resources such as machinery, labor, and land. Thanks to their features and core position in the network, intensive farmers have created their own "in-house expertise" for technology and policy knowledge as well as for labor and machinery resource exchange dynamics.

The knowledge sharing asymmetry that we found in the Navarre case study reinforces the view that the agricultural intensification occurring in the region is made possible by the close connections between intensive farmers and local organizations and institutions that favor intensification (Albizua et al., 2019a, 2019c). In this way, the results suggest that the social structure in Navarre may be reflecting a positive feedback loop between the colluded interests of formal organizations and those of intensive farmers, and landscape intensification and homogenization, further marginalizing small-scale farmers in the region. In line with Inman et al.'s (2018) findings, the data suggest that landholders also colluded with intensive farmers' interests. This is probably explained by the fact that intensive farmers' experience with sharing and their long-term membership in the local cooperative makes them valuable (high reputation) for knowledge exchange. Thus, social network analysis is aligned with the expansion of intensive farmers' practices in the Navarre region (Albizua et al., 2019a, 2019b).

Fieldwork observation and interviews in the region revealed that landholders preferred renting out their land to intensive farmers for cultivating their lands, normally leaving intensive farmers to decide their farming strategies. These relationships can be depicted as fueling the 'instrumental power' (Wong et al., 2017) of intensive farmers. That is, intensive farmers and farming organizations in the region can exercise their influence over less powerful actors (in this case small-scale farmers) through the control of the exchange of knowledge, e.g., over finance and technology, as well as resources. This indicates that intensive farmers are in a strong position to influence landholders' access to knowledge and resources, and thus their behavior regarding land management.

We argue that the high level of bonding capital among intensive farmers, as well as their bridging capacity with formal organizations and landholders, are necessary conditions for the intensification of land management and the spread of their farming strategies. In contrast, small-scale farmers mainly interact with other small-scale farmers and landholders for the sharing of knowledge about land management. Hence, small-scale farmers' alternatives to intensive farming do not find sufficient support in the network to grow or spread. Small-scale farmers occupy peripheral positions and other landholders typically do not take into account their management-related knowledge. We also found that few small-scale farmers connect to external actors and appear in isolated subgroups; their lack of strong local networks seems to prevent the diffusion of their farming strategies. Interviews provided some additional evidence about small-scale farmers still holding to non-intensive land management, characterized by growing mainly vegetables and fruit trees and following more traditional practices in terms of irrigation, pest control and fertilizer use (Albizua, 2016). Hence, we posit that the ensuing farming and social homogeneity may impede the uptake of innovative management strategies that favor less intensified agriculture, for which diverse knowledge, values, and perspectives are required (Lyon, 2000; Prell et al., 2010). Further, we argue that, with time, intensive farmers and local organizations may increasingly be able to influence small-scale farmers' identities and behaviors. As Van Hecken et al., (2015) pointed out, the lack of recognition towards weaker actors is, at least in part, the result of institutional exclusion processes and deserves more attention in future research.

We acknowledge that structure is not everything and small-scale farmers' behavior also depends on other contextual factors such as their governing institutions, socio-demographic factors, as well as their attitudes, beliefs, and intentions (Barnes et al., 2017). In this regard, complementary interviews revealed that most small-scale farmers are part-time or retired farmers still laboring land as a hobby and/or because of the importance they attach to self-consumption crop quality. This typology of farmers has low interest in engaging in the agricultural commodity market, they do not tend to self-organize, as intensive farmers do, and are not actively resisting intensive farmers' management expansion. Albizua and Zaga (2020) show some struggle between intensive and small-scale farmers at the beginning of the large-scale irrigation implementation but as Bebbington (1997) pointed out, once intensive farming practices are settled, those seem to become widely accepted and they have gradually turned into deep structures taken-for-granted.

Other relevant factors that may be shaping the current land use intensification spread leading to landscape homogenization, are connected to policy and development interventions (Bebbington, 1997), which are for the most part oriented to intensive farmers' needs. One example in this context is the Foral Law 1/2002, which requires the local government to subsidize approximately 40–50% of investment costs to farmers adopting the new large-scale irrigation technology. Besides, most small-scale farmers found that this irrigation technology does not fit with their livelihood strategies and hence decided not to invest in the uptake of modern irrigation. This fact, on top of the aging of the farming population and the lack of family members interested in keeping the traditional agrarian activity, led some small-scale farmers to arrange land deals with intensive farmers (Albizua and Zaga-Mendez 2020). All in all, our results indicate that small-scale farmers' low activity and peripheral position limit their ability to influence the rules and deployment of agriculture intensification in the region (Calvário, 2017). Likewise, small-scale farmers show a low capacity to incorporate their cultural values and land management practices into the dominant agricultural model (Smit and Wandel, 2006).

We acknowledge some limitations in this study. Although we aimed to approach all farmers and landholders in the local community, the use of free fixed recall of mentioning up to five people means that we were not able to include all potential ties, which may add some bias to our results, over-representing those perceived as the most central actors. This choice was taken based on that the empirical literature on social network analysis generally relies on an individual's ability to freely recall their interactions and give the example of asking an upper limit (“list up to 5 people . . . ”) or period (“within the past 2 years . . . ”) (Groce et al 2019). Since the number of intensified farmers and small-scale farmers is similar, the initial number of farmers surveyed is unlikely to have a major influence on centrality.

We have also calculated an exponential random graph model (ERGM) to check the effect of homophily and probability to receive ties based on the type of farming (see supplementary material for more details). We found that homophily is not a significant factor in determining the network configuration. However, the group of farmers the member of the networks belong to is important when it is the case of small-scale farmers and landholders.

We also acknowledge the importance of paying attention to connections outside the community boundaries that we defined. Our reasoning about how the current network structure is displacing small-scale farmers could be incorrect if small-scale farmers were involved in other networks beyond the community studied here. However, our analysis would have allowed us to detect if small-scale farmers were part of an external community by checking whether the nominees are part of our defined community or not. In this regard, we found that only a few small-scale farmers were part of other networks outside the community we have analyzed. While some of those small-scale farmers may be resisting the influence of large-scale actors, relying on agro-technology may be the exception rather than the norm. Finally, it should also be noted that since our dataset is not longitudinal, it is not possible to identify clear cause-effects in the network.

Despite the limitations noted, our qualitative and quantitative findings, taken together, offer some support for the hypothesis that influential network members – intensive farmers –can affect other farmers’ management decisions and that this may be one of the main reasons for the ongoing (and likely future) spread intensive farming practices in the region, leading to a homogenization of the landscape.

6. Conclusions

The results of our case study in Navarre, Spain, improve understanding of how agricultural intensification can spread once initially established in a community. In this community, the social structure led to uneven access to knowledge and resources. We found that intensive farmers had an important brokerage role in most of the knowledge and resource exchange networks in the community we studied. Moreover, they balanced bonding with brokerage, which enabled them to have a better vision of, and access to, important external resources and knowledge. These farmers' position in the network also facilitated their ability to control knowledge and resource flows, which meant they could influence other farmers' decisions about farming strategies and land use (Ernstson et al., 2010; Isaac et al., 2007). We further showed how those powerful farmers were aligned with landholders. This alignment, together with intensive, central farmer's frequent connection to regional organizations, allowed them to take advantage of their social connections, maintaining their position and ultimately spreading their farming strategies through the community. The knowledge and resource exchange affected farmers' land-use decisions, which, in the aggregate, can affect the structure of the landscape because it encourages the adoption of similar practices over time, making the landscape more homogenous (Isaac and Matous, 2017). We posit that the core-periphery network we identified, and intensive farmers' position within this network, reinforce the worldwide phenomenon of agricultural intensification (Campbell et al., 2009) that co-exists with rural abandonment (Rivera-Ferre, 2008), especially among farmers attached to traditional farming (Proebstl-Haider et al., 2016).

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"How are social networks structuring agricultural sustainability? An example from Navarre (Spain)"

Response to Editors and Reviewers

We are grateful to the editors and the four reviewers of our manuscript for their insightful comments. We provide below a detailed account of how we have addressed each of their remarks, and we use a table to facilitate crosscheck. Thanks to these and previous comments, we think that the manuscript now is more clear and robust and the story-line is more comprehensible and focused. The manuscript presents more clear research questions and hypothesis and the discussion has further being elaborated in correspondence with them. We have also completed the introduction and the methodology explains now how each of the analyses performed helps to answer the research questions.

We hope that the re-submitted manuscript now meets the required scientific standards of Regional Environmental Change and it is finally considered positively for future publication. Please do not hesitate to contact us for any further clarification on how we have interpreted or addressed the comments below.

Yours sincerely,

Dr. Amaia Albizua
Dr. Elena Bennett
Dr. Unai Pascual

Comment	Response
Reviewer 3 I think the manuscript has largely improved since the first round. While I still have some methodological questions remaining in terms of sampling techniques and interpretation of network metrics, I think these are issues that would need a broader exchange, and might risk to go beyond what is possible in one, empirically oriented paper. I think it is much clearer now what the aim and context of the study was, and how the authors went about.	
1) I have one issue, that I would ask the authors to revise (one again), before giving my green-light for publication. I think the paper would benefit a lot from setting out from the beginning the difference between sharing knowledge and sharing resources (as I have mentioned this in my previous review). While the authors do make an attempt to distinguish between the two (especially in the results and discussion sections), it would help the argument of the paper (and the conclusions which can be drawn) to distinguish between these two distinct issues right from the beginning. In terms of the literature, there are also two distinct strands, one on resource-exchange, the other on knowledge-exchange and proliferation. While the authors quote seminal papers from both strands, it would help the reader to better distinguish between the two, and derive distinctive questions for resource vs. knowledge-sharing in the farming communities of the Spanish region into which the authors are looking. This allows to set the insightful results from this case-study into the overall academic discourses related to the two issues, access to resources on the one hand, and knowledge-sharing and control on the other.	We agree that making clearer the difference between knowledge and resource exchange at the beginning of the paper can help to interpret the results from this case study in a way that can contribute to the academic debate. We have now included the difference between sharing knowledge and sharing resources in the introduction (page 3 L61:72). We have done so by reflecting the importance of this difference regarding asymmetric social power relations. We believe that bringing in power relations further helps understand some of our results such as the interdependencies between landholders and intensive farmers as well as the asymmetric exchange of knowledge and resources. This illustrates the extent to which intensive farmers control some types of knowledge. Besides, making the difference between resources and knowledge allows a more nuanced discussion regarding the brokerage results.
2) I have one additional, content-related question which intrigued me: in table one (and less clearly in the text), you speak of small-scale landholders. What do you mean with this? Are all landholders owning only small parcels of land, or is it to make the distinction from (implicitly large-scale) intensive farmers clear? Are the intensive farmers all owners of their land, or are there intensive farmers who farm the land for LARGE-SCALE landholders? This distinction should be made clear, in order for not appear arbitrary in the eyes of the reader.	Thank you. We have clarified this further in Table 2: small-scale landholders are landholders owning small parcels of land. Information from interviews indicated that if we account for the whole surface owned by these small landholders, it could represent a large amount of land (this is perhaps why it was confusing in Table 2 explanation). We hope it is clearer now. By contrast, we describe some farmers as *large*-scale intensive farmers when they labor a large area of land. They may either own or rent the land they labor. Table 2 shows that there are three different groups of large-scale intensive farmers. The main characteristic of the large-scale intensive farmer group is that their farming strategies are intensive regarding the level of inputs they use in farming, the type of machinery used as well as the types of crops grown. We have also

	added further information about farmers' groups' characteristics (i.e. ownership, socio-demographic features). This helps understand better that for instance in the case of small-scale landholders, they are normally old retired farmers. We also make this information explicit in section 3.2. page 9 L269:275.
3) Then, and that is my last comment, I think the authors should think again about the temporal dimension in their analysis. They write in the conclusion, that this study contribute(s) to better understanding how agriculture intensification spreads once it is initially established in a community. I only partially agree with this. While the interviews conducted in the region might suggest this, the network analysis only allows to show how the agricultural actors in this region interact with each other, and might hint at certain (future) outcomes of these exchanges, both in goods and knowledge/information. In my view, it does not allow, however, to make the bold statement that intensification will spread in any case, since there might very well be influence factors which balance or counteract this tendency. I would like to see this point discussed a bit more critically. For example, the predominance of interactions between small-scale farmers mentioned on page 14 (lines 424 and 425) could also lead to strong(er) communities resisting the influence of large-scale actors relying on agro-tech, as we see it in many parts of the world, e.g. also in Western Europe.	Thank you for this insightful comment. We do agree that the network analysis only allows showing how the agricultural actors in this region interact with each other, and might hint at certain (future) outcomes of these exchanges. While it is indeed not possible to infer from the network analysis the evolution/spread of different farming approaches, supporting material based on interviews and previous work in the same region since 2013 (see references in page 7 L 197 and L201) suggests that the temporal tendency has been for the spread of large scale intensive farming. Thus, we bring this additional information more explicitly to the paper now. Additionally, we further discuss the fact that in this context, small-scale farmers are not interested in a strong engagement in the market and are not organizing themselves to resist the spread of intensive farmers' practices, as far as we are aware (page 17 L505:508). One way to hint at this phenomenon is provided by bringing in some new data to the paper about how many small-scale farmers decided to abandon farming altogether after the introduction of large-scale irrigation (page 7 L206:208). Interestingly, information from the interviews also reflected that only a minority of small-scale farmers sell their produce in the market and had their own network community (external to the assessed community). Together these pieces of information support our view that in this area large scale intensive farming is likely to spread viz-a-viz small-scale farming. We thus hypothesize that although intensification consequences could have supposed some struggle between intensive and small-scale farmers in the beginning, once it is settled, it is probably becoming widely accepted and gradually turning into deep structures taken-for-granted (page 17 L508:512). We have now clarified this line of argument both in the discussion and conclusion sections.
Reviewer 4: In this manuscript the authors explore the role of social networks in decision-making among farmers in Navarre (Spain) to understand the adoption of certain agricultural practices. As they find, the centrality of intensive farmers can be associated to the dominance of intensive farming practices and the homogenization of agricultural landscapes. The study is innovative and very promising but has also some deficits that prevent its publication for now.	
Major	

In the introduction, the research questions are a bit descriptive and not too problematized theoretically. They seem to address a problem (i.e., that of intensification of agricultural practices and homogenization of landscapes) but I missed a bit of theoretical problematization (for example one that revolves around the distinction between resource and knowledge exchange or one about the different roles that farmers can have in a network.	Thank you. Following the suggestion of the reviewer, a theoretical problematization around the distinction between resource and knowledge exchange has been included in the page 3 L61:72). We address the importance of this difference regarding existing asymmetric social power relations. We believe that bringing in power relations further helps understand some of our results such as the interdependencies between landholders and intensive farmers as well as the asymmetric exchange of knowledge and resources, and illustrates the extent to which intensive farmers control some types of knowledge. Besides, making the difference between resources and knowledge allows a more nuanced discussion regarding the brokerage results. The issue about the different roles farmers have in the network is already explained on page 10 L307:309. We have now emphasized this in the second section of results page 14 and on page 13 L387:402, where we explain the module-to-module results. We then bring this back to the discussion and conclusions sections.
The authors have a hypothesis but I wonder whether the hypothesis is not a bit trivial given that the literature (as per the author's account) already supports the claim that networks do affect farmer's decisions. Also, the authors do not discuss the hypothesis in their results or discussion sections	The novelty we bring in the paper is the point about how the impact of the network on farmers' decisions helps to understand (un)sustainable agricultural pathways in the context of rural Navarra, a historically rich agricultural region of Spain. We believe that the analysis and results contribute to useful knowledge for decision-makers interested in understanding how in a given context farmers' interaction, access and control of resource and knowledge flows, for example when designing rural development and land-based environmental policies. In our specific case study, the analysis also allows knowing the importance of landholders trusting intensive farmers (i.e. landholders leave intensive farmers decide about the farming strategy in their land), as well as the role of the local cooperative, which by acting as a mediator between intensive farmers and landholders, shapes the network among farmers, in terms of exchange of land, labor and machinery within the network. We think this context may share key similarities to what is happening in other Mediterranean rural landscapes. To recap, our motivation for the paper is to understand to what extent and how that influential network members can make other farmers adopt similar practices, ultimately leading to modifying the agroecosystem towards homogenization. We suspect that this is occurring and that large intensive farmers are the main drivers of such

	homogenization of the landscape. To understand this phenomenon, our goals are to check 1) how different types of farmers (e.g., large vs. small scale farmers) are connected to each another via resource and knowledge flows; 2) who the central network members are and how much and with whom they mostly interact; and 3) by understanding the main features of the social network structure, shed light on what this could imply for the landscape structure. We have clarified the motivation of the paper. We have also re-written the discussion to make more clear how we have answered these questions (see the last paragraph of the discussion). We believe the paper now makes it clearer that our results support our original expectation regarding that intensive farmers are influential and their practices are spreading in this region rural landscape, leading to a homogenization of the landscape.
Also, it is difficult for me to see how the authors connect knowledge/resource exchanges/networks with land use decisions. They claim that the former affect the later but I wonder whether the later may also affect the former. The assumptions made by the authors (lines 99 to 102) are not clear in this regard.	We created the groups performing a HCA based on the farming practices performed by farmers. The variables included in the HCA were the types of fertilizers used (organic, mineral and mixed), the type of irrigation performed (sprinkler, dropping, other), and the type of crops grown (including maize and biofuels or trees and vegetables). We, therefore, assume that each farmer category is associated with a different type of farming practice or land management. Assessing how such different groups relate to each other is the way we connect knowledge/resources exchange networks with land use decisions. We now explain in section 3.3. how the groups of farmers were created (Table 1 now better describes the farmers' groups). The reviewer is right that it is not possible to conclude what comes first (network exchanges or land management decision-making) since we believe it is a bi-directional process with a continuous feedback loop (see page 4 L112:114). We acknowledge it as a limitation of the paper (in the Discussion section, page 18 L539:544). However, during the fieldwork, we formulated the question as with whom and about what did they talk to make their decisions about farming, so the direction was established in this way, in the design of the analysis. Interviews made us suspect which direction is stronger, i.e. from knowledge and resource exchange to land management (rather than the opposite) Included on page 9 L264:266.

In the methods section I find particularly important the question about "if and how they thought that connections to the mentioned people influenced their farming practices". This seems to me critical to test the hypothesis. However, I could not easily track the results emerging from this question, which left me wondering how the authors finally proved that the expansion of intensive farming in the region under study has anything to do with the central role of intensive farmers in the knowledge and resource sharing networks (and, ideally why couldn't we think that the causality is the other way around).	Reviewer is right, we have certainly not developed much the “how their farming practices were influenced” by their nominees, but all respondents affirmed their decisions were influenced by the knowledge and resources shared. We formulated the question in this way (advisors influence their decision-making); this is, with who and about what they talk to decide their land management. We found a central role of intensive farmers not only regarding technology, finance, and policy-related information shared but also management which includes new crops, fertilizers, pesticides, laboring techniques, pest control, etc. Most of the participants did not develop their answer much but attending to the topics or resources they said they exchanged and the profile of the farmer they talked to, we can deduce how their farming is affected (concerning the farming practice decision-making). We have added a bit more detail in the 4.2. results section, page 13 L380:386 and we have also turned the potential impacts on the landscape into a more speculative position in the discussion. If farmers affirm that their network community influences their farming practices and we found that landholders group normally left intensive farmers to decide the farming practices. We can affirm that the central role of intensive farmers in the knowledge and resource sharing networks is associated with the expansion of intensive farming. Indeed, more land plots are being labored intensely due to the land resource exchange dynamic between landholders and intensive farmers. The reviewer is right regarding that social network is one factor more in the expansion of intensive agriculture. There may be, and there are, others, such as policies, global trade, etc. that influence agriculture intensification expansion (included now in the discussion section and the introduction). As said in a previous review we present this paper as a descriptive paper with the main aim of disentangling who holds the power and capacity for keeping and spreading intensive farming strategies within the rural community.

Related to the above, I believe the analysis would be clearer if the authors developed more detailed hypotheses or provided clearer explanations that justify the different analyses the run (HCA, module-to-module calculations, several network structure measures…). What is each piece of the analysis helping the authors do with regard to their research question? For example, why do they need HCA and then the module-to-module calculations if both allow to identify groups of farmers? Do they need to look at all the network structure measures to test the hypothesis? How are they informing they hypothesis differently?	We have now added more detail on the reasons for each of the analysis run and how they contribute to answering our research questions and hypothesis. This can be found in section 3.3. at the end of each analysis explanation. The HCA allows us to see the different groups of farmers we have in this context (based on their land management) and the resulting groups of farmers are used in the module-to-module calculation, to check with whom each group exchanges knowledge and resource, but they are not the same analysis. We acknowledge it was not well explained in the Methods section and we have now corrected it (page 11 L316:325). Every analysis complements each other and confirm and reaffirm our hypothesis regarding which group of farmers controls the flow of knowledge and resources, and have the potential to influence other groups' farming decision-making.
All the above is also important also when looking at the discussion section. A careful second read of this section made me realize that it mostly centers around the dominant position of intensive farmers, which makes me wonder whether the authors needed all the network calculations to arrive at that conclusion. I like that the authors did all the network analysis work but I see two issues there. First, it seems to me that most of it only speaks about the independent variable and misses the connection with behavior (i.e., the "influence on farming practices" part). Second to me there is a mismatch between the richness of the results (i.e., regarding the independent varaible) and the shallow discussion. For example, the authors spell out in the results section the different "representative", "coordinator", "gatekeeper, etc., roles that farmers can take, illustrate show how organizations are important in some regards but not others, and point to the core-periphery differences between the knowledge and resource sharing networks, but all this is not further commented in the discussion section.	Thank you. We have now enriched the discussion regarding the behavior of farmers regarding their management decisions. We have maintained and added more nuance to the discussion about how different farmers' position in the network, their level of activity, the asymmetrical access to knowledge and resources, and especially the role of intensive farmers as gatekeepers, as well as their alignment with local institutions favor their powerful position. We have also improved the discussion regarding how the network structure may influence on farming practices and implications for the landscape structure. We have also triangulated other information from qualitative data and previous analysis to strengthen our interpretation of the results towards understanding future social-ecological pathways (social structure leading to future land homogenization)

Minor There are a number of methodological questions that I believe need clarification (see commented pdf).	Amended. We have answered all the comments in section 3. Some answers to comments that have not been much extended here: 1. Interviews were made to outsiders of the community **to better understand their role influencing farmers' decision-making.** 2. We first performed a hierarchical cluster analysis (HCA) to classify farmers and landholders in different groups (García-Llorente et al., 2008) based on their land management decisions. **We have corrected this and explain all the variables regarding management that were considered in the HCA.**
In the results and discussion sections, I missed better substantiation of the authors claims (this has to do with the issue about the connection between the network analysis and behavior). I have signaled those paragraphs in yellow. In the results section, I believe it is just a matter of better referring to the numbers in the tables and guiding the reader in comparing them, and maybe also offering more (qual. or quant.) evidence that shows how position in the network affects decisions (and not the other way around). In the discussion section, I believe the authors just need to better structure the paragraphs, so they are clearer about when they talk about their data vs. build on others' findings vs. make conjectures.	Amended. We have followed the suggestions indicated by the reviewer in the pdf and we have changed the order of some paragraphs and specified whether some statements correspond with results or not. Some answers to comments that have not been much extended here: 1. The graphs do distinguish different information and resource sharing networks but the stats tables do not. **Tables 3 and 4 do**. 2. Not sure that I understand. So intensive farmers play many roles regardless of how the data is aggregated? **No, they play many roles when checking the data aggregated (Table 5)**. **However, when we pay attention to the roles in resource exchange (see** the Tables that used to be in the supplementary material but they have now been moved to the main manuscript. Those are now **Tables 6, 7and 8**) we found that other actors also play important roles such as landholders who can be gatekeepers of land and "other" actors that are itinerant for land exchanges. For labor exchange, intensive farmers still play several roles such as representatives, coordinators, and gatekeepers. 3. We have now added some captions to Tables 5, 6, 7 and 8 that explain better how to interpret the roles played by the different groups in our rural community. Columns show the roles whereas rows represent each group. If we compare values at each column, we can identify with whom the highest value corresponds, so that we can attach such a role to a specific group. A further explanation has also been included in the text page 13 L387:389. 4. We have also included more qualitative evidence to show how our results align with farmers' decisions taken in the case study.

	5. We have better substantiated the indicated statements, normally adding explanations after them.

Figure

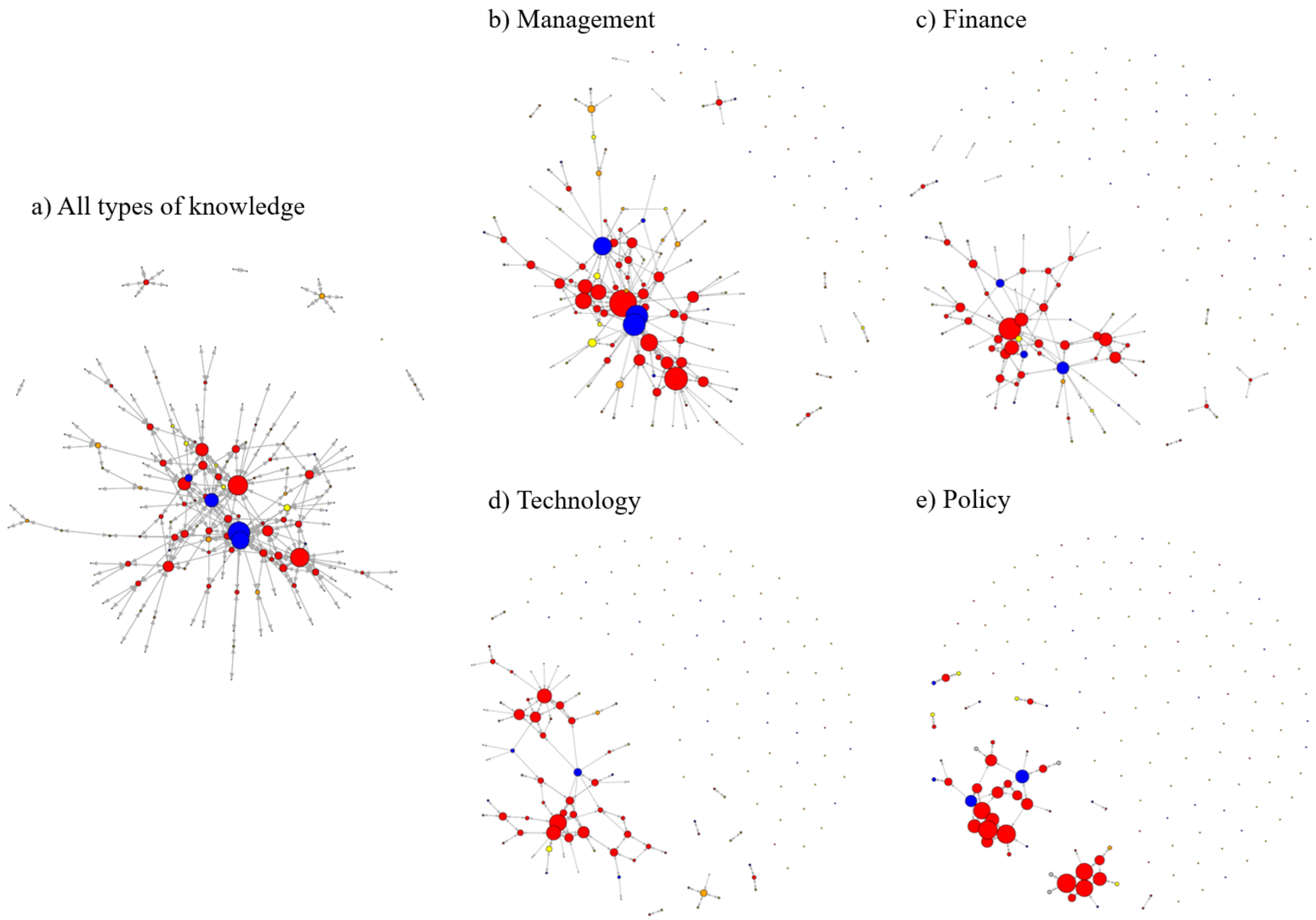

Figure 1. A) Knowledge exchange networks. (A) Networks of actors exchanging knowledge about management, finance, technology, and policy. All individuals with intensive farmers in red, small-scale farmers in orange, landholders in yellow, organizations in blue, and 'other' individuals in grey.

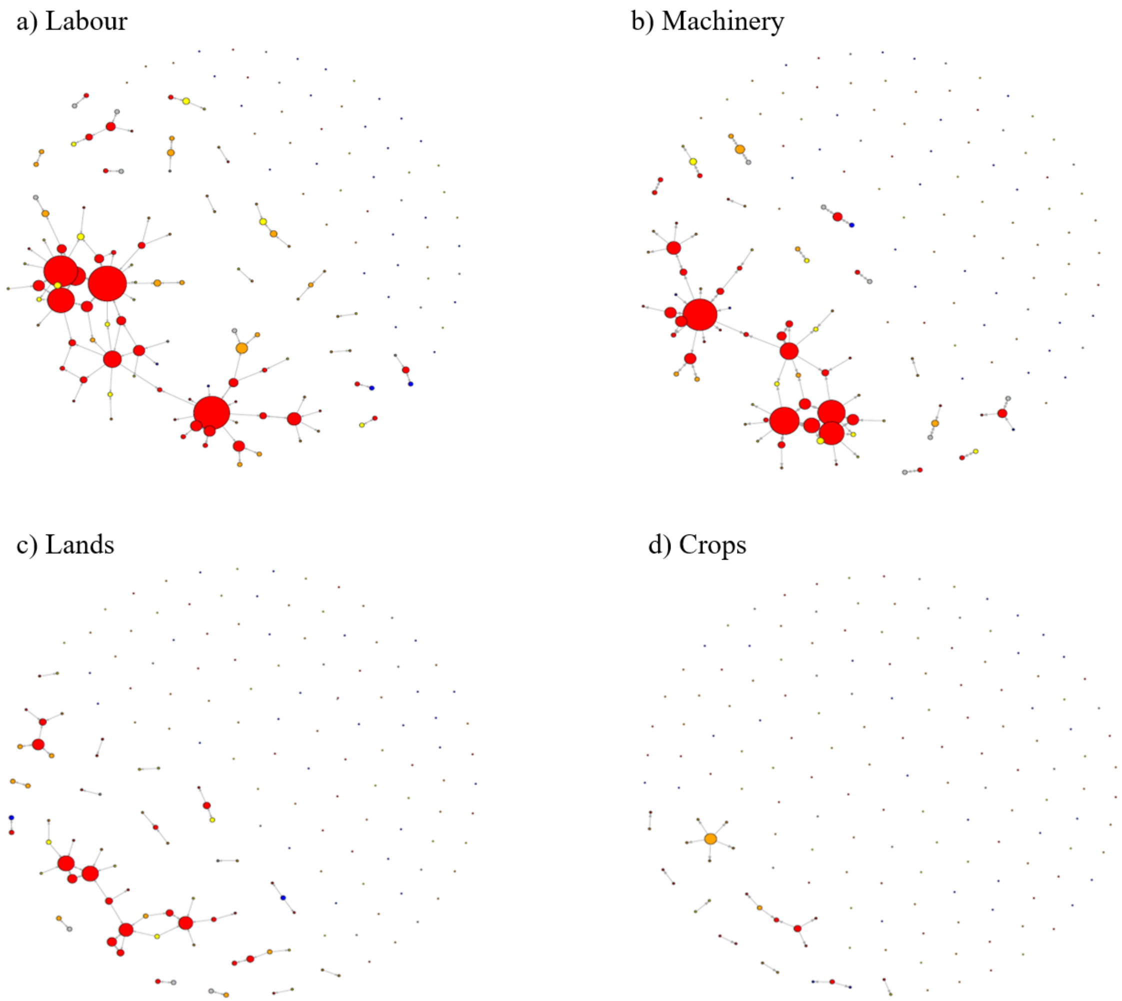

Figure 1. B) Resources exchange networks (B) Networks of actors exchanging resources such as labor, machinery, land, and crops. All individuals with intensive farmers in red, small-scale farmers in orange, landholders in yellow, organizations in blue, and ‘other’ individuals in grey.

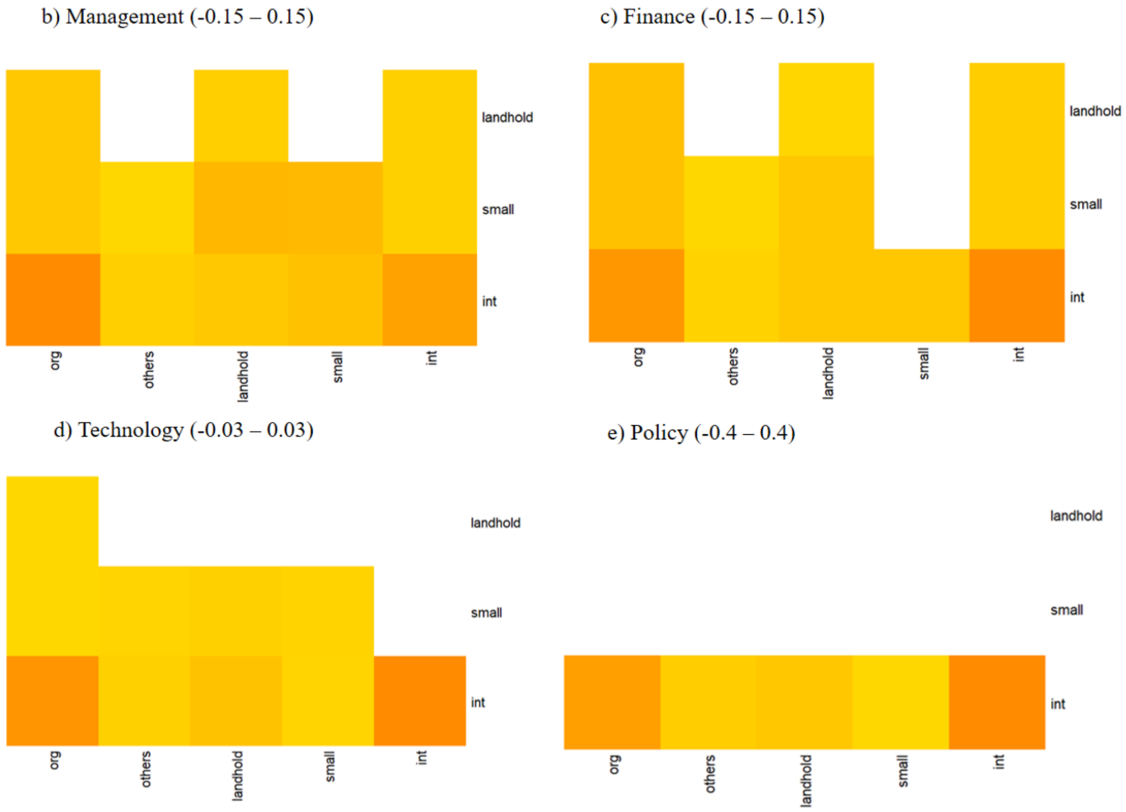

Figure 2. Mean module-to-module knowledge exchange scores among different groups for different types of knowledge

Caption. Colors indicate the mean of knowledge exchange score by the group. Data should be read across in rows; for example, the lowest row represents scores from intensive farmers to other types of farmers or organizations (directed ties are considered). When analyzing different relationship types, isolates (i.e., nodes without edges to other nodes) were removed. For this reason, there are some empty blocks.

Table

Table 1. Types of knowledge and resource exchange

Knowledge		Resources	
Farm management knowledge exchange (aggregated categories)	**Knowledge type mentioned during the survey**	**Farming resource exchange (aggregated categories)**	**All resources mentioned**
Management	Crop varieties; seeds; fertilizers; pesticides; irrigation management; tillage; crop rotations; yields; crop illnesses; land quality state; organic farming;	Labour	Labour Machinery Land Crops Seeds Water Money
Finance	Farm expenses; land trade; subsidies; insurance; crop prices; crop trade; inputs prices; water tariffs	Machinery	
Technology	Irrigation infrastructure, large/heavy machinery;	Land	
Policy	Agrarian normative related to the allowed use of fertilizers and pesticides, subsidies; communal land access;	Crops	

Table 2. Network nodes characteristics

Sampled community (N=161)	**Farmers' types of management / other nominees' main characteristics (N=161)**
Intensive farmers (N=48) hold large areas with agro-industry oriented crops (maize, grass, biofuels, cereals), sprinkling irrigation, mixed fertilization They make all decisions about farming and investments. They normally contract labor.	Large-scale intensive farmers (N=22) cultivating maize, biofuel crops in plots larger than 300 Ha, and using sprinkling irrigation and all type of fertilizers.
	Large/Medium-scale intensive organic farmers (N=12) cultivating mainly maize and grass in plots of 50-100 Ha and using organic fertilizers
	Medium-scale intensive cereal farmers (N=14) cultivating cereals in plots of 5-50 Ha, using sprinkling irrigation and only mineral fertilizers.
Small-scale farmers (N=44) hold plots between 0-5 hectares of "other" crops (vegetables, fruit trees). Not sprinkling irrigation, not main commercial crops (maize, vineyards, and biofuels).	Small-scale organic farmers (N=7) only organic fertilizers are used.
	Small-scale conventional farmers (N=37) mix mineral and organic fertilizer but they mostly use mineral fertilizers.
Small-scale landholders (N=29) are not directly associated with farming and they do not make decisions on it either on technology investments. They are normally retired farmers who own many small surfaces of arable land in the village and rent those lands to other farmers to labor them.	Small-scale landholders do not make decisions about farming but they do about their land management.
Others nominees mentioned in the survey (N=13). They were mentioned by farmers as key people they interacted with for land management decision-making.	Family nominees (N=4); Land labor service enterprise workers[1] (N=4), Unknown (N=5).
Formal organizations mentioned in the survey (N=27). The farmers mentioned such organizations regarding who influenced them in their farming decision-making.	Local cooperative (N=7), CPAEN[2] (N=2), Food enterprises (N=6), INTIA[3] (N=4), Private service(consultancy and water Company) (N=2), seed Enterprise (N=3), agrarian union (N=3).

[1] Land labor enterprises refer to small cooperatives in which farmers join for the use of agricultural machinery

[2] CPAEN - Consejo de la Producción Agraria Ecológica de Navarra, in English: Council of the Ecological Agrarian Production of Navarre.

[3] INTIA, Tecnologías e Infraestructuras Agroalimentarias. The public company attached to Navarre Government that projected the irrigation canal and advice farmers about farming techniques, new strategies etc.

Table 3. Degree of cohesion in knowledge and resource networks

	Knowledge			
	Management	**Finance**	**Technology**	**Policy**
Density	0.011	0.0067	0.00628	0.0038
Reciprocity	0.69	0.76	0.81	0.78
Centralization	0.111773	0.06563	0.03221	0.00613
Diameter	9	8	10	6
Average path length	3.82056	3.7467	4.27187	2.8218

	Resources				
	Land	**Labor**	**Money**	**Crop**	**Machinery**
Density	0.0025	0.0055	0.0021	0.001	0.00427
Reciprocity	0.46	0.47	0.07	0	0.56
Centralization	0.00023	0.00891	0.00046	0	0.003279
Diameter	2	7	3	1	5
Average path length	3.4176	4.7206	4.4412	1.72	4.3928

Density scores range from 0 (no exchange of knowledge or resources) to 1 (all the people in the network are involved in such exchanges). Reciprocity ranges from 0 (all exchanges go only in one direction) to 1 (all exchanges are reciprocal). Centralization can range from 0 (exchanges are not concentrated in one person but rather everybody is equally central) to 1 (one person is most central for exchanges). Diameter for knowledge exchange ranges from 6 (the longest minimum distance between any two individuals is 6 for policy-related knowledge flow) to 10 (the longest distance between any two individuals is 10 for technology-related knowledge flow). For resource exchange, the diameter was smaller, ranging from 1 to 7. The average distance ranges from 2.8 to 4.2 (the minimum value is approximately 3 people between any two individuals who exchange policy-related knowledge and the maximum value is around 4 people when they exchange technology-related knowledge). For resource exchange, the average path length ranges from 1.7 to 4.7.

Table 4. Descriptive statistics (mean) of degree centrality and betweenness centrality types for each of the knowledge and resources exchange networks

	Knowledge				**Resources**			
Degree	**Management**	**Finance**	**Technology**	**Policy**	**Land**	**Labor**	**Crop**	**Machinery**
Intensive farmers (11.3)	7.54	5.19	4.94	3.19	1.65	3.79	0.33	3.19
Small-scale farmers (3.23)	1.68	0.34	0.43	0.05	0.57	1.23	0.34	0.64
Small-scale landholders (3.6)	1.86	1.03	0.86	0.28	0.48	1.14	0.1	0.76
Others (2)	1.46	0.69	1.08	0.69	0.62	1	0	0.92
Organizations (6.2)	3.15	1.67	1.07	0.81	0.15	0.22	0.07	0.19
	Knowledge				**Resources**			
Betweenness	**Management**	**Finance**	**Technology**	**Policy**	**Land**	**Labor**	**Crop**	**Machinery**
Intensive farmers (819)	360	185	131	25	0.625	19.1	0	8.6
Small-scale farmers (127)	33.3	2.41	1.61	0	0	0.955	0	0.0682
Small-scale landholders (130)	36.4	5.12	2.86	0	0	0.069	0	0.0345

Others (0)	0	0	0	0	0	0	0	0
Organizations (409)	116	27	25.1	5.59	0	0	0	0

Values in brackets in the first column refer to the overall network degree (activity) and betweenness (bridge role). These values are mean values by group of farmers and stakeholders. For example, in the case of activity, scores range from 2 to 11.29 being those values the minimum and maximum levels of activity respectively.

Table 5. Expected brokerage score matrix for all knowledge exchanges aggregated by farming group

Roles	**Coordinator**	**Itinerant**	**Representative**	**Gatekeeper**	**Liaison**
Intensive farmers	0.14	0.23	1.35	1.35	0.58
Small-scale farmers	0.12	0.25	1.24	1.24	0.61
Small-scale landholders	0.05	0.32	0.84	0.84	0.78
Other farmers	0.01	0.36	0.37	0.37	1.03
Organizations	0.04	0.33	0.78	0.78	0.81

Coordinator role: the broker mediates contact between two individuals from his or her group.
Itinerant broker role: the broker mediates contact between two individuals from a single group to which he or she does not belong.
Representative role: the broker mediates an incoming contact (from an out-group member to an in-group member).
Gatekeeper role: the broker mediates an outgoing contact (from an in-group member to an out-group member).
Liaison role: the broker mediates contact between two individuals from different groups, neither of which is the group to which he or she belongs.

Coordinator scores range from 0.01 (no coordinator role of knowledge flow) to 0.14 (the group with the highest score to coordinate knowledge exchange). Itinerant scores range from 0.23 (the lowest itinerant role for knowledge exchange) to 0.36 (highest score to play an itinerant role). Representative scores range from 0.37 (lowest value to act as representative) to 1.35 (highest value to act as representative). Gatekeeper scores range from 0.37 (lowest value to behave as the gatekeeper) to 1.35 (highest value to behave as the gatekeeper). Finally, liaison scores range from 0.58 (lowest value to act as liaison) to 1.03 (highest value to act as liaison).

Table 6. Expected brokerage score matrix, by group, when lands are exchanged

	Coordinator	**Itinerant**	**Representative**	**Gatekeeper**	**Liaison**
Intensive farmers	7.03	11.59	2.91	2.91	29.59
Small-scale farmers	5.88	12.77	3.22	3.22	31.39
Small-scale landholders	2.46	16.29	3.46	3.46	39.98
Other farmers	0.43	18.42	2.11	2.11	52.37
Organizations	2.11	16.65	3.38	3.38	41.34

Coordinator scores range from 0.43 ("others" play a very low coordinator role for land exchange) to 7.03 (intensive farmers have the highest score to coordinate land exchange). Itinerant scores range from 12.77 (small-scale farmers have the lowest itinerant role for land exchange) to 18.42 ("others" have the highest score to play an itinerant role). Representative scores range from 2.11 ("others" have the lowest value to act as representatives) to 3.46 (landholders have the highest value to act as representative). Gatekeeper scores range from 2.11 ("others" have the lowest value to behave as gatekeepers) to 3.46 (landholders have the highest value to behave as gatekeepers). Finally, liaison scores range from 31.39 (small-scale farmers have the lowest value to act as liaison) to 52.37 ("others" have the highest value to act as liaison).

Table 7. Expected brokerage score matrix, by group, when labor is exchanged

	Coordinator	Itinerant	Representative	Gatekeeper	Liaison
Intensive farmers	1.56	2.57	3.32	3.32	6.55
Small-scale farmers	1.30	2.83	3.16	3.16	6.95
Small-scale landholders	0.54	3.61	2.36	2.36	8.85
Other farmers	0.10	4.08	1.15	1.15	11.59
Organizations	0.47	3.68	2.23	2.23	9.15

Coordinator scores range from 0.10 ("others" play a very low coordinator role for labor exchange) to 1.56 (intensive farmers have the highest score to coordinate labor exchange). Itinerant scores range from 2.57 (intensive farmers have the lowest itinerant role for labor exchange) to 4.08 ("others" have the highest score to play an itinerant role). Representative scores range from 1.15 ("others" have the lowest value to act as representatives) to 3.32 (intensive farmers have the highest value to act as representative). Gatekeeper scores range from 1.15 ("others" have the lowest value to behave as gatekeepers) to 3.32 (intensive farmers have the highest value to behave as gatekeepers). Finally, liaison scores range from 6.55 (intensive farmers have the lowest value to act as liaison) to 11.59 ("others" have the highest value to act as liaison).

Table 8. Expected brokerage score matrix, by group, when machinery is exchanged

	Coordinator	Itinerant	Representative	Gatekeeper	Liaison
Intensive farmers	7.03	11.59	2.91	2.91	29.59
Small-scale farmers	5.88	12.77	3.22	3.22	31.39
Small-scale landholders	2.46	16.29	3.46	3.46	39.98
Other farmers	0.43	18.42	2.11	2.11	52.37
Organizations	2.11	16.65	3.38	3.38	41.34

Coordinator scores range from 0.43 ("others" play a very low coordinator role for machinery exchange) to 7.03 (intensive farmers have the highest score to coordinate machinery exchange). Itinerant scores range from 11.59 (intensive farmers have the lowest itinerant role for machinery exchange) to 18.42 ("others" have the highest score to play an itinerant role regarding machinery flow). Representative scores range from 2.11 ("others" have the lowest value to act as representatives) to 3.38 (organizations have the highest value to act as representatives). Gatekeeper scores range from 2.11 ("others" have the lowest value to behave as gatekeepers) to 3.46 (landholders have the highest value to behave as gatekeepers). Finally, liaison scores range from 29.59 (intensive farmers have the lowest value to act as liaison) to 52.37 ("others" have the highest value to act as liaison).

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