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Social network effects on the adoption of agroforestry species: Preliminary results of a study on differences on adoption patterns in Southern Ecuador

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Abstract

A case study in South Ecuador serves as an example to understand the dynamics of adoption of agroforestry species. Qualitative research shows that there are potential differences in adoption between two ethnic groups. The adoption rate of Saraguro communal leaders may be an indicator of lower contagion than Mestizo-colonos. Thus, we propose a heterogeneous diffusion model that addresses network exposure effects and a generalized blockmodel for relational data analysis. We hypothesize that Mestizo-colonos have higher adoption rate than Saraguros. The Saraguro indigenous group may have lower access to the information necessary for the adoption of the innovation than Mestizo-Colonos.

Keywords: Social network analysis; adoption of sustainable innovations; Southern Ecuador ethnic-groups

1. Introduction

Southern Ecuador has witnessed rapid socio-economic development in recent years. Mining, tourism, and agriculture have expanded and lead to large-scale ecological changes in this global 'hotspot' of biological diversity (Levin & Reenberg, 2002; Myers, Mittermeier, Da Fonseca, & Kent, 2000). Illegal timber extraction and the conversion of partly protected forests to pastures pose ongoing challenges to the regional human-environment relationship (Gerique & Pohle, 2006). To reduce biodiversity loss and other unwarranted consequences of deforestation, the Podocarpus National Park and the surrounding Podocarpus-El Condor UNESCO Biosphere Reserve were established at the border of the Loja and Zamora-Chinchipe provinces. The region is not only biologically, but also ethnically diverse with at least three ethnic groups living in the area. Two are indigenous. Since several years, ecological as well as socio-economic conditions for the conservation of biodiversity and for sustainable land use options in the area are investigated by an interdisciplinary research group funded by the German Science Foundation (research groups 413 and 816; www.tropicalmountainforest.org). One of the options to

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reduce the stress on biological diversity and natural resources is the adoption of agroforestry practices. Basically, this means little more than that trees are incorporated in agriculturally productive landscape (see Section 3.3). Several agroforestry systems have been shown to harbour a substantial part of the biological diversity of the original ecosystems while providing improved sustenance for the local population (Price, 1995; Steffan-Dewenter et al., 2007).

From the perspective of a local farmer practicing an exclusively pasture-based form of diary and cattle production, the inclusion of trees represents an innovation. Innovation is defined as *"Ideas or practices that are perceived as new, applied in the productive system and spread"* (cf. Rogers et al., 2005). Innovation theory suggests that the diffusion of an innovation is strongly associated with social network effects (Rogers, 1995; Valente, 1999). The adoption of agroforestry tree species in our southern Ecuador research area offers an opportunity to study ethnicity and socio-cultural effects on agricultural adoption patterns. This topic is pressing because the indigenous populations in many regions worldwide are particularly susceptible to environmental or social changes, e.g., because they command less financial capital or have more narrowly defined natural resource-dependent livelihood options (Schneider et al., 2007).

In this paper we analyse the results of a preliminary qualitative study on ethnic, socio-cultural and socio-structural factors that potentially influence the adoption of smallholder agroforestry options in the Podocarpus-El Condor region. In the project region two ethnic groups can be found that practice pasture-based agriculture, the indigenous Saraguros - a Quechua-speaking group of highland dwellers -, and Spanish-speaking Mestizo-colonos representing the non-indigenous majority population in Ecuador. From previous research it is known that Saraguros and Mestizo-Colonos differ in their agricultural resource use. Specifically, it was claimed that the Saraguros tend to have more trees on their farms (Pohle and Gerique in Beck et al., 2008). But does the adoption of agroforestry tree species in fact differ between Saraguros and Mestizo-colonos? If so, can these differences be traced back to differences in the social structure of the communities with respect to communication patterns about agricultural innovations? We propose to use social network analysis tools to answer these questions.

The paper is structured as follows. First it has a section that describes the theoretical and conceptual background of the diffusion of innovations. The a section that describes the sample and research area, and presents our empirical results follows. The last section is dedicated to the proposed models for a further quantitative phase.

2. Background: The diffusion of innovations

2.1. Adoption and diffusion of innovation studies: Brief overview

In 1943 a pioneering study of Ryan and Gross demonstrated that not only economic factors but also social factors influence technology adoption (Ryan and Gross 1943; Valente and Rogers, 1995). One form of incorporating such social factors is based on the analysis of learning from others (Acemoglu et al., 2008; Besley & Case, 1993; Conley & Udry, 2001, 2005; Jackson, 2008; Stoneman, 1981). This is taken one step further in explicit network perspectives on innovation. Within such networks social processes occur that influence *"how individuals form opinions and eventually adopt or not adopt an innovation"*, a concept called *contagion* (Valente, 1999).

There are different models that address the diffusion of innovations, such as threshold models of collective behaviour (Delre et al., 2007; Granovetter, 1986; Valente, 1996), which are important since the adoption rate and the adoption threshold depend on the network structure (Jackson & Yariv, 2005). Other models, like deterministic diffusion models, perform a cumulative analysis of adopters over time (Rogers, 1995; Valente & Rogers, 1995). Due to some disadvantages diffusion models have been translated into event history. Conceptually, some variables such as individuals' intrinsic characteristics, spatial position, and time decay influence are incorporated (Greve et al., 1995; Myers, 2000; Strang & Tuma, 1993). For this reason the latter models are of interest to us to explain the adoption of an innovation in different periods of time.

There are also some theories that are important to explain the diffusion process. One important approach within social network theory that tries to explain why some individuals are capable to innovate and change more quickly than others is Strength of Weak Ties (SWT) theory (Granovetter, 1973, 1983). Granovetter`s important contribution is a classification of connections in a social network based on the degree to which they convey information. Another remarkable approach, known as Innovation Theory, was developed by Everett Rogers (1995). Developed in the early 60's, it explores how new ideas are incorporated into a culture. More recently, Rogers et al. (2005) argued that in heterogeneous groups connected by common aims an innovator may guide, to a certain extent, the emergence of innovation adoption.

2.2. Network analysis and the diffusion of innovations

How can network analysis help us understand the spread of the adoption of agroforestry species in southern Ecuador? Traditionally, in the region cattle ranging and timber extraction have been non-integrated activities. Nonetheless, in this context agroforestry integrates the concept of planting tree species within the farms exclusively used for cattle ranching. Thus, for the local farmers this represents an innovation as it is perceived as a new practice in the productive system. Importantly, the diffusion process of the adoption of these species flows through social networks. Farmers interact with other farmers and disseminate their ideas about whether to plant these trees species or not. Thus, we can determine who influences whom. Theoretically, the people with whom we interact may influence our own ideas and decisions since the spread of ideas flows through social interaction networks.

Interestingly, in different populations the social network can have different characteristics that make the individual have more access to information or even become totally excluded (Valente & Davis, 1999). Here the authors want to underscore the advantage of network analysis in determining whether one ethnic group is more related to and receives more benefits from the adoption of agroforestry species than the other ethnic group. Thus, a better understanding of a diffusion process is possible by understanding the spread of ideas and opinions through social networks. Individuals are exposed to the innovation through their contact with others in the social network.

2.3. Network concepts

In this section we provide the necessary conceptual background for the empirical analyses. Formally, a network consists of a set of nodes (also points or vertices) with connections between them called edges (or links). In social networks, the nodes represent social actors, often individuals. Thus, the social network is represented by the graph **G**, with **N** nodes and **E** edges, **G={N,E}**. Formally speaking, network structure is the pattern of edges between such nodes. The edges can either be undirected or directed. In directed networks each link has an origin (tail) and a destination (head) (Brandes & Elebach, 2005). The most fundamental network configurations in directed networks between two (*dyad*) or three nodes (*triad*). An undirected dyad *i, j* is usually symbolized by {i, j}, and by (i, j) for a directed dyad. The case of dyad mutuality may represent a restricted exchange of resources or information (Koehly & Pattison in Carrington, Scott & Wasserman, 2000). The three-cycle may represent a more *generalized exchange* in substructures larger than a dyad, where no prompt reciprocity is necessarily required.

Centrality of a node is a very important concept of network analysis (cf. Freemans, 1977). *Degree* is the simplest centrality measure of a node *i* that is specified as *d(i)* of *i* if the relation in the graph is *undirected* (Kosschützki et al., in Brandes & Elebach, 2005). *Out-degree* centrality $d(i) = d+(i)$ is the number of edges that have *i* as origin. *In-degree centrality* $d(i) = d-(i)$ is the number of edges that have *i* as destination. A second, more complex measure of centrality is *betweenness* of a node (Freeman, 1977). If we look at two nodes that need not be directly linked, there may be one or more paths between them. The shortest path is called *geodesics*. Thus, one node is considered to be central at the degree in which the node is found between other nodes on their shortest paths. A node has a high betweenness if a high fraction of all geodesics of the network pass through it. Thus, *b(i)* is defined as the fraction of the shortest paths between all pairs of nodes that pass through node *i* (Rozenfeld et al., 2008). With $\delta_{ju}(i)$ the number of shortest paths passing through *i*, we obtain formally, $b(i) = \sum_{j \neq u \neq i} \delta_{ju}(i) / \delta_{ju}$. *(1)*

It has been observed that network actors with high centrality measurements also tend to be connected with other highly connected actors. This characteristic is known as assortativity (Rozenfeld et al., 2008). A third centrality measure is *max-flow-betweenness vitality* **CF(i)** (Koschützki et al., in Brandes & Erlebach, 2005), which determines the maximum flow between *u* and *j* through *i*. Flow is the amount of information that is conveyed. In our case the flow will depend on the frequency of the contact between actors. The objective of max-flow-betweenness vitality is to measure to what extent the maximum flow between two actors depends on a third actor *i*. This measure is highly useful since it takes into account all independent paths along which information can flow, and not just the shortest paths (Freeman, Bogartti & White, 1991).

If $u, j \in N$ and $i \neq j$, $i \neq u$; thus: $C_F(i) = \sum_{u, j \in N, fju > 0} f_{ju}(i) / f_{ju}$ *(2)*

and $f_{ju}(i) = f_{ju} - f_{ju}'$. $f_{ju}'(i)$ is the maximal j - u flow in $G \setminus i$ (without i), $f_{ju}(i)$ is the amount of flow which must pass through actor i (Koschützki et al. in Brandes & Erlebach, 2005). In other words, if the flow going through i is divided between all pairs of actors where i is neither a source nor a receiver, we can estimate the proportion of the flow that depends on i. This produces a measurement between 0 and 1 (Freeman, Bogartti & White, 1991). In our case, if Mestizo-colonos concentrate a significant part of the information flow that may lead to an unbalanced share of the information between ethnic groups.

Structural Equivalence is a network measure that refers to nodes with a structurally similar position in the network which do not necessarily have a direct link between them (Valente, 1999). Two nodes are said to be structurally equivalent if they have the same relation to all other nodes. Therefore, two structurally equivalent nodes are exactly interchangeable (Hanneman & Riddle, 2005). Regular Equivalence also refers to two nodes which have an identical relative position with respect other nodes. In this case, however, the other nodes need not be identical (Hanneman & Riddle, 2005).

3. Semi-structured survey

3.1. Sample description and hypotheses

As mentioned in Section 2.2 the adoption of agroforestry species is perceived as a new practice for the households in the region. The transition to an integrated system like agroforestry implies a change in the local productive structure. The adoption process that stays behind is complex and dynamic. Thus, as was explained in the last sections, social network analysis is an important methodological tool to understand the diffusion of innovation process. In the following we explain why we selected this research region and what the importance of planting agroforestry species in this context.

A survey of 135 local farming households in the region shows that 35% of the households get a survival subsidy (=30 USD/month; *Bono De Desarollo Humano*), and that 17% work as farm hands. The main products are meat, curd, and a traditional maize-bean-mix. Pastures are manually weeded and not fertilized. Their main interest in extension services is in cattle reproduction, pasture/resource conservation management and new crops (Maza et al., 2010). Southern Ecuador is highly heterogeneous in terms of culture and traditions. Thus, the local farming households do not form a uniform group (Pohle & Reinhardt, 2004). While the indigenous Saraguros are a Quechua-speaking group of Inca-descendants, the Mestizo-colonos represent the non-indigenous rural population of Ecuador. In spite of several differences, the members of both groups are predominantly smallholder farmers with a livelihood based on dairy and meat production.

Mestizo-colono communities are more numerous in the project region than Saraguro communities. Most Mestizo settlers came to the region as result of the agrarian reform during the 1960s. Their main income-generating activity is cattle ranching. Pohle & Gerique in Beck et al. (2008) report that, in the areas where the Saraguros settle, the landscape displays more trees, while the areas settled by Mestizo-colonos are at times completely devoid of trees. In comparison to Saraguros, Mestizo-colonos have a reduced knowledge of local flora, but have a more comprehensive knowledge of crop plants and pasture varieties (Pohle & Gerique in Beck et al., 2008; Gerique & Pohle, 2006). Production function analysis suggests that, on average, Mestizo households generate higher per hectare income from their farms than Saraguro household (Maza et al., 2010).

The Saraguros have been practicing cattle ranching since the early nineteenth century (Pohle & Reinhardt, 2004). Their traditional system of arable agriculture includes maize, beans, potatoes, other tubers and fruit. Their home gardens can include trees in a multi-strata arrangement, and have been hypothesized to be a sustainable, near optimal form of rural land use (Pohle & Reinhardt, 2004). Nonetheless, cattle ranching has become the most important income-generating activity for the Saraguros of the project area. Gerique & Pohle (2006) suggest that the higher prevalence of trees in the case of the Saraguros may be an expression of a more sustainable form of agriculture based on traditional knowledge. Thus we hypothesize that

(i) the adoption of tree planting is higher in Saragoro households

(ii) inter- and intra-ethnic differences in agroforestry options in adoption can be explained by differences in social network structure.

3.2. Research region conditions

The biological diversity of Southern Ecuador is extremely high even by global standards, probably because of the extreme topographic heterogeneity of the region (Homeier, 2008). The topography is generally very steep and rugged, and also the soils are very heterogeneous. More than 280 tree species have been identified at the northern tip of the Podocarpus National Park alone (Homeier, 2008). Tropical rain forest is widespread at up to ~1800 m a.s.l. Tropical evergreen cloud forests are found at higher elevations (Rollenbeck, 2006). Eight out of 15 main vegetation types identified in Ecuador are present (Beck et al. chapter 36 in Beck et al., 2008).

Some of the principal problems in the region have been deforestation and illegal timber extraction. In the survey by Maza et al. (2010), 10 of 135 respondents admitted openly to have cut forest for pastures, partly inside the local forest reserve. Deforestation affects the ecological integrity of the adjacent Podocarpus National Park (146,280 hectares), southern Ecuador's first conservation area (Pohle & Reinhardt, 2004). The communities of the region are interconnected by a road and path system of differing quality. The bigger communities are connected by principal roads suitable for motor traffic. Smaller communities are connected often only by secondary roads accessible at maximum by four-wheel drive cars, or even by small paths (see Figure 1). The road from Loja to Zamora is mostly inhabited by Mestizo-colonos. The Saraguros settle north of the road betwen Loja and Zamora in communities such as *El Tibio* and *El Cristal* (Figure 1). Communities as *Imbana* and *El Tibio* have been recently well connected by secondary roads.

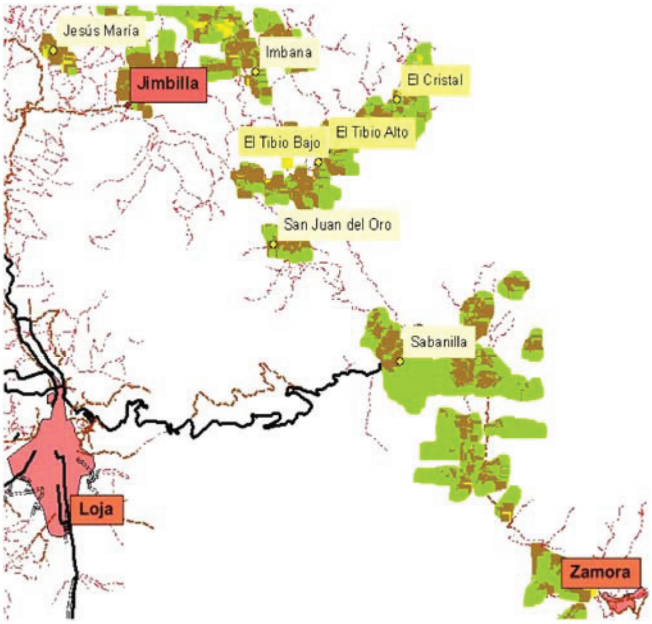

Figure 1. Spatial representation of the research area - includes main and secondary roads – thicker lines depict more important roads

3.3. Agroforestry options

Of 135 farmers interviewed in the research region, 42% have planted trees (Maza et al., 2010). The tree species planted by more than 5% of the sample are shown in Table 1. The fact that almost half of the farmers have planted at least one tree species shows that tree planting is widespread among local farmers. *Pinus patula* is a fast growing exotic pine used for timber. *Alnus acuminata* is a fast growing native tree used for timer and fuel wood that has the additional potential to improve soil conditions, since Alnus is a nitrogen-fixing species. Of all trees, farmers rate this species best on average (Maza et al., 2010). *Eucapyptus globulus* is a fast-growing exotic specie used for timber and fuel wood. *Cupressus macrocarpa* is a rather slow-growing native tree with high timber value. Moreover, several fruit tree species are grown in larger quantities, totalling more than 5%. In addition to timber production, the non-fruit trees are often used as live fences. From a conservation point of view, it is hoped that local farmers reduce illegal timber extraction and at the same time increase household income by planting trees on their farms. In the ideal case, the landscape recovers some of its original biological diversity, farming household incomes are increased, soil-erosion is avoided, and the need for further deforestation is alleviated. Furthermore, if local tree species are planted, agroforestry can be a complementary means to protect forest genetic resources (Günter, Stimm & Weber, 2004).

Table 1. Tree and fruit tree species adopted by farmers in the research region

Scientific Name	Common Name	Main Use	Origin
Pinus patula	Pino	Timber-Life fence	Exotic
Alnus acuminata	Aliso rojo	Timber	Native
Eucalyptus globulus	Eucalipto	Timber-Life fence	Exotic
Cupressus macrocarpa	Cipré	Timber-Life fence	Exotic
Juglans neotropica	Nogal	Timber	Native
Tabebuia chrysantha	Guayacán	Timber-Life fence	Native
Prunus persica	Durazno	Fruit tree	Exotic
Erythrina edulis	Guato	Fruit specie-life fences	Native
Nectandra laurel	Laurel	Timber-Life fence	Native
Inga spp.	Guaba machetona	Fruit tree	Native
Ficus spp.	Higuerón	Timber-Life fence	Native
Brugmansia candida	Guando	Medicinal plant in home garden	Exotic
Malus domestica	Manzana	Fruit tree	Exotic
Persea americana	Aguacate	Fruit tree	Native
Prunus serotina	Capulí	Fruit tree (Home Garden)	Exotic
Citrus sinensis	Naranjo	Fruit tree	Exotic
Cedrela montana	Cedro rojo	Timber-Life fence	Native
Grias peruviana	Iñaco	Fruit tree	Native
Syzygium jambos	Poma Rosa	Fruit tree	Exotic

3.4. Overall research design

The results presented below were obtained during the first phase of a two-phase research project on social network effects on the adoption of agroforestry tree species in south Ecuador. The core of the first phase consists of a small number of in-depth semi-qualitative interviews with opinion leaders in several local communities. Rogers (1995) points out that opinion leaders have extensive interpersonal links with their followers. Importantly, they adopt innovations before their followers. If they do not adopt an innovation, they can have a negative effect on diffusion (Valente & Davis, 1999). Thus, we hoped that the interviews will improve our understanding of the local adoption processes enough to qualitatively test our initial hypotheses. By including leaders from different communities and differing ethnicities, it should be possible to disentangle pure location from ethnic effects. Ideally, we hoped to derive some first analytical models of network structure. Finally, the results will be used to construct a questionnaire for the second, quantitative phase of the research that will include all household heads of eight communities (Figure 1).

3.5. Empirical methods

During the first field visit, we interviewed ten community leaders from five communities (*El Tibio*, *El Cristal*, *Los Guavos*, *Imbana* and *San Juan de Oro*). The selection of the leaders was done with help of other researchers who had been working in the research area. Leaders were selected who appeared to (i) be actively involved in community life, (ii) act as opinion leaders, (iii) be able to be trusted and relied upon, and finally (iv) have a positive attitude towards collaboration. The interview guide included questions about the history of innovations in the region, whether the respondents adopted them or not, characteristics of the innovations, and when and how the innovation was introduced to the community, and by whom. Additionally, we asked whether our key informants knew the other community leaders on our list of informants, and how frequent the contact was. Of several addressed innovations, the adoption of agroforestry species turned out to be most suitable for further study as a major local agricultural innovation. Thus, the innovation in our context is the adoption of at least one of the tree species listed in Table 1.

The main results of this phase of the study are presented as a series of network graphs (see section 3.6). These graphs depict the network structure based on contacts between informants that occurred at least once in the last three months. By calculating the adjacency matrix **N x N** of 10 key informants to analyze the interaction patterns based on the information of agroforestry species, we display results of the centrality measures *betweeness* and *degree*. In the graphs, the nodes (informants) are spatially arranged by community. The size of the node symbols represents their centrality. The colour of the nodes depicts the ethnic group. The shape of the symbol shows if the actor has adopted agroforestry species or not. The graphical representations and centrality calculations were estimated with **NETDRAW**, package for social network analysis (http://www.analytictech.com).

While we present all connections between the actors in Figure 2, only selected connections are shown in Figure 3 to highlight the role of ethnic groups in adoption. We form a group of adopters $\mathbf{N_A}$ (circles) and of non-adopters $\mathbf{N_{NA}}$ (triangles). Furthermore, we subdivide the set of edges **E**: $\mathbf{E_W}$ is the set of edges within each of the subsets, and $\mathbf{E_B}$ are the edges between sets. To test empirically for the existence of subgroups, the Girvan-Newman algorithm was used along with the Factions method (Figure 4). The Girvan-Newman algorithm is based on measure of edge betweenness that change as edges are successively removed (Girvan & Newman, 2002). The Factions method organizes actors into mutually exclusive groups that maximize the connectivity of each partition (Hanneman & Riddle, 2005).

3.6. Empirical results

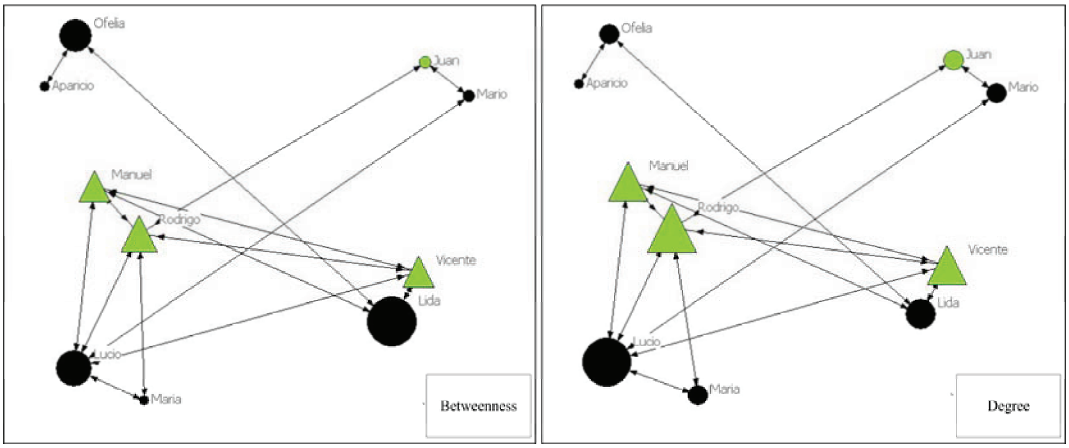

Figure 2. Interactions of key informants; size of the symbols represent *betweeness* and *degree* of centrality (Saraguros green; Mestizo-colonos black; circles: adopters, triangles: non-adopters).

The *betweeness* graph (Figure 2) does not show any notable difference between adopters and non-adopters, and between ethnic groups. Of the four Saraguro opinion leaders, three have not adopted. They did not adopt although they did interact with adopters. Apparently, there is a low "infectiousness" of contagion between ethnic groups. The graphs also show *assortativity*, for instance, Lucio and Rodrigo are two highly connected nodes,and they are directly connected.

In Figure 3, we isolated the possible influence of adopters on non-adopters. Graph 3A reveals that adopters form two distinct groups. In comparison to 3B, we find that there are the same number of links between adopters and non-adopters (8) and between groups (7). This difference is the same if community leaders are grouped according to ethnicity (8:7). Accordingly, Saraguros' (green colour) interaction is basically the same in Graph A and C; and also if we compare Graphs B and D (Figure 3). It is important to mention that within non-adopters 100% of the possible links are present. However, just 27% of the possible links within adopters are fulfilled. Furthermore, within Saraguros 87% of all possible intra-links are present, but within Mestizo-colonos just 27%. It seems that group cohesion within Saraguros is stronger than within Mestizo-colonos. It is difficult to obtain much deeper information from the analysis of graphs with such a small number of nodes. However, some additional results can be extracted. Interactions of a higher order are observed within adopters, e.g. 3-stars and more than one cycle. We also observe dyad restricted exchange.

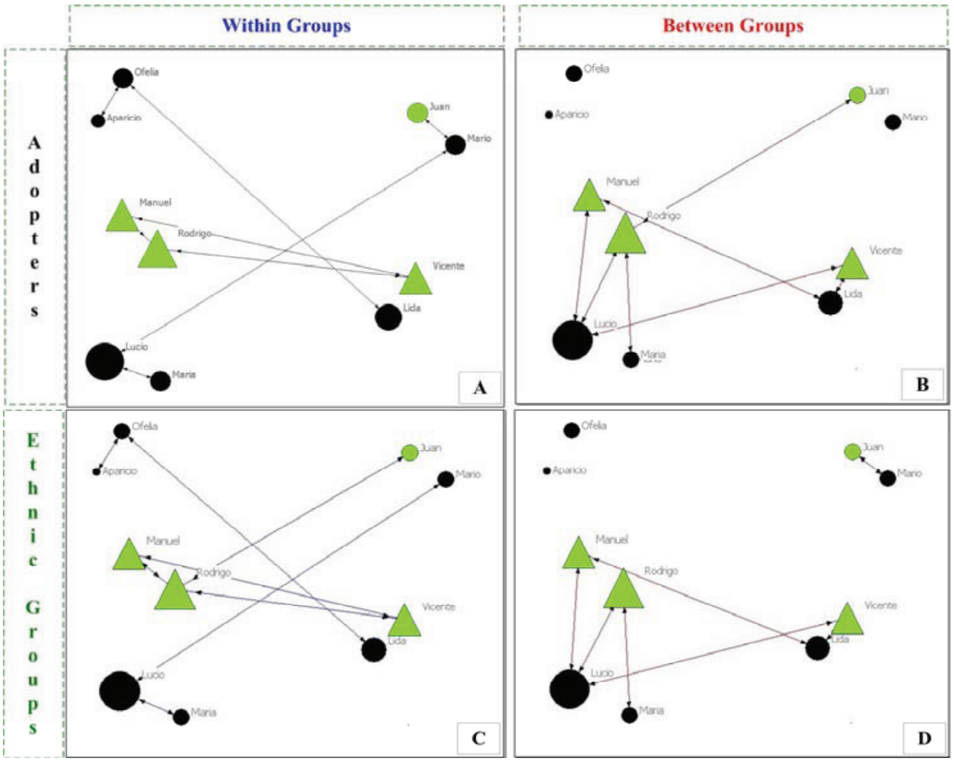

Figure 3. Comparisons within and between adopters and non-adopters A and B, and within and between ethnic groups C and D (Saraguros green; Mestizo-colonos black; circles: adopters, triangles: non-adopters).

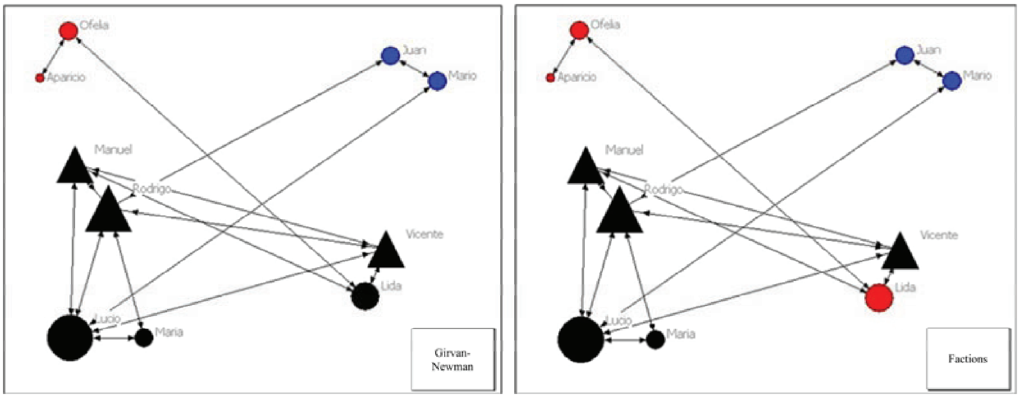

Figure 4. Sub-groups defined by the Girvan-Newman and Factions methods (subgroups indicated by colour-coding)

Interestingly, the actors with higher degree centrality are from the communities *Imbana* and *El Tibio* (Lucio & Maria; Manuel & Rodrigo). Figure 1 shows that these two villages are connected by a secondary road facilitating contact between communities. Therefore, it seems that there is a subdivision which may reflect geographical and local limitations on infrastructure. Clearly, the subgroup represented by black nodes is the most highly connected sub-group including the most central actors (Figure 4). Those actors are also geographically close. The results from both methods are very similar in this respect.

3.7. Discussion of empirical results

Contrary to the expectations based on previous literature on the project area, we did not find that the interviewed Saraguro households plant trees more often on their farms more often than the Mestizo-colonos. Although the small sample of our mainly qualitatively-oriented study does not allow for statistical tests of the respective hypothesis (section 3.1), the results are suitable to call into question our initial hypothesis however: Adherence to traditional more poly-cultural forms of agriculture (including home gardens) does result in a higher adoption of tree planting in Saraguro households (Table 2). This is clearly not the pattern that we have in our small sample. Furthermore, the network analyses carried out are consistent with the lower adoption rates of the interviewed Saraguro community leaders. In particular, there are two, internally well-linked groups of adopters. One consists exclusively of Mestizo-Colonos, and the group of the three non-adopters. Quantitative methods to identify subdivisions detect that one of the adopter groups, the second adopter group and the non-adopter group are found in the "central" subgroup (black in Figure 4). Some of these results may be best explained by local geographical factors that have the potential to shape communicative networks, i.e., via the road network. This indicates that spatial proximity in terms of access may override ethnic influences in social network terms. Consequently, we adjust our hypotheses for the next step of quantitative research as follows (see Table 2):

(i) Mestizo-Colonos are more likely to adopt tree planting on their farms.

(ii) Saraguros may have less access to information on (often introduced) tree species useful for agroforestry.

Table 2. Evolution of research main hypothesis about the diffusion of the adoption

Items	Before field research	After field research
Comparative Hypotheses	Saraguros' probability to adopt is higher than for Mestizo-colonos	Mestizo-colonos' probability to adopt is higher than for Saraguros
Justification	Saraguros have more experience with multi-crop and home garden production	Saraguros may have less access to the information about adoption

4. Plans for the quantitative research phase

4.1. Characterization of the social network

The quantitative study to be carried out in summer 2010 is planned to go far beyond the initial empirical analyses presented in Section 3. The social network samples will be composed of around i=240 nodes with $\boldsymbol{i} \in \mathbf{N}$, $\mathbf{N} = \{\mathbf{n_1 \ldots n_{240}}\}$ and edges $\mathbf{e} \in \mathbf{E}$, $\mathbf{E} = \{\mathbf{e_1, \ldots e_r}\}$. The nodes are distributed in a set of **M** villages, $\mathbf{m} \in \mathbf{M}$, $\mathbf{M} = \{\mathbf{m_1 \ldots m_8}\}$. One actor is assigned only one village. Furthermore, it is pertinent to make a distinction between the two ethnic groups: Let $\boldsymbol{L}$ be actor's attribute Ethnic-group, where $\boldsymbol{L} = \{\mathbf{1, 0}\}$. Thus, a node $\boldsymbol{i} \in \mathbf{m}$ can belong to one of two possible ethnicities Mestizo-colonos or Saraguros:

$$\boldsymbol{L} = \begin{cases} 1, \text{ if } \boldsymbol{i} \text{ Mestizo-colono} \\ 0, \text{ otherwise} \end{cases} \qquad (3)$$

By asking the respondents "Who do you seek out for advice regarding agroforestry? And who are your friends?", directional information on network interactions can be collected. Let **W** be the set of the type $\mathbf{W} = \{\mathbf{w_1, w_z}\}$ with **z** representing the local universe of types of social relations. The type of the relationship **w** codes for the directionality information. Directionality allows us to set up a "block model" with $\mathbf{W} = \{\mathbf{w_1, w_2}\}$, for **W = {Advise, Friendship}** (cf. Koehly & Pattison in Carrington, Scott & Wasserman, 2005). If there is a relationship between two individuals i and j, for $\boldsymbol{i, j} \in \mathbf{N}$; $i \neq j$; then the interaction of the network individuals will be represented in a **N x N** adjacency matrix denoted as **X**. Accordingly, in the set of ordered pairs we record the presence or absence of an edge as follows. $\mathbf{X_{ij}}$ can be:

$$X_{ij} = \begin{cases} 1, \text{ if } (i\,j) \in E \\ 0, \text{ otherwise} \end{cases} \quad (4)$$

4.2. Positional analysis: Block model

The purpose of the block model is to test the following hypotheses:

H₁: The individuals that are higher in the rank are Mestizo-colonos.

H₂: The role conveying information of agroforestry species of the most connected actors in the Saraguro community is not as important as in the Mestizo-colono community.

Based on Doreian et al. (in Carrington, Scott & Wasserman, 2005), a generalized ranked-cluster block model is constructed. Let **P** be a set of positions or images of clusters of nodes. In addition, $\mu : N \rightarrow P$ is the mapping that assigns each individuals to its position based on the network links. Therefore, a cluster of units **C(t)** with some position $t \in P$ is: $C(t) = \mu^{-1}(t) = \{x \in N : \mu(x) = t\}$. Thus, $C(\mu) = \{C(t) : t \in P\}$, that is, the partition or clustering of the individuals in **N**. The type of link is recalled here, once we know the kind of link between the positions **u** and **v**. The respective clusters C_u and C_v are mapped into the image. So $E(C_u, C_v)$ reflects the structure of the block. For the partitions of the set **N** into clusters, we assume an equivalence relation. Recalling our network $G = \{N, E\}$, let Φ be the set of equivalence relations of the regular equivalence in **G**. Therefore, each equivalence relation ~ on **N** estimates the partition **C** of **N**. If Ψ is the set of all partitions into ***h*** clusters from the relationsships from Φ, than the next step is to construct an **F(C)** criterion function which has the following properties: (i) $F(C) \geq 0$, and (ii) $F(C) = 0 \Leftrightarrow \sim \in \Phi$. To estimate **F(C)**, we have to measure the fit of a clustering by comparing it to an ideal cluster. The ideal cluster has relations within each partition and between them. Thus,

$$F(C) = \sum_{C_u, C_v \in C} \min_{B \in B(C_u, C_v)} \delta(E(C_u, C_v), B) \quad (5)$$

where δ determines the inconsistency between the block $E(C_u, C_v)$, and **B** is the ideal block. The sum of local inconsistencies $\delta(E(C_u, C_v), B)$ is the global inconsistency. The local inconsistency is also the sum of the differences between the observed link and the value of the ideal block (Doreian et al. in Carrington, Scott & Wasserman, 2005). After construction the appropriate criterion function that reflects the selected equivalence, a local optimization clustering process must be carried out. It should be repeated for different initial partitions to find the highest number of possible clusters.

4.3. Influence of the social network on the adoption of agroforestry species

To test for social network influences in detail, we need a model that accounts for adoption and for ethnic differences. Moreover, the role of the more central actors should be analysed to understand the spread of the adoption. With such a model, we should be able to test the following hypotheses:

H_1: Actor centrality may directly affect the individual propensity to adopt.

H_2: Actors with high centrality measurements are more influential within their communities.

H_3: Mestizo-colono leaders may be more infectious in their respective communities than Saraguro leaders.

H_4: Mestizo-colonos are more *susceptible* to adopt than Saraguros.

H_5: Actors with a max-flow betweeness vitality closer to one are mainly Mestizo-colonos.

H_6: Adoption is positively correlated with the similarities of actors' characteristics related to their ethnic group.

The model assumes time-constant links. In other words, whoever was a friend at the moment of the survey was also a friend at the moment of adopting agroforestry species. The only time variant variable will be the moment at which each farmer adopted. Our model follows the explanations of Valente in Carrington, Scott & Wasserman (2005) and the models developed by Strang & Tuma (1993) and Greve, Strang & Tuma (1995). We start with:

$$\log Pr(y_{i,\,t} = 1) = \beta_0 + \sum \beta_D D + \beta_O O + \sum \beta_T T_t + \sum \beta_A A + \sum \beta_X X + \beta_I I_t\, C_{(X)}(y) + \beta_U U_t\, C_{(X)}(y) + \beta_F C_F(i) \quad (6)$$

where: $y_i(t)$ is the binary indicator of behaviour (adoption), following Strang & Tuma (1993), $Y_i(t) = \{1, 0\}$ is a binary variable:

$$Y_i(t) = \begin{cases} 1, \text{ if } \boldsymbol{i} \text{ adopted by time } \boldsymbol{t} \\ 0, \text{ otherwise} \end{cases} \quad (7)$$

β_0 is the intercept. β_D is the parameter that estimates vectors of **D** socio-demographic characteristics constant in time. β_O is the parameter that estimates the geographical characteristics **O** of the communities constant in time. β_T is the parameter of $\mathbf{T_t}$ time variant terms, for details about time transformations, see Strang & Tuma (1993). β_A is the parameter that estimates vectors of **A** intrinsic characteristics of individual *i*, namely the ethnic group. β_X is the parameter of **X** social network matrices, constant on time.

β_I is the parameter that estimates vector of **I** that describes the infectiousness of actor *j* as it influences all other actors by his behaviour. More specifically, it explains the influence of each individual (*who has adopted*) over all others in the social network **G**. If there are more adopters in the network in each period, there is a higher probability of influence on future adopters. Thus, *infectiousness* at time ***t*** is the sum of *in-degree* centrality multiplied by the time-varying proportion of adopters in the social network (Valente in Carrington, Scott & Wasserman, 2005). We have that $\boldsymbol{i}, \boldsymbol{j} \in \mathbf{N}$. The population **N** is divided into sets, **N'(t)** of adopters in a period *t*, and a set of **N''(t)** of non-adopters in a period *t*. e.g., $\boldsymbol{i} \in$ **N'(t)** and $\boldsymbol{j} \in$ **N''(t)** (Greve, Strang & Tuma, 1995).

β_U is the parameter that estimates vector **U** or the susceptibility of actor *i* (*who has not adopted*) to be influenced by the group of prior adopters. An important interaction is to determine susceptibility as a function of the size of the ethnic group. In this case, one can multiply the measure of centrality (*out-degree*) by the rate of time varying adoption of Mestizo-colonos (cf. Myers, 2000). This variable describes susceptibility to intrapopulation linkages (Strang & Tuma, 1993). β_F is the parameter that estimates vectors of **CF(i)** max-flow-betweenness vitality (see Section 2.3). Here we want to measure the maximum flow of information related with agroforestry species that flows through each single node in the social network, and the frequency of the contacts.

Extensions of the proposed model can be done by including structural equivalence (see Section 2.3). The model parameters can be estimated by maximum likelihood estimation. If one of the parameters is significant, it indicates that change in behaviour (adoption) is associated with network exposure.

5. Conclusion

The type of results we hoped to generate are likely to find an interested audience not only in the scientific community but also in policy makers. The successful application of the UNESCO Biosphere Reserve needs to be complemented in a long-term management plan that takes into account the ecological as well as the cultural diversity of the area. The expected results may be highly useful not only for promoting tree planting on farms but also for the design of more general communication strategies with the rural population. This will be particularly true if we do in fact find that there are different patterns for sharing information among and between the ethnic groups.

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References

Acemoglu, D., Dahleh, M., Lobel, I., & Ozdaglar, A. (2008). Bayesian learning in social networks. Cambridge: National Bureau of Economic Research, Working Paper, 14040.

Beck, E., Kottke, I., Bendix, F., Makeschin, F., & Mosandl, R. (2008). *Gradients in a Tropical Mountain Ecosystem of Ecuador: Vol. 198. Ecological Studies*. Berlin Heidelberg, Germany: Springer-Verlag.

Besley, T., & Case, A. (1993). Modelling technology adoption in developing countries. *The American Economic Review*, 83(2), 396-402.

Brandes, U., & Erlebach, T. (2005). *Network analysis: Methodological foundations*.(1st ed.). Berlin: Springer-Verlag.

Carrington, P., Scott, J., & Wasserman, S. (2005). *Models and methods in social network analysis: Structural analysis in the social sciences*. (1st ed.) New York: Cambridge University Press.

Conley, T., & Udry, C. (2001). Social learning through networks: The adoption of new agricultural technologies in Ghana. *American Journal of Agricultural Economics*, 83(3), 668-673.

Conley, T., & Udry, C. (2005). Learning About a New Technology: Pineapple in Ghana. Yale University: Economic Growth Center, Working Paper, 817.

Delre, S., Jager, W., & Janssen, M. (2007). Diffusion dynamics in small-world networks with heterogeneous consumers. *Comput Math Organiz Theor*, 13, 185-202.

Freeman, L. (1977). A set of measures of centrality based on betweenness. *Sociometry,* 40(1), 35-41.

Freeman, L., Borgatti, S., & White, D. (1991). Centrality in valued graphs: A measure of betweenness based on network flow. *Social Networks,* 13, 141-154.

Gerique, A., & Pohle, P. (2006). Traditional ecological knowledge and biodiversity management in the Andes of southern Ecuador. *Geographica Helvetica*, 61(4), 275-285.

Girvan, M., & Newman, M. (2002). Community structure in social and biological networks. *PNAS*, 99(12), 7821-7826.

Granovetter, M. (1973). The strength of weak ties. *American Journal of Sociology,* 78(6), 1360-1380.

Granovetter, M. (1983). The strength of weak ties: A network theory revised. *Sociological Theory,* 1, 201-233.

Granovetter, M., & Soong, R. (1986). Threshold models of interpersonal effects in consumer demand. *Journal of Economic Behavior and Organization,* 7, 83-99.

Greve, H., Strang, D., & Tuma, N. (1995). Specification and estimation of heterogeneous diffusion models. *Sociological Methodology*, 25, 377-420.

Günter, S., Stimm, B., & Weber, M. (2004). Silvicultural contributions towards sustainable management and conservation of forest genetic resources in Southern Ecuador. *Lyonia*, 6(1), 75-91.

Hanneman, R., & Riddle, M. (2005). Introduction to social network methods. University of California, Riverside, CA, USA. [Text file] http://faculty.ucr.edu/~hanneman/

Homeier, J. (2008). The influence of topography on forest structure and regeneration dynamics in an Ecuadorian montane forest. In: S.R., Gradstein, J. Homeier, & D. Gansert (Eds.), *Biodiversity and Ecology Series (2): The tropical mountain forest* (97-107). Göttingen: Universitätsverlag Göttingen.

Jackson, M. (2008). *Social and economic networks*. (1st ed.). New Jersey: Princeton University Press.

Jackson, M., & Yariv, L. (2005). Diffusion on social networks. *économie publique*, 16(1), 3-16.

Levin, G., & Reenberg, A. (2002). Land use driven conditions for habitat structure: A case study from the Ecuadorian Andes. *Geografisk Tidsskrift, Danish Journal of Geography*, 102, 79-92.

Maza, B., Barkmann, J., von Walter, F., & Marggraf, R. (2010). Modelling smallholders production and agricultural income in the area of the Biosphere reserve "Podocarpus-El Condor", Ecuador. Georg-August-Universität Göttingen: Department of Agricultural Economics and Rural Development, Working Paper, 1004.

Myers, D. (2000). The diffusion of collective violence: Infectiousness, susceptibility, and mass media networks. *American Journal of Sociology*, 106 (1), 173-208.

Myers, N., Mittermeier, G., Mittermeier, R., Da Fonseca, G., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858.

Pohle, P., & Reinhardt, S., (2004). Indigenous knowledge of plants and their utilization among the Shuar of the lower tropical mountain forest in southern Ecuador. *Lyonia*, 7(2),133-149.

Price, C. (1995). Economic evaluation of financial and non-financial costs and benefits in agroforestry development and the value of sustainability. *Agroforestry Systems*, 30, 75-86.

Rogers, E. (1995). *Diffusion of innovations*. (4th ed.). New York: The Free Press.

Rogers, E., Medina, U., Rivera, M., & Wiley, C. (2005). Complex adaptive systems and the diffusion of innovations. *The Innovation Journal: The Public Sector Innovation Journal,* 10(3), article 29.

Rollenbeck, R. (2006). Variability of precipitation in the Reserva Biólogica San Francisco / Southern Ecuador. *Lyonia*, 9(1), 43-51.

Rozenfeld, A., Arnaud-Haond, S., Hernandez-Garcia, E., Eguiluz, V., Serrao, E., & Duarte, C. (2008). Network analysis identifies weak and strong links in a metapopulation system. *PNAS*, 105(48), 18824-18829.

Ryan, R., & Gross, N. (1943). The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology*, 8, 15 – 24.

Schneider, S.H., Semenov, S., Patwardhan, A., Burton, I., Magadza, C.H.D., Oppenheimer, M.,… Yamin, F. (2007). Assessing key vulnerabilities and the risk from climate change. In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J van der Linden & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (779-810). Cambridge: Cambridge University Press.

Steffan-Dewenter, I., Kessler, M., Barkmann, J.,Bos, M., Buchori, D., Erasmi, M.,…Tscharntke, T. (2007) Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *PNAS*, 104, 4973-4978.

Stoneman, P. (1981). Intra-firm diffusion, Bayesian learning and profitability. *The Economic Journal*, 91(362), 375-388.

Strang, D. & Tuma, N. (1993). Spatial and temporal heterogeneity in diffusion. *The American Journal of Sociology*, 99(3), 614-639.

Valente, T. (1996). Social network thresholds in the diffusion of innovations. *Social Networks*, 18, 69-89.

Valente, T. (1999). *Network models of the diffusion of innovations*.(2nd ed.). New Jersey: Hampton Press, INC.

Valente, T., & Davis, R. (1999). Accelerating the diffusion of innovations using opinion leaders. *ANNALS, AAPSS*, 56, 55-67.

Valente, T., & Rogers, E. (1995). The origins and development of the diffusion of innovations paradigm as an example of scientific growth. *Science Communication*, 16(3), 238-269.