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The Influence of Social Networks on Agricultural Technology Adoption

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Abstract

This paper applies Social Network Analysis (SNA) to the effects of professional collaboration within social networks on farmers' decision-making behavior when adopting irrigation technology. This paper addresses professional collaboration found in tenure relations, social and professional organizations. The sample consists of 195 fields farmed over a five-year period in southeast Texas by 37 farmers. The analysis suggests that participation in organizations is a key factor influencing adoption of irrigation technology. After initial implementation by central farmers, technology is transferred either through tenant or kinship relationships. Results suggest that ownership-stake is a factor as to whether a farmer participates in organizations.

Selection and/or peer-review under responsibility of Dr. Manuel Fischer

Keywords: agriculture; social networks; irrigation; technology; adoption

1. Introduction

The application of Social Network Analysis (SNA) to understand the diffusion and adoption of irrigation technology in agriculture has the potential to improve the effectiveness of water conservation programs throughout the world. With a better understanding of the social factors that influence the flow of knowledge and the adoption of new water-conservation technology in the agricultural sector, researchers and policy makers will be able to identify and reduce barriers to technology diffusion and adoption. This study contributes to ongoing efforts to promote the adoption of water-conservation technology in agriculture, which aims to reduce water usage by improving irrigation efficiency. Improving irrigation efficiency is critical given increasing water demands, limited water resources and uncertain precipitation patterns. This paper builds on the idea that social context (Feder et al., 1984; Umali, 1993) influences farmers' decisions to adopt irrigation technology. Farmers do not act unilaterally; instead they collaborate, consult and negotiate. Embedded in these interactions is a flow of knowledge, ideas and information that shapes their decision to adopt irrigation technology. This paper examines the role that professional interactions in different social settings play in farmers' technology adoption decisions, an area where there has been little recent analysis.

This paper uses SNA to analyze the social interactions that shape farmers' decision-making behavior when adopting new technology. The specific technology this paper looks at is precision leveling, which is a water-conservation technology that has been shown to reduce water use in rice fields (Agarwal et al., 1981; Anderson et

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al., 1999; Bjornlund et al., 2009; Smith et al., 2007; Ramirez et al., 2010). Its diffusion relies more heavily on second-hand, publicly disseminated information from either government-sponsored extension services or from the hands- on learning experience of neighbors and colleagues who have already implemented this technology.

Technology diffusion and adoption is important given the pervasive "policy recommendation that farmers need to be convinced to use these new and better technologies" (Doss, 2006). The underlying rationale is that to increase water savings from technology-based agricultural conservation programs, farmers—assumed to be unaware and uniformed about technology—first need information to later consider adopting technology. Identifying the constraints to technology transfer and adoption is paramount for effective water policy formulation. Better understanding adopters' profile will result in better policy-making, a pre-requisite for the judicious use of irrigation water.

The rest of the paper proceeds as follows. Section 2 describes previous research in irrigation technology adoption. Section 3 describes data, methods, and the case study located in the Lower Colorado River Basin (Texas, United States). Section 4 presents results and discussion. Section 5 gives a summary and presents the conclusions.

2. Literature Review and Theory

Most research on the adoption of agricultural technology (Slade et al., 1984) focuses on the head of household as the only decision-maker. Recent studies draw attention to the broader social setting where adoption decisions occur (Doss, 2006) by focusing on the family unit instead of the individual head of household. Aging farm population is one reason why this shift of focus from the head of household occurred. Asfaw et al. (2004) capture the effects of differing education levels within a family unit by including in their analysis the family member with the highest education level other than the head of household. Barham et al. (2004) investigates access to family labor by incorporating the age of family members—other than the head of household—involved in farm management.

Many studies investigate exposure to information in explaining farmers' adoption behavior. These studies account for formal knowledge by incorporating the number of years of education (Anderson et al., 1999; Wozniak, 1993; Bjornlund et al., 2009). Empirical evidence from these studies indicate that education is positively related to the probability of adoption; the argument put forth is that educated farmers are more likely to adopt on-farm irrigation technology because they are better equipped to select and assimilate first-hand information and to analyze the future outcomes of their investments.

The literature has also shown that, regarding the costs and benefits of irrigation technology, government sponsored information reduces the gap between farmers' perceptions and objective information. Extension agents disseminate technical information to farmers in at least four ways: travel to individual farms talking to managers, demonstrations, field days, and meetings. Contact with extension services is a common proxy for access to public information. Doss (2006) reports two quantitative measures of access to information that most studies in the field have used: number of extension visits and whether or not a farmer received any extensions.

The review of existing literature shows that farmers with large farm holdings have a higher probability of adopting agricultural technology (Bjornlund et al., 2009; Anderson et al., 1999). Farm size is a common proxy variable for income (Wozniak, 1993), given that directly gathering information on farmers' income is difficult (Anderson et al., 1999). Slade et al. (1984) theorizes that larger farm holdings, indicative of farmers with higher incomes, devote larger amounts of resources to gathering information. Greater financial resources increase farmers' opportunities to gather and access information needed to assess adopting irrigation technology. Slade (1985) and Wozniak (1993) examine the association between size of landholdings and access to financial resources. Their empirical evidence suggests that there are limited financial opportunities available for smaller farmers. Research indicates that larger farm operations have more collateral and are more likely to have easier access to credit and with lower interest rates (Wozniak, 1993).

Land ownership stake is another factor that influences whether a farmer is likely to adopt water-conservation technology. Researchers theorize that the ownership stake of a field influences the amount and type of investment a farmer is willing to make. One reason ownership influences adoption behavior is that land owners have greater opportunities to access financial resources than renters. Also, as Umali (1993) points out "renters of farmland are less likely to invest in conservation practices." From the perspective of renters, a frequently irreversible lump-sum investment to improve irrigation technology is reasonable only if the return rate falls inside the lease term.

A few studies have investigated the role that informal knowledge has in farmers' decision-making for adopting agricultural technology. Slade et al. (1985) and Smith et al. (2007) demonstrate that farmers who invest in more efficient irrigation technology are prompted by word-of-mouth testimonials. In other words, farmers "view other farmers as their main source of advice" (Slade et al., 1985). According to this view, interaction between farmers fosters adoption of agricultural technology. Most research on this topic (Slade et al., 1984; Asfaw et al., 2004; Barham et al., 2004) focuses on the family unit in the decision-making process. Building on the theoretical conception that externalities are to be found in the broader social and cultural contexts of farmers' decision making (Slade et al., 1984; Umali, 1993), further work is needed to better understand the social factors that influence the flow of knowledge that may lead to technology adoption.

This paper contributes to the literature on technology adoption decision-making by examining the role that professional collaboration plays towards farmers' technology adoption decisions, particularly in the three social settings of: family, work, and professional and social organizations. This study examines how social networks in agriculture help explain farmers' technology adoption behavior through the following hypotheses:

1) **Family relationships are a conduit for the transfer of farming knowledge which influences adoption decision making.**
   Knowledge is traditionally passed between generations (i.e. father to son), and this knowledge transfer may play in influencing the adoption of technology.
2) **Once a tenant has successfully implemented a technology, other tenants who lease from the same landowner are likely to adopt subsequently.**
   This results because tenants are indirectly interconnected through the landowner. The interests, activities and decisions of one tenant can indirectly influence other tenants through exchanges with the same landowner.
3) **Farmers access to external knowledge through numerous networks, including consultancies, professional associations, and clubs encourages the adoption of technology.**
   Trade shows and associations are institutional practices that exist for the purpose of knowledge diffusion. Antonelli (1999) points out that "[p]rofessional association[s] and industrial clubs [that] provide important opportunities for technological communication [are] basic institutions that facilitate the diffusion of relevant knowledge." Each club and association entails different forms and frequencies of human interaction and provides distinct pieces of information and knowledge. Antonelli (1999) argued that "multichannel communication systems…favor access to external knowledge," and that these pieces of information and knowledge are likely to be complementary and additive.

This paper assumes that the diffusion of precision leveling relies more on social networks than on other traditional factors, such as farm size or farmer's age, because precision leveling is a proven, mature technology. For example, as a mature technology, precision leveling is subsidized by federal and state agencies, and therefore the adoption of this technology more accessible.

3. Conceptual Framework/Research Design

3.1 Analytical Approach to Farming Networks

Technological communication takes place through an array of networks with diverse conditions in which human interaction shapes technology diffusion. Covering an array of networks improves our understanding of the structure, dynamics, and influence that different social settings have on technology diffusion. Each type of social network impacts technology diffusion differently, because relations between individuals involved with technology occur in diverse social contexts. Professional collaboration can take place in three social settings: kinship relations (family), land owner-tenant relations (work), and affiliations (social associations).

This paper examines first how professional collaboration through kinship influences farmers' technology adoption decisions. Kinship relations refer to relations between members of the same extended family involved in farming. A significant body of literature focuses on the family as a determinant of technology adoption. The present approach moves beyond the family unit to professional collaboration through tenure relations and organizations to gain a deeper understanding of the multiple types of social settings and interactions influencing agricultural technology transfer and farmers' adoption behaviors.

The second type of network deals with tenure relations between landowners and tenants. Professional collaboration based on tenure relations is another way farmers can access knowledge. Exchange of information and know-how are common in landlord-tenant relations. Although it is plausible that a single landowner could manage only one field, this one-to-one relationship is unlikely. A landowner often owns several fields, each of which could have different lease arrangements. A farmer could own, cash-rent or share-rent the land he farms. When a farmer share-rents, the farmer and the landowner share the costs and profits from crop production. On the other hand, a farmer who cash-rents bears all the financial risk involved with crop production. It is also common for a landowner with multiple landholdings to rent fields to several farmers. Because several tenants may rent land from the same owner, these tenants are interconnected, thus forming a network based on tenure relations. Hence, landowner-tenant relationships form professional collaboration networks where technology diffusion and transfer could occur. Figure 1 shows a schematic representation of landowner-tenant relations. A landowner can lease land to more than one farmer. Each of the farmers can then operate more than one field. Due to crop rotation, a particular field may not be in production in sequential years, but rather goes in and out of production**.** The hierarchal nature of field-farmer-landowner relations exemplifies how the adoption of irrigation technology in a particular field can depend on both the farmer and landowner. This diagram shows: (a) the interdependency between a farmer who rents from a landowner and (b) the potential knowledge flows from one tenant to another through the landowner. The interdependencies between farmers and landowners, evident by the nested structure of the data, may be able to explain the adoption of irrigation technology.

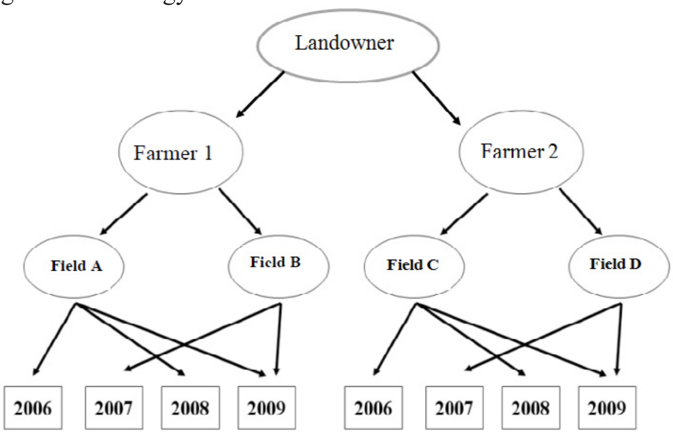

Fig. 1. Landowner-Tenant Relations. Source: Modified Graph of Nested Analytical Approach from Ramirez, A.K., Eaton, D. J. (2010) "Statistical Testing for Precision Graded Verification."

In this type of network, the landowner at the center of the network, functions as the intermediary, or mediator of knowledge flows, among tenants. To increase productivity and make technological improvements on his land, a landowner is likely to transmit technological knowledge from one tenant to another. Through the landowner, tenants are indirectly interconnected. Thus, the interests, activities and decisions of one tenant can indirectly influence other tenants through exchanges with the same landowner. One could argue that once a tenant has successfully implemented a technology, other tenants who lease from the same landowner are likely to adopt subsequently.

3.2 Case Study

This paper applies SNA to a case study in Lakeside Irrigation District, located in Texas' Colorado and Wharton Counties, as an example of how this type of analysis can be used to improve the understanding of agricultural technology adoption. Lakeside Irrigation District presents an interesting case study to apply SNA because it contains both a variety of stakeholders, and these stakeholders report that informal communication with family and peers is their main source of knowledge.

This study takes advantage of the fact that in the past three years, the author has worked in partnership with the Lower Colorado River Authority. The Lower Colorado River Authority (LCRA), a quasi-governmental agency established in 1934 by the Texas Legislature, manages the water use of the Lower Colorado River Basin. The

LCRA, controls five dams along the Lower Colorado River to serve an area of 25,900 square kilometers, providing water and electric power to 1.8 million people in 14 counties in Texas (LCRA, 2010). The LCRA also provides water to four irrigation districts one of which is Lakeside, the irrigation district chosen for this study. Irrigation water makes up 80 percent of all water withdrawals from the Lower Colorado River (Kracman, 2000). Since 2006, LCRA has invested in water conservation technology by cost-sharing with farmers to encourage them to precision-level their fields and reduce their irrigation water.

Precision-leveling is a proven agricultural technology for reducing water use in rice fields (Goel et al., 1981; Anderson et al., 1999; Bjornlund et al., 2009; Smith et al., 2007; Ramirez et al., 2010). A field is precision-leveled by GPS-controlled laser equipment that cuts the slope of the land to a specific level based on topographical and hydrological information. When a field is precision leveled, the highs and lows of the field's natural topography are flattened. By flattening the topography, water evenly distributes itself across the field, thus lowering the required flood depth and reducing the water needed to uniformly irrigate the field. Precision leveling is what Wozniak (1993) calls a mature technology. As a mature technology, its diffusion relies heavily on second-hand, publicly disseminated information from either extension services or from the hands-on learning experience of neighbors and colleagues who have already implemented the technology.

Table 1 shows that, every year, fields in production have a diversity of ownership arrangements: farmed by owner, cash-rented or share-rented. Farmers who rent (either share-rent or cash-rent) the fields they farm are common in this irrigation district. Descriptive statistics on fields operated by farmers shows that, on average, each actor included in the analysis, farms four fields, but can potentially farm up to 14 fields in a given year (see Table 2). Table 3 shows annual statistics for the irrigation district in terms of cultivated acreage, number of irrigated fields and field size. Over the course of the study Lakeside Irrigation District had on average 305 fields in production annually, totaling 39,878 acres.

Table 1. Fields Farmed by Ownership Stake

Year	Owner	Cash-rent	Share-rent
2006	16	43	64
2007	17	56	61
2008	28	51	65
2009	27	74	72
2010	25	65	59

Source: Calculated from Survey 2006-2010

Table 2. Number of Fields per Farmer

Year	Average	Maximum
2006	4	10
2007	4	14
2008	4	14
2009	5	14
2010	4	11

Source: Calculated from Survey 2006-2010

Table 3. Annual Statistics for Lakeside Irrigation District

Year	Acreage	No. Fields
2006	38,238	317
2007	35,245	267
2008	44,475	313
2009	40,275	329
2010	41,158	302

Source: Calculated from Survey 2006-2010

4. Data and Method

4.1 Description of the data.

This previous project, concerned with irrigation technology in agriculture, included the first survey of farming practices and technology in the region, which collected 5-years of data (2006-2010). The first section of the survey included farmers' demographic information such as age, education, and the number of years of farming experience. The second section included questions about farmers' rationale for adopting water-conservation technology, off-farm work, as well as farmers' main sources of knowledge. These sources of knowledge included self experience, relatives, other farmers, extension services, and school. The last section included questions regarding field characteristics, infrastructure upgrades, ownership, as well as other farming practices per fields over the course of the study. Lakeside Irrigation District's survey results are useful inputs for research into the social dimension of technological transfer and adoption.

The data collected in the survey are farmers' self-reported information. This study uses a sample set of approximately 150 fields and 26 farmers every year over a five-year period. There are two categories of data used for this analysis, relationship and attribute data. The relationship data describes the ties between farmers and the attribute data describes the characteristics of farmers in the network.

4.2 Relationship data

The analysis is done on a one-mode network, which is derived in part from a two-mode affiliation network. The relation between farmers is operationalized as a tie and is represented as undirected, binary data. If a farmer has one or more types of relationships (kinship, affiliation or owner-tenant relationships) with another farmer, then the tie has a value of 1, otherwise it has a value of 0. One reason for including the three types of relationships together is that there can be an overlap of relations in real-world circumstances. For example, there would be an overlap in the types of relationships when a father and son participate in the same association and the son rents from the father, however this is represented as a single tie in this study.

The affiliation relationships are derived from a two-mode network data but are transformed into one-mode network data, such as relating relationship in a group as a type of tie between farmers. Farmers are assumed to have affiliation relationships (tie=1) if they are involved in the same organizations. Similarly, tenants are related (tie=1) if they rent from the same farmer, and farmers are related (tie=1) if they have some form of kinship relationship.

This study categorizes the components derived from the Girvan-Newman as either landowner-tenant, kinship, or affiliation. The landowner-tenant components were identified from the survey based on the data from tenant and landowners for each field in every year for the 5 year study period. Kinship components were identified based on conversations with the farmers. The affiliation components were identified based on published information from committees, associations, and clubs.

4.3 Attribute data

The main types of attribute data in this analysis are regarding farmers' adoption behavior. The adoption behavior is operationalized in two different ways, in terms of the quantity and the timing of adoption. To capture the quantity, adoption is operationalized as a discrete variable that measures the total number of fields a farmer has precision leveled. To capture the timing, adoption is operationalized as the number of years since a farmer precision leveled the first field. A farmer is characterized as an early adopter of technology (an innovator) if more years have passed since first precision leveling a field, while a farmer is characterized as a late adopter of technology if fewer years have passed since first precision leveling a field (i.e. they recently adopted the technology). Other attribute variables describe the specific attributes with each farmer. These include attributes such as the number of leadership positions held, the number of fields, and the ownership stake.

4.4 Network description

This network consists of 26 nodes $N=\{n_1,\dots,n_{26}\}$ where each node n_i represents a farmer. There are several attributes tied to each node, including ownership stake, affiliations, technology adoption, number of fields, and years since first field was precision leveled. Ownership stake $O=\{o_L,o_{SR},o_{CR}\}$ refers to whether the farmer is the landowner (o_L), share-renter (o_{SR}), or cash-renter (o_{CR}). There are 15 affiliations considered in this analysis $A=\{a_1,\dots,a_{15}\}$, which include 6 government-sponsored organizations, 2 civic clubs, and 7 professional organizations. The number of fields precision leveled $PL=\{pl_1,\dots,pl_j\}$ is the key attribute used to quantify the level of technology adoption, and the total number of fields for a farmer $F=\{f1,\dots,fk\}$ provides a comparison with which to compare PL. A continuous variable was chosen to represent technology adoption PL, because it provides a more meaningful variation than a dichotomous variable (Umali 1993). The years since farmer N first implemented the precision leveling technology $T=\{>6,5,\dots,1\}$, used as an attribute, operationalizes the time since implementation of the technology to account for the dynamic nature of technology adoption.

In this binary matrix, edges within this network are divided in to three categories $E=\{e_k,e_w,e_a\}$, kinship, work, and affiliation. Kinship ties (e_k) result from a common ancestry, work ties (e_w) result from landowner-tenant relationships, and affiliation ties (e_a) results from membership within the same professional organizations and social clubs.

This paper discusses conventional network measures such as degree centrality and density to characterize actors and the entire network. Degree centrality is calculated in Equation 1 as:

$$C_D(i) = \sum_{j=1}^{n} x_{ij} = \sum_{i=1}^{n} x_{ji} \qquad (1)$$

where x_{ij} is "the value of the tie from actor i to actor j (the value being either 0 or 1)", and n is "the number of nodes in the network (Prell, 2012)." The density, as defined by Wasserman and Faust (1994), measures the "proportion of ties that are present" in "a dichotomous relation." The density of the network is calculated as

$$d = \frac{L}{n(n-1)/2} \qquad (2)$$

where L is the "actual number of lines present in the network," and n is "the number of nodes present in the network (Prell, 2012)." Due to co-membership in overlapping groups, the Girvan-Newman algorithm was used to identify sub-groups within the network. The maximum range of cohesive groups used was 12. This analysis explores the influence of these sub-groups on knowledge flow and technology diffusion.

5. Results and Discussion

The flow of knowledge is the central conduit by which social networks influence the adoption of new technology, a flow of knowledge embedded within the interactions between farmers. However, the type of knowledge changes based on which sub-group a farmer belongs to, as each sub-group accesses a different pool of knowledge.

Figure 2 represents the network of farmers in Lakeside Irrigation District using Girvan-Newman Components. This method eliminates the weaker linkages in a network in order to clearly see the stronger linkages that form cohesive communities. In this diagram, each circle represents a farmer and the connecting arrows show linkages between the different farmers. These linkages between farmers indicate any of the three types of relationships:

family, work, or affiliation. Figure 2 shows 12 components in the farming network; these sub-groups are represented by group number.

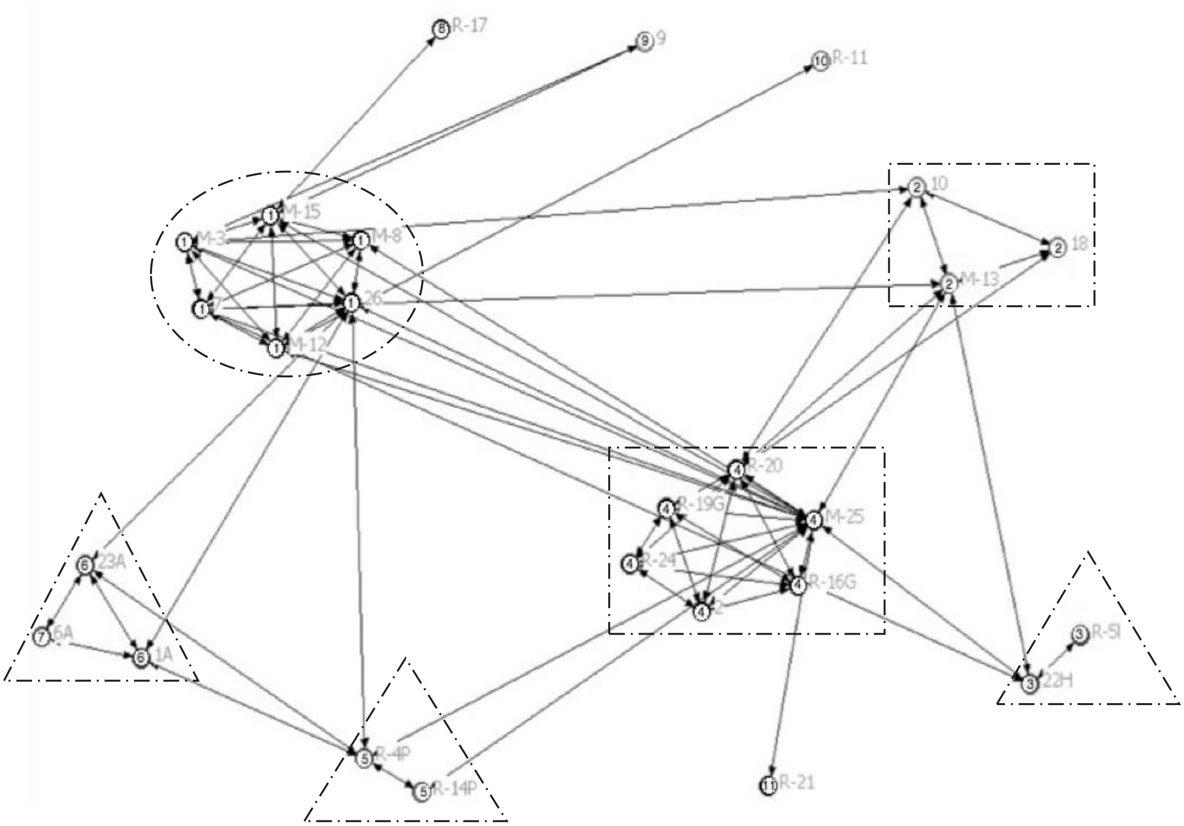

Fig. 2. Girvan-Newman Components of Network

The diagram shows two large sub-groups, four minor groupings (dyads and triads) and several isolates. These subgroups within the farming network can be explained in terms of the following relationships: (a) kinship (b) tenure and (c) affiliation (see Figure 2). Kinship between brothers and different generations of farmers within an extended family form dyads and triads in the farming network (group numbers 3, 5, and 6). Tenure relationships, which appear in the diagram below as a large cluster and a triad, are cohesive clusters in the network formed by farmers who rent fields from the same landowner (group numbers 2 and 4). The other large cluster represents affiliation, by which the author means farmer 'leaders' who are members and representatives at civic, local, regional and state organizations (group number 1).

Knowledge among farmers comes from different social settings. Each of these sub-groups access different pools of knowledge and this knowledge is transferred between subgroups by farmers who are linked with more than one sub-group.

Node M-25 (see Figure 2) is the central actor in the farming network and he exemplifies this knowledge transfer. Farmer M-25 is a landowner who participates in organizations. Through his participation, he accesses knowledge on irrigation technology that he can later transmit to his tenants, some of which may subsequently adopt this technology.

5.1 Centrality

Before describing the centrality of actors, Table 4 provides descriptive information about the cohesion of the farming network, which shows that 20 percent of the potential links between farmers that could exit in the farming network are actually present. The longest geodesic distance is 5 and the average path length is 2.23.

Table 4. Cohesion Measures for Farming Network

Measure	
Density	0.20
Diameter	5
Average length path	2.23

Source: Calculated from Survey 2006-2010

Managers or landowners, who do not farm their own land but instead rent their land, play a central role in the network. These farm managers can serve as major information channels, given the number of landowner-tenant relationships they have. The number of landowner-tenant relationships results in their high degree of centrality within the farming network. These managers also have a high betweenness centrality as they are intermediaries between the farmers who they manage or rent to.

Farmers' participation and leadership in clubs, committees and other organizations can influence knowledge diffusion. The participation of farmers who are managers ranges from council men, president of civic organizations, to representatives at local, state or regional government-led committees. The high between centrality score accurately reflects their role as leaders within the farmer network.

The network mapping in Figure 3 shows Freeman's Degree of Centrality. In Figure 2 each circle is a farmer, the circle size indicates the number of affiliations while the color black represents farm mangers and the color gray represents farmers who cash-rent (white=other ownership status). The degree of centrality is useful to understand the underlying structure of the network by quantifying the importance of farmers as communication channels for the diffusion of technology. Farmers with higher degrees of centrality are likely to be major communication channels. The upper-right corner of this image indicates the prevalence of one farm manager with the highest degree of centrality. A grouping of farm mangers, with the second highest range degree of centrality, appears at the center of the image above. In the left, the lowest degree of centrality can be found among farmers who cash-rent (colored gray) and other farmers (colored white) who have diverse tenure portfolio. A diverse tenure portfolio consists of a variety of landowner-tenant arrangements (cash-rent and share-rent) and a farmer may or may not own some land. As a result of the strikingly dissimilar pattern among mangers and cash-renters, the subsequent analyses in this paper will be done in terms of these two types of farmers

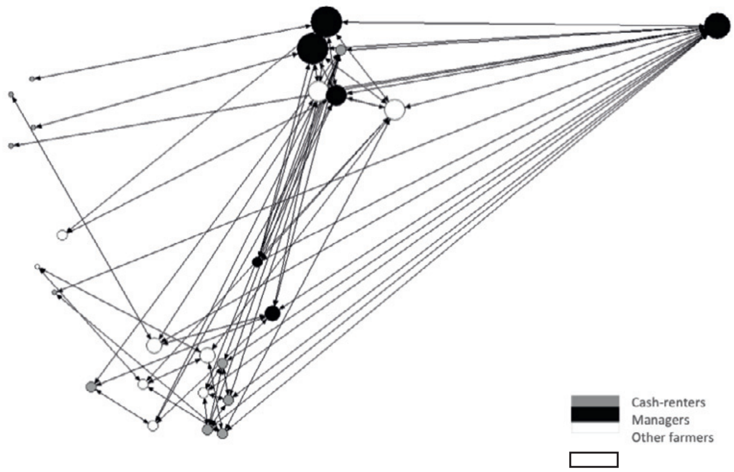

Fig. 3. Degree of Centrality

5.2 Managers

Figures 4 and 5 present the same farming network in terms of the Girvan-Newman subgroups, but use the sizes and colors to represent different attributes of the farmers. In this diagram each circle represents a farmer. The larger the circle, the more precision-leveled fields a farmer has. In Figure 3, the black color indicates the farmer is a manager (other farmers=white) while in Figure 5, the dark rims around spotted circles shows the farmer is involved in two or more organizations (1 or 0 affiliations=white). The dashed boxes represent the components characterized as landowner-tenant relationships and the dashed circles represent the components characterized by affiliation relationships. These figures show that managers involved with organizations are likely to have a large number of precision-leveled fields. Results suggest an association between being a manager and being involved with organizations.

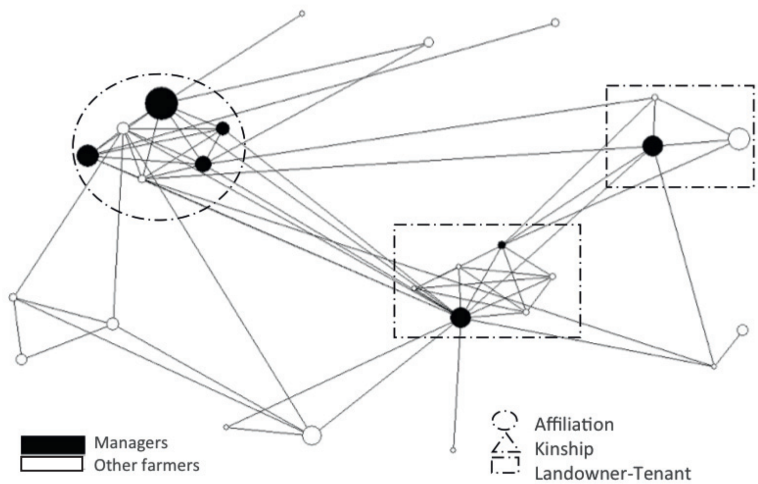

Fig. 4. Managers mapped on the Girvan-Newman Components of Network

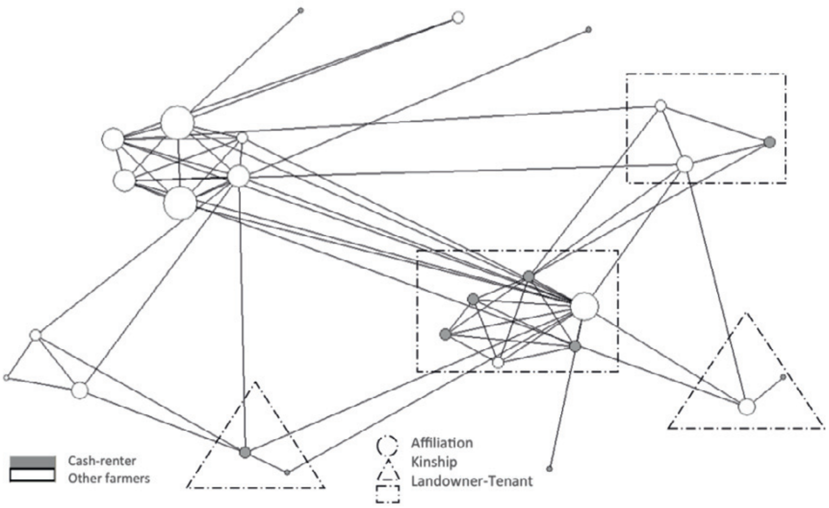

Fig. 5. Farmers with multiple affiliations mapped on the Girvan-Newman Components of Network

5.3 Cash-renters

In contrast to managers, cash-renters may not have the time required to participate in organizations, because active membership and leadership in organizations requires dedicated time away from day-to-day farm operations. For a farmer who cash-rents a field, the effect of costs and profit are tangible and immediate, and therefore time constraints may be a decisive factor that limits their participation in professional organizations and clubs. Because farmers who cash-rent bear all the financial risk involved with crop production, they are likely to spend more time and attention on their crop production than would landowners or farmers who share-rent. This is consistent with Ramirez et al.'s (2010) finding that farmers in Lakeside who cash-rent use 0.20 acre-feet less irrigation water per acre of rice farmed than do farmers who share-rent or farm their own land. The underlying rationale may be that farmers who rent pay closer attention to their water use as part of their overall crop production.

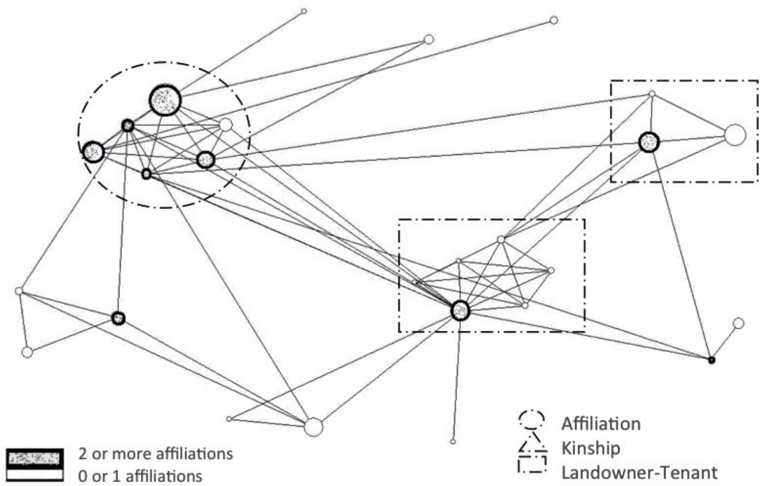

Fig. 6. Number of Affiliations mapped on Girvan-Newman Components of Network

Figure 6 presents the same Girvan-Newman components of the farming network, but uses sizes and colors to represent different attributes of the farmers. In this diagram, each circle represents a farmer. The larger the circle, the greater number of affiliations a farmer has to organizations and clubs. The gray color represents farmers who only cash-rent the land they farm while the white color represents everyone else. This figure shows that there is an association between renting land for cash and lack of affiliation with organizations and clubs.

Results suggest that farmers who cash-rent have few or no precision leveled fields, because they miss out on information and knowledge that can be gained from organizational affiliations. Cash-renters can access knowledge through three sources: the landowner, other farmers who rent from the same landowner, and through kinship relations. In landowner-tenant relations, the cohesion between tenants comes from a common landowner.

5.4 Kinship

The kinship relations identified as cohesive 'subgroups' by the Girvan-Newman analysis are sibling relations, father-son relations and combinations of siblingship and descendence leading to kinship chains. Results suggest similar patterns of technology adoption and affiliation among kinship. For example, if a farmer precision levels few or no fields, his kin will display similar trends.

5.5 Adoption of Precision Leveling

Figure 6 presents the same farming network organized from upper-right to lower-left in terms of the number of fields a farmer has precision leveled. Each circle represents a farmer while the size of the circle represents the number of affiliations a farmer has. The upper-right and lower-left corner of Figure 6 shows farmers with the most and fewest precision leveled fields respectively. Black color indicates mangers; gray represents farmers who cash-rent and white represent all other farmers.

The mapping in Figure 7 shows that, in Lakeside, mangers have precision-leveled the most fields. They have also the largest number of affiliations, as indicated by the circle size. A significant number of cash-renters (gray circles) have both fewer precision leveled fields and fewer affiliations. Results suggest that collaboration through organizations plays an important role in the adoption of precision leveling. Although any farmer is free to join organizations and tap into diverse knowledge pools, participation in organizations requires a commitment of time that most who cash-rent may not have available. Managers, who have more resources to participate than renters, can access more knowledge through their affiliation networks. Well-connected managers access a wider range of local and external networks that provide them with exposure to new knowledge.

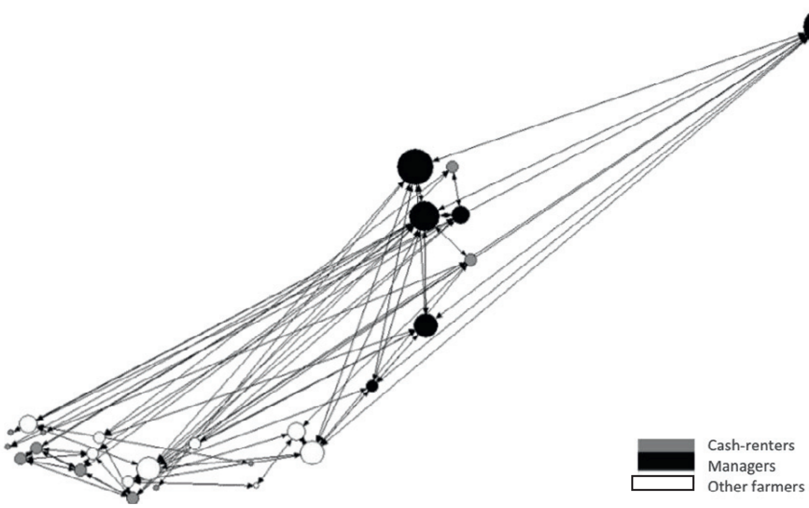

Fig. 7. Number of Precision Leveled Fields by Farmer Profile

Another aspect to consider in this analysis is the time at which the agricultural technology was adopted by individual farmers. Wozniak (1993) dissected technology adoption into two categories, early and late adopters, allowing for different farmer profiles in distinct phases of the adoption process. The early adopters are the 'innovators' of the farming community, who bring new ideas to the network, whereas the late adopters are the 'imitators' who adopt the technology after observing others successfully use the technology (Umali 1993)

Figures 8 and 9 depict the mapping of the farming network in terms of farmers' degree of centrality. Circles represent farmers, and colors represent ownership stake of the farmers (black=mangers; gray=cash-renters and white=other farmers). In Figure 8 and 9, circle sizes represent different attributes of the farmers. In Figure 8 the size of circle represents the number fields a farmer has precision leveled. The farmer in the top right has the highest degree of centrality, while the farmer in the bottom right has the lowest degree of centrality. In Figure 9, the circle size indicates the years since precision leveling. The larger the circle, the more years have elapsed since a farmer precision-leveled his first field. Similar to Figure 8, the top right has the highest degree of centrality and the bottom left has the lowest degree of centrality.

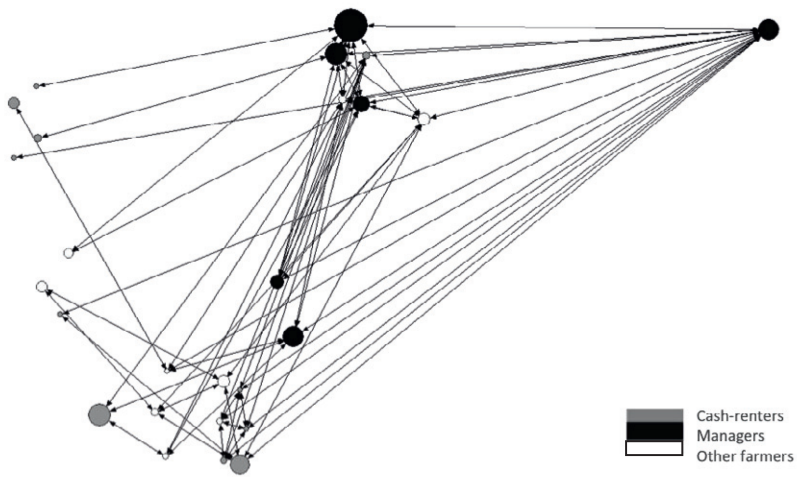

Fig. 8. Number of Precision Leveled Fields mapped on Freeman Degree of Centrality

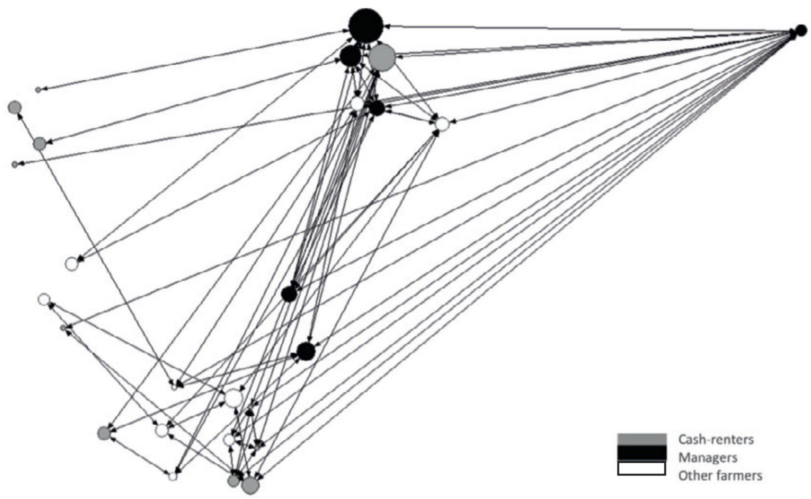

Fig. 9. Years since Precision Leveling mapped on Freeman Degree of Centrality

Results indicate that managers are early adopters of technology as they have been precision leveling fields for at least a decade, approximately five years before other farmers in the irrigation district. In Lakeside Irrigation District, a five-year time period differentiates early and late adopters. Managers, the early adopters of precision-leveling, actively participate in leadership roles in regional and state government-led committees. These results are consistent with Wozniak's (1993) empirical evidence that suggests that these early adopters depend on first-hand, timely and relevant information in their decision-making. Results also suggest that cash-renters are late adopters or imitators. Managers who are innovators depend more on information from outside their community (exogenous sources) versus cash-renters who, as imitators, depend for the most part on information insider their community (endogenous sources). Information can be characterized as endogenous (internal) or exogenous (external) in relation to the irrigation district's learning networks.

Renters are likely to be connected to a strong actor (landowner) and to several weaker actors (other renters). This tenure-based subgroup is endogenous to the farmers' learning networks and does not favor access to new knowledge. However, the diffusion of technology occurs through the innovator-imitator relationship. While for innovators, first-hand information from affiliation to state and regional committees is critical in their decision-making, learning from the experience of neighbors is what bolsters imitators' decision to adopt.

6. Conclusions

This paper used social network analysis (SNA) to understand the diffusion and adoption of water conservation technology within the farming community. The Girvan-Newman algorithm was used to identify subgroups in the farming networks and the results from this algorithm illustrate how farmers' adoption behavior may be influenced by knowledge transfers in their day-to-day interactions within their sub-groups. This analysis by sub-group contributes to the irrigation technology adoption literature because little work has been done on examining how farmers' profiles and immediate context influence their adoption behavior. Classic determinants of adoption (age, education and landholding size), while valuable, do not explain the influence of knowledge flows on technology adoption. This study suggests that technology adoption takes on a two-tiered progression, beginning with early adopters who receive information from external organizations. After initial implementation by farmers involved with these organizations, the technology is then transferred either through landowner-tenant or kinship relationships. The key contribution from this analysis is that opportunities to tap into knowledge pools are not equally accessible to all farmers. Ownership-stake appears to be an important factor as to whether a farmer has dedicated time to participate in organizations and clubs. The best way to increase the adoption of irrigation technology may be to create more opportunities for renters, in particular cash-renters, to be exposed to new knowledge.

Peers (kinship and other farmers) are main sources of farmers' knowledge, based upon a survey question asking about sources of information (Ramirez et al., 2010). Trust among farmers may be one reason why word-of-mouth testimonials, advice and other types of knowledge from fellow farmers play a major role in farmers' adoption behavior, and an outsider' top-down communication, such as extension services, may lack this degree of trust. The results suggest that participation in organizations and clubs may be a key factor influencing farmers' adopting irrigation technology. Organizational affiliation appears to depend on the type of ownership stake of a farmer, and consequently, on having the time required to participate. Managers are central actors in the farming network because they dedicate time to participate actively in organizations and have landowner-tenant linkages with renters. Cash-renters are more likely to form ties with one another through their landowner and with their landowner. Results suggest that once a tenant has successfully implemented precision leveling, other tenants who lease from the same landowner are more likely to adopt. Knowledge acquired through landlord-tenant relations is characteristic of late adopters. Given the association between affiliation and technology adoption, subsidies and cost-share programs in water-conservation technology should be paired with investments on smart diffusion strategies. The key to smart diffusion strategies may be to capitalize on existing communication channels in the social networks, as identified by SNA analysis.

One effective investment in diffusion and adoption may be government-sponsored events led by farmers at existing organizations and clubs. In these events, farmers' participate both as recipients and generators of information and knowledge. Cash-renters, who are peripheral farmers, would benefit from having managers as facilitators and presenters. Managers, with resources to participate and lead organizations, are natural conduits for knowledge transfer. Using the managers' leadership abilities not only strengthens local capacities but also provides a conduit for cash-renters to access new knowledge. By opening up the access to new knowledge to a larger audience, farmer-led events accelerate the adoption of irrigation technology such as precision leveling and other water-conservation technology. Accelerating adoption of water-conservation technology would lead to a reduction in water usage and ultimately improve water availability. This is one example of how using SNA analysis could inform policy makers and consequently help them adjust the deployment of programs and resources to take advantage of knowledge transfer within social networks.

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