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Rural innovation systems and networks: findings from a study of Ethiopian smallholders

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Abstract Ethiopian agriculture is changing as new actors, relationships, and policies influence the ways in which small-scale, resource-poor farmers access and use information and knowledge in their agricultural production decisions. Although these changes suggest new opportunities for smallholders, too little is known about how changes will ultimately improve the wellbeing of smallholders in Ethiopia. Thus, we examine whether these changes are improving the ability of smallholders to innovate and thus improve their own welfare. In doing so, we analyze interactions between smallholders and other actors to provide new perspectives on the role played by smallholder innovation networks in the agricultural sector by drawing on data from community case studies conducted in 10 localities. Findings suggest that public extension and administration exert a strong influence over smallholder networks, potentially crowding out market-based and civil society actors, and thus limiting beneficial innovation processes. From a policy perspective, the findings suggest the need to further explore policies and programs that create more space for market and civil society to participate in smallholder innovation networks and improve welfare. From a conceptual and methodological perspective, our findings suggest the need to incorporate rigorous applications of social network analysis into the application of innovation systems theory.

Keywords Africa · Ethiopia · Agricultural development · Innovation · Participatory rural appraisal · Social networks · Social learning · Technology adoption

Abbreviations

ADLI	Agriculture Development-Led Industrialization
BoARD	Bureau of Agriculture and Rural Development
CSI	Credit and Savings Institution
ERSS	Ethiopia Rural Smallholder Survey
NGOs	Nongovernmental organizations
PRA	Participatory rural appraisal
SNA	Social network analysis

Introduction

Ethiopian agriculture is increasingly characterized by new policies, actors, and relationships that influence how small-scale, resource-poor farmers access and use information and knowledge. These changes are partly due to the increasing emphasis by the government on agriculture-led development. While this growing complexity suggests opportunities for Ethiopian smallholders, little is known about how those opportunities can be effectively leveraged to promote pro-poor processes of rural innovation.

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Growth and innovation in Ethiopia's agricultural sector are, by most measures, fairly weak. Agricultural GDP per capita grew just 0.48% per year between 1996 and 2005 and displayed significant volatility year to year. Grain production per capita grew just 1.38% per year, while cereal yields stagnated around 1.2 metric tons per hectare. The use of inorganic fertilizer is limited to just 37% of farmers, and application rates remain at about 16 kg per hectare. Use of improved seed varieties is relatively low, as is the use of many other agricultural technologies. And while the proportion of Ethiopians living below the poverty line declined between 1995 and 2005, it remains at 40% (World Bank 2005). Thus, rural incomes and livelihoods remain largely unchanged throughout the country, despite recent upswings resulting from several successive years of favorable rainfalls and some positive policy reforms related to commodity marketing, agricultural export promotion, and social safety nets.

An analysis based on an innovation systems framework can contribute to addressing the discrepancy between the changes in policies, actors, and relationships, on the one hand; and productivity on the other. The framework draws attention to the diverse actors that contribute to agricultural innovation processes—public research organizations, private companies, nongovernmental organizations (NGOs), civil society organizations, and smallholders themselves—by shedding light on the roles and responsibilities, actions and interactions, and institutions that condition behaviors and practices. This study examines how Ethiopian smallholders innovate—how they make use of new or existing knowledge and technology in their livelihood decisions; how their social networks contribute to innovation processes; and how those decisions, networks, and processes are influenced by policy- and market-driven factors. This examination is particularly relevant in light of the slow rate of technological change in Ethiopia's agricultural sector and the slow emergence of alternative institutional and organizational arrangements to enhance growth and development in the sector.

The question this study sought to answer is whether the new forms of interaction and the increasing diversity of actors within Ethiopia's agricultural innovation system are having an impact on the capacity of smallholders and rural communities to beneficially participate in innovation processes.

A conceptual framework

We begin by introducing a conceptual framework based on the innovation systems approach to studying how society generates, exchanges, and uses information and knowledge, and how these processes can be strengthened to promote innovation and distribute the benefits of innovation more widely. The framework represents a significant change from the conventional linear perspectives on technological change by emphasizing the importance of studying an "innovation system" as a single unit comprising the actors involved in the innovation process, their actions and interactions, and the formal and informal rules that influence their practices and behaviors. We define an innovation as any knowledge (new or existing) introduced into and used in an economically or socially-relevant process (OECD 1999). For the purposes of this study, the term innovation included not only the adoption of a new agricultural technology, but also a range of other processes, such as the reorganization of marketing strategies by a group of smallholders, the use of a new learning and teaching method by agricultural extension agents, and the introduction of a new processing technique by an agroindustrial company. We define an "innovation actor" as someone who introduces or uses such knowledge—a process that entails seeking information from various sources and integrating elements of the information into social or economic practices in a way that changes the behaviors and practices of individuals, organizations, or society. Innovation actors include public sector entities (research organizations, agricultural extension and education services, state marketing agencies, state-owned enterprises, institutes of higher learning, international research centers, and foreign universities); private actors such as traders, entrepreneurs and for-profit companies; collective action entities such as farmers' cooperatives; civil society, including NGOs and community-based organizations; and, of course, farmers, members of farm households, agricultural laborers, and residents of rural communities.

The key commodity linking these actors is knowledge. Although knowledge is a difficult commodity to characterize, we assigned to it several key properties that were useful for the purposes of this study. Knowledge may be scientific or technical in nature, or it may be organizational or managerial. It may occur in a codified or explicit form, or it may be tacit or implicit. Knowledge may originate from foreign sources of discovery or emerge from the use or reorganization of internal and indigenous practices and behaviors (Clark 2002; Malerba 2002).

Because innovation results primarily from the exchange and use of knowledge, the nature of interactions between and among actors is another important aspect for consideration. Interactions may be spot market exchanges of goods and services that embody new knowledge or technology; costless exchanges of knowledge conducted in the public domain; long-term, durable exchanges that incorporate complex contractual arrangements and learning processes; local- or community-level systems of knowledge sharing; or hierarchical command structures. The study of how actors structure their interactions in the exchange of knowledge gives the innovation systems framework its definitive systems perspective.

An important element of an innovation system is the array of social networks within which innovation actors interact with one another, or the sets of individuals or organizations in which each has connections of some kind to some or all of the other members of the set (see Rycroft and Kash 1999; Malerba 2005; Mowery and Sampat 2005). Social networks can define, limit, or enhance an individual's opportunities for social learning by influencing membership or participation in a given innovation process, thereby affecting access to knowledge (Besley and Case 1994; Foster and Rosenzweig 1995; Munshi 2004; Bandeira and Rasul 2006). The form, function, and boundaries of a social network are often determined by social and economic institutions, conventionally defined here as the rules, conventions, traditions, routines, and norms of a given social or economic system (North 1990).

A comprehensive description of the innovation systems approach was first set forth by Lundvall (1985) and applied to national comparisons of innovation systems by Freeman (1987). The concept was further elucidated in Dosi et al. (1988), Lundvall (1988, 1992), Freeman (1988, 1995), Nelson (1988, 1993), and Edquist (1997), with empirical applications focusing primarily on national industrial policy in Europe, Japan, and several East Asian countries that were experiencing rapid industrialization during the 1980s. While their work emerges partly from Schumpeterian traditions in evolutionary economics, it also draws heavily on theories of organizational behavior and sociology (Balzat and Hanusch 2004; Spielman 2006).

Yet the innovation systems approach is still young in its application to developing-country agriculture. Biggs and Clay (1981) and Biggs (1989) offer an early foray into the approach by introducing several key concepts—institutional learning and change, and the relationship between innovation and the institutional milieu in which innovation occurs—that become central to later innovation systems studies on developing-country agriculture. Later studies by Hall and Clark (1995), Hall et al. (1998), Johnson and Segura-Bonilla (2001), Clark (2002), Arocena and Sutz (2002), Hall et al. (2002, 2003), and World Bank (2007) introduce the innovation systems approach to the study of developing-country agriculture.[1] For example, Ekboir and Parellada (2002) examine the social and economic changes that encouraged the diffusion of zero-tillage cultivation in Argentina, a process that resulted from a complex series of events and interactions among farmers, farmers' organizations, public researchers, and private firms. Hall et al. (2002) studied the organizational learning processes that stimulated the diversification of agricultural research financing in India to include new actors (e.g., medium-sized firms and producer cooperatives) and new modalities (e.g., contract research, public–private partnerships). Clark et al. (2003) detail the factors contributing to the success of a project in postharvest packaging for small-scale farmers in Himachal Pradesh, India, by studying the institutional learning and change processes that were incorporated into the project design.

Common to all of these studies is the emphasis placed on the role of diverse actors and interactions within complex systems of innovation, and the institutional context within which these processes occur. In essence, they argue that the conventional emphasis on linear innovation processes—moving knowledge from scientists to extension agents to farmers—is an oversimplication of complex processes that are highlighted by non-linear learning processes, feedback loops, and other complex interactions that occur among far more heterogeneous actors. Policies and investments in support of linear innovation models, they argue, are bound to fail if they do not take into account these complexities in promoting innovation.

But while these studies tend to provide insightful analyses at the project, sectoral, or national level, they do not address the most basic level of innovation—that of the farmer. In an attempt to fill part of this knowledge gap, both conceptually and empirically, we examined how social networks facilitate the transfer of knowledge externalities—knowledge made available to an individual as a result of the practices or behaviors of other individuals—and how those externalities affected individual decisions to innovate with respect to farmers' agricultural practices or technology adoption choices. An early model of information externalities and agricultural technology was described by Besley and Case (1994) in reference to the adoption of improved cotton cultivars. The model was later refined by Foster and Rosenzweig (1995) in a study of high-yielding varieties (HYVs) of wheat and rice in India during the Green Revolution.

Several modifications to the social learning/social networks model have since entered the literature. Munshi (2004) adds nuance to the social learning model by demonstrating that information flows related to a new technology are weaker in heterogeneous populations. Bandeira and Rasul (2006) add yet another twist by modeling social learning as a nonlinear process and testing it with a study of sunflower adoption in northern Mozambique. Similarly, Darr and Pretzsch (2008) improve on the original models by comparing innovation processes within situations of information availability and scarcity. These studies provide several testable hypotheses. First, a distinction can be made between the effects of "learning by doing" (a function of

[1] See Spielman (2006) for a review of the literature on innovation systems applications to developing-country agriculture.

one's own innovative capabilities) and "learning from others" (a function of one's social networks). Second, while imperfect knowledge about new agricultural practices is a barrier to adoption, the barrier decreases as farmers and their neighbors gain experience. Third, innovation can occur both through strong, cohesive networks when there is abundant information, and through weakly-knit networks where there is scarce information. These hypotheses underlie the key question being asked by our study—whether new forms of interaction and increasing diversity within Ethiopia's agricultural innovation system are benefiting smallholders and rural communities—because they highlight the need for more analysis of the nature and function of smallholder networks and their contribution to the adoption of new agricultural practices.

Background: smallholder innovation in Ethiopia

Improving smallholder productivity is a central theme in Ethiopia's development discourse. Approximately 80% of the country's population is rural, and rural poverty is widespread. A range of factors contribute to this situation, including: high rural population densities and extreme land shortages (especially in the relatively fertile highlands where per capita land area has fallen from 0.5 ha in the 1960s to only 0.2 ha by 2008); recurrent droughts, variable rainfall, and declining soil fertility that lead to low output; high variability of agricultural production (with cereal yields averaging around 1.5 ton/ha); limited access to modern inputs and infrastructure such as improved seed, fertilizer, and irrigation; and a weak market for agricultural commodities (World Bank 2005).

There is ample recent literature to suggest that raising agricultural productivity, and thus improving rural welfare, remains a fundamental challenge in Ethiopia (see Diao and Pratt 2006; Taffesse 2008; Dercon and Hill 2009). The government—through its economic growth strategy, Agriculture Development-Led Industrialization (ADLI)—argues that a phased approach that focuses on boosting agricultural productivity before investing in industrialization is an optimal development strategy for the country. This translates into a strategy that has focused on the promotion of new agricultural technologies, the introduction of better price incentives for agricultural commodities, and greater investment in rural roads and other infrastructure (MoFED 2002, 2005).The strategy draws heavily on the resources and capacities of public agencies that are pillars of the country's formal innovation system: public sector research, extension, and education services, all of which are recognized as the most prominent sources of information, technology, and inputs for the Ethiopian smallholder (Kassa 2005). The strategy also calls for active engagement with other potential sources of innovation, such as the private and civil society sectors, cooperatives and cooperative unions, domestic and foreign firms, rural investors and entrepreneurs, and NGOs and community-based organizations.

Yet while the ADLI strategy implicitly recognizes that a more dynamic and competitive innovation system is critical to transforming agriculture in Ethiopia, it has yet to translate that notion into a system with the potential to improve rural livelihoods. This is due in part to a continuing focus on traditional, linear modes of technology transfer and a strict focus on production quantities. Specifically, Ethiopia is struggling with a deeply path-dependent tendency to promote organizational cultures that inhibit innovation, particularly among public providers of rural services. These organizations are often deeply hierarchical, averse to change, focused on linear science, and driven by unchanging sets of shared beliefs. These beliefs and customs come in part from Ethiopia's culture, history, and politics, and likely began within the feudal system of Imperial regime, were reinforced during the military *Derg* regime (1974–91), and are likely present within much of in the current regime (1991–present).[2]

Public policies, programs, and investments in Ethiopia are largely driven by one particular set of static shared beliefs—that food security and food self-sufficiency are largely synonymous, that the development and dissemination of new technologies to smallholders will generate the yield and output increases needed to achieve food security and reduce poverty, and that the innovation system's primary function is to develop and disseminate these new technologies. This belief eschews a more nuanced understanding of innovation systems and processes, and the need for integration among heterogeneous actors to successfully promote innovation. These beliefs also fail to recognize the need for new, more creative approaches to strengthening individual capacities of the research, education, and extension systems; transforming organizational cultures into cultures more responsive to the changing needs of the agricultural sector; and forging links among smallholders, extension agents, and actors in private industry and civil society that comprise the wider innovation system.

Thus, the development of Ethiopia's innovation system faces several obvious challenges. The most critical challenges include (a) how to design and implement policies to create and strengthen the formal organizations engaged in the innovation process (universities, private firms, and research organizations); (b) how to facilitate innovation

[2] For a review of the literature on rural governance in Ethiopia, see Dom and Mussa (2006a, b), Segers et al. (2008), Aalen (2002), Pausewang et al. (2003), Vaughan and Tronvoll (2003), and Gebre-Egziabher and Berhanu (2007).

among smallholders with support cooperatives, extension services, and civil society actors; and (c) how to mediate effectively between and among these actors. Studies on Ethiopia's general innovation system (UNCTAD 2002; IKED 2006; Spielman et al. 2007), its agricultural research system (Abate 2006), and its agricultural education and extension systems (Kassa 2004a, b, 2005; Gebremedhin et al. 2006; Davis et al. 2007) make these points quite clearly.

Conceptually, these challenges inhibit the very kinds of innovation being promoted by the government for Ethiopian agriculture, as demonstrated by theoretical and empirical research on innovations systems presented earlier. Practically, these challenges also indicate the need for incentive mechanisms that promote greater cooperation and coordination between different public organizations at different levels (i.e., at the federal and regional levels) and between public organizations and newer players in the system (i.e., between public education, research, and extension on the one hand, and private companies and civil society organizations on the other).

Methods, sources, and data

Site and household selection

To examine these issues more closely, this study made use of several methods, data, and data sources. Geographic sites and households chosen for case studies of smallholder innovation networks were drawn from the 2005 Ethiopia Rural Smallholder Survey (ERSS). This section describes the survey itself, and then defines the site and household selection criteria. Finally, the section provides an overview of the focus group and semi-structured interviews conducted for this study.

Ethiopia rural smallholder survey

The ERSS was designed to collect data on the economic activities and behaviors of smallholders, with emphasis on efforts to improve rural welfare and income through increased market interaction. The stratified sample used in the survey comprised 7,186 households randomly drawn from 293 enumeration areas (each roughly mapping to a *kebele*)[3] from which 25 randomly drawn households were surveyed. The ERSS sample is considered representative at the national level as well as at the regional level for Ethiopia's four largest regions.

Geographic site selection

Using ERSS data, a set of 16 enumeration areas was initially identified based on evidence suggesting that multiple households within each enumeration area were engaged in what the research team identified as innovative agricultural practices. These practices were associated with the adoption of the following crop/technology packages: oilseed (linseed, sesame, sunflower, canola, niger seed); apiculture (primarily modern beehives); nontraditional beans (mainly fasiola and haricot beans); potatoes (improved varieties); and onions, garlic, and leeks. A total of 10 enumeration areas were selected for further exploration based on criteria designed to provide a heterogeneous sub-sampling of (a) agroclimatic or agropotential regions, (b) one or more crop or technology packages being used in a given site, (c) administrative regions/regional states, and (d) physical accessibility of the site (Table 1).

By design, these criteria do not generate a nationally-representative subsample of the ERSS. More importantly, these criteria bias the subsample toward those areas where innovation of some type was observed or reported. This means that these particular areas differ from what is occurring in the majority of areas in Ethiopia in terms of innovation. Specifically, farmers in these areas were cultivating new crops, using new production technologies and techniques, or capitalizing on new market opportunities to sell surplus production. These innovative practices, whether pursued singly or jointly, represented an important deviation from the norm in other ERSS sites, where farmers were pursuing crop production, technology, and marketing practices that were much more narrowly and traditionally defined. Thus, the selected sites provided us with a set of informative case studies that had much to say about what was actually occurring—on the ground and within local innovation systems—with potential significance for national and regional policy that targets areas where innovation is lagging.

Household selection

Households for further study were selected from each enumeration area based on a rough index generated from the ERSS data. The index was composed of equally weighted values for (a) adoption of one or more of the identified crop/technology packages, (b) adoption of one or more complementary cultivation practices (e.g., innovative water management techniques or use of improved seed), (c) ownership of modern production assets (hand- or foot-operated mechanical water pumps and motorized water

[3] In Ethiopia, *kebeles* or peasant associations (PAs) are the smallest administrative unit below the *woreda* (district) level. For purposes of comparison, *kebeles* correspond to a cluster of villages in most other sub-Saharan African countries.

Table 1 Selected sites for in-depth study

Woreda (region)	Crop/technology package	Agro-ecological zone[a]	Growth/development potential[b]
Wemberma (Amhara)	Apiculture/onions	M1, M2	Medium potential, low risk
Janamora (Amhara)	Oilseed/apiculture/potatoes	M2	Medium potential, low risk
Hawzen (Tigray)	Apiculture/oilseed	SM2	Low potential, high risk
Hintalo (Tigray)	Apiculture/onions	SM2	Low potential, high risk
Ambo (Oromia)	Oilseed/potatoes	M2	Medium potential, low risk
Becho (Oromia)	Beans/oilseed	M2	Medium potential, low risk
Tikur Inchini (Oromia)	Oilseed	SH2, M2, H2	High potential, low risk
Kedida Gamela (SNNP)[c]	Beans/potatoes	SH2	Low potential, low risk
Badawacho (SNNP)	Beans	SH1	Low potential, low risk
Soro (SNNP)	Oilseed/potatoes	SH2	Low potential, low risk

[a] M1 is hot-to-warm, moist lowlands; M2 is tepid-to-cool, moist midhighlands; SM2 is tepid-to-cool, submoist highlands; SH1 is hot-to-warm, subhumid lowlands; SH2 is tepid-to-cool, subhumid midhighlands; and H2 is tepid-to-cool, humid midhighlands. *Source*: EIAR (Personal Communication)

[b] *Source*: World Bank (2004)

[c] SNNP: Southern Nations, Nationalities, and Peoples regional state

Table 2 Social network analysis: descriptive statistics for focus group participants

Characteristics	Innovators	Non-innovators	Group mean difference test (*p* value)
Number of observations	49	48	
Mean group size	5	5	
Female participants (%)	12	28	
Mean age (years)	45 (12.8)	46 (16.9)	0.7757
Mean education (years)	3 (3.0)	1.8 (3.0)	0.0373**
Mean land size (hectares)	1.84 (1.6)	1.23 (0.9)	0.0283**
Participants who are household heads (%)	92	90	
Participants from women-headed households (%)	4	4	

Notes: Standard deviations given in parentheses

* Mean between innovators and non-innovators significantly different at confidence interval of 90%; ** 95%; *** 99%

pumps), and (d) contact with agricultural extension services. The five households with the highest index scores and the five households with the lowest index scores were selected for separate focus group interviews and were denoted (for convenience only) as innovators and non-innovators, respectively. As shown in Table 2, these groups differed in terms of education level and land holding size, with innovators exhibiting higher mean values for both. This approach allowed the research team to identify groups that, according to ERSS data, were using agricultural practices different from those used by other members in their community, thus offering potentially valuable insights into the role of smallholder innovation networks.

Focus group interviews and semi-structured interviews

In mid-2006, the research team conducted a total of 20 focus group interviews (two at each of the 10 sites, one with innovators and one with non-innovators) composed of five individuals each. Focus group interviews were conducted using pretested participatory rural appraisal (PRA) tools that focused on identifying sources of production knowledge and information, inputs and materials, credit and finance, and market links and price information. See Spielman et al. (2008) for details. Following the focus group interviews at each site, additional semi-structured interviews were conducted with key actors identified by the focus group participants. These interviews were used to further validate information provided by the focus group participants and included key informants in the immediate locality of the site (e.g., development agents,[4] cooperative managers, *kebele* officials, and leaders of community-based organizations); and in the *woreda* (district), zonal, or

[4] Development agents are trained extension agents who are employed by the regional bureaus of agriculture, managed by *woreda*-level offices of these regional bureaus, and posted directly to the *kebeles*.

regional headquarters (e.g., Bureau of Agriculture and Rural Development (BoARD) officers, managers of credit and savings institutions, traders, brokers, staff at NGOs, and others). Interviews were guided by questions similar to those posed to PRA participants. Data gathered from the PRA and semi-structured interviews were then used to conduct social network analysis of each site, as discussed in the following section.

Social network analysis: methods

Social network analysis (SNA) is a useful, but relatively underutilized tool designed for the study of innovation network data such as that gathered from the interviews described above. As is the case with the innovation systems approach, SNA has been around for some time but only recently has been applied to developing country agriculture. SNA was developed by sociologists and further enhanced as an analytical technique by the fields of mathematics and statistics. The rapid growth and spread of SNA into fields beyond sociology and mathematics was due to the development of better SNA tools, including powerful software applications. Thus it is only now being applied to developing country agriculture. To date there is no case in the scientific literature of this method being used together with the innovation systems approach. However, we have found SNA useful in understanding and mapping innovation systems because of its analytical focus on relationships and interactions between people and groups, and its ability to capture knowledge flows and other attributes contained within such interactions.

SNA allows for the study of relationships among multiple and diverse actors by providing tools with which to visualize, measure, and analyze the relationships (Borgatti 2006). In the context of innovation, SNA provides an understanding of how actors interact, how information and resources move between and among them, and how actors' roles and relationships are structured. Data for SNA are commonly based on measurements of relationships between actors and sets of actors, in addition to the attributes of individual actors. Because SNA is a relatively new application in this type of research, we describe it here in some detail (Table 3). For further details on the methodology, see Borgatti (1998), Hanneman and Riddle (2005), and Scott (2000).

In SNA, each actor in a network—whether an individual, organization, or some other entity of interest—is termed a "node."The actor of interest within a network is known as the "ego." Links between nodes, termed "ties," denote some form of interaction between nodes. In a tie linking an ego to another node, the other node is referred to as an "alter." Ties can be analyzed with respect to their strength, frequency, distance, or other such measures depending on the focus of inquiry. Ties also reflect the key unit of analysis in SNA—the "dyad," or a pair of nodes. Dyads may be composed of direct ties between nodes, or indirect connections that pass through a series of interconnected nodes, termed "walks." Dyadic attributes can include the nature of social or economic relationships captured by the dyad, the characteristics of interactions in the dyad, or the ways in which information or resources flow in the dyad. Each network has a size—determined by the total number of nodes—and a boundary—a natural delineation between actors and relationships or an artificial limit set by the researcher.

Data for SNA can be collected through any number of conventional data collection tools, including household questionnaires, focus group interviews, and key-informant interviews. Data for the study of unimodal networks—for example, smallholder innovation networks—are compiled in a square ($n \times n$) matrix of n actors (nodes) in which matrix element $n_{ij} > 0$ denotes the presence of a tie between actors i and j, while $n_{ij} = 0$ denotes the absence of a tie.[5] A simple nondirectional tie between two nodes is represented as $n_{ij} = n_{ji} = 1$ in the matrix. A directional tie—denoting, for example a flow of funds from node i to j but not from j to i—is represented as $n_{ij} = 1$ but $n_{ji} = 0$. Directed ties in a network graph are indicated by arrows, and an undirected graph shows only the lines between nodes. A valued tie in which matrix elements assume values in the set of real numbers ($a_{ij} \in \Re$) can add further information to the analysis, with values assigned to each characteristic of the tie—for example, strength, frequency, or distance Several useful measures drawn from these relational data are discussed here. Network density (D), for example, measures the number of nodes that are actually tied to other nodes in the network and is expressed as a proportion of all the possible ties in a network or

$$D = \frac{\lambda}{N(N - \lambda)/2} \quad (1)$$

where denotes the total number of lines (ties) present and N is the number of nodes in the network.

Degree centrality (C_d) measures the number of ties that a node has relative to the total number of ties existing in the network as a whole, or

$$C_d(n_i) = \lambda_i(n_i)/(N - 1) \quad (2)$$

where n_i denotes the ith node in the network, $\lambda_i(n_i)$ denotes the number of ties to n_i, and $N - 1$ represents the size of the network less the node of interest.

[5] SNA data can also be used to study bimodal networks in which nodes are tied by affiliations (e.g., memberships of actors in different types of associations) and are compiled in nonsquare $(n \times m)$ matrixes in which matrix element a_{ij} denotes actor i's tie with association j.

Table 3 Social network analysis elements

Element	Definition
Node	Any individual, organization, or other entity of interest
Ego	Actor of interest within a network
Alter	Node directly connected to an ego
Ego network	Network that only shows direct ties to the ego and not between alters
Dyad	Pair of nodes linked by a tie
Walk	A series of interconnected nodes
Path	Walk where each node and line is only used once
Geodesic distance	Shortest path connecting two nodes
Network	Graphical representation of relationships that displays points to represent nodes and lines to represent ties; also referred to as a graph
Network boundary	Natural delineation between actors and relationships, or artificial limit set by a researcher
Network size	Total number of nodes in a network
Network centralization	Degree to which a network revolves around a single node
Network density	Nodes that are actually tied as a proportion of all possible ties in a network
Centrality	Measure of the number of ties that a node has relative to the total number of ties existing in the network as a whole; centrality measures include degree, closeness, and betweenness
Degree	Number of ties a node has to other nodes
Closeness	Measure of reciprocal of the geodesic distance (the shortest path connecting two nodes) of node to all other nodes in the network
Betweenness	Number of times a node occurs along a geodesic path
Cliques	Maximum number of nodes that have all possible ties present among themselves
Core	Cohesive subgroup within a network in which the nodes are connected in some maximal sense
Periphery	Nodes that are only loosely connected to the core and have minimal or no ties among themselves
Coreness	Degree of closeness to the network core of each node
Structural hole	Weak connection area between two or more densely connected subgroups in a network, measured by either effective size or redundancy
Effective size	Network size of an ego minus the average degree centrality of its alters
Redundancy	Average degree centrality of an ego's alters, not counting their ties to the ego

Source: Authors; Borgatti (1997, 1998), Davies (2004), Hanneman and Riddle (2005)

Closeness centrality (C_c) measures the reciprocal of the geodesic distance (the shortest path connecting two nodes) of node n_i to all other nodes in the network, or

$$C_c(n_i)^{-1} = \sum_{i=1}^{N} d(n_i, n_j) \quad (3)$$

where $d(n_i, n_j)$ denotes the number of ties in the geodesic paths linking n_i and n_j.

A "clique" denotes the maximum number of nodes that have all possible ties present among themselves (Fig. 1). "Coreness," a related indicator, measures the degree of closeness of each node to the network core, wherein the network core is defined as a cohesive subgroup of nodes in which the nodes are connected in some maximal sense. Network cores are a function of network structure, meaning that identification of a core is easier in some networks (e.g., in a hub-and-spoke configuration) than in others (e.g., in a network with evenly disbursed ties or multiple cliques).

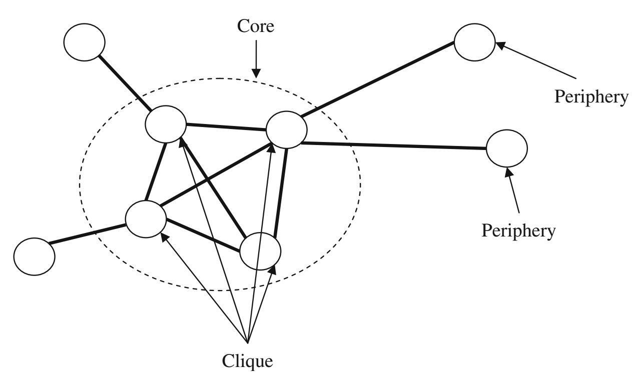

Fig. 1 Illustrations of coreness and cliques. *Source*: Adapted from Borgatti (1997, 2006)

Whether a node is a member of a network core is determined as follows. Each node is assigned a coreness score based on how close it is to the network's maximally connected subgroup. The coreness score is normalized so

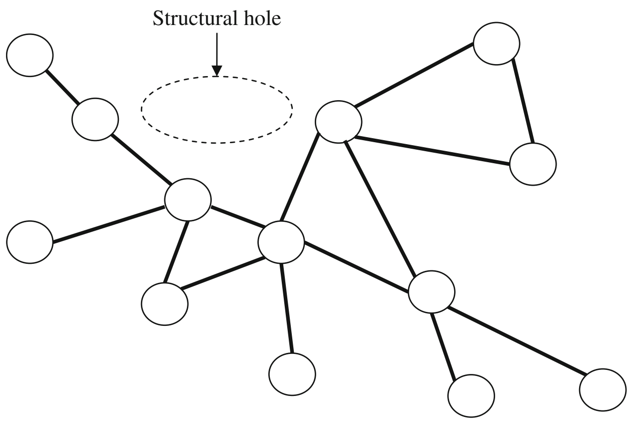

Fig. 2 An illustration of a structural hole. *Source*: Adapted from Moody (2004)

that the sum of squares is equal to 1. Concentration measures are then obtained by testing the model for different sizes of the core. This is done by first placing only the node with the highest coreness score in the core and all other nodes in the periphery. The model continues testing for different sizes of the core, from 1 to *N*. For each different size of the core, concentration scores are given for each node along with a correlation score that correlates the given coreness scores with the ideal scores of 1 for every core node and 0 for every peripheral node. A core size of *x* nodes that generates the highest correlation score identifies the core membership. Core members are identified as those with the highest coreness scores.

Structural holes denote weak connection areas between two or more densely connected subgroups in a network (Fig. 2). A test for the existence of structural holes measures the network's effective size, or the number of ties between an ego and all its alters minus the average number of ties that each alter has to other alters (i.e., ego network size minus redundancy in the network). The larger the effective size of the network, the more chances an ego has to act as a broker between two unconnected alters. A broker is the middle node of a directed triad. It may occur, for instance, when in a triad ($N = 3$) of nodes n_1, n_2, and n_3, n_1 has a tie to n_2, and n_2 has a tie to n_3, but n_1 has no tie to n_3. In other words, there is a lack of ties among an ego's alters (Borgatti 1997).

Therefore, a node's "brokerage position" is the number of nodes not directly connected to it. If a broker in a network with a relatively high effective size is removed from the network, a large number of other nodes also become separated from the network. Note that unlike coreness, there is no particular value against which to determine whether structural holes exist or whether a node is a broker; certain network structures may indicate the possible existence of structural holes, and certain nodes may have an effective size that indicates the possibility of greater chances to act as brokers.

Centrality, coreness, and the presence of cliques or structural holes have important consequences for network members. Power is relational, and the network structure can affect power relations and can offer opportunities and constraints (Hanneman 2001). For instance, an actor with high closeness centrality will be closely connected to many actors, and thus be in a position to receive information or other resources from the network. One's location in the network can offer opportunities and impose constraints. Actors with high centrality have a greater variety of choice, since they are connected to a large number of other actors. Other actors, who are cut off from parts of the network due to structural holes, or because they must go through a broker, will have fewer opportunities and choices than those who are highly connected. Structural holes can be risky; if the actor connecting two parts of the network pulled out, there would be a disconnect between two parts of the network.

Despite the useful set of indicators described above, SNA has several weaknesses. First, "complete" SNA data sets, where researchers examine every tie between actors, are extremely large. The resources needed to create a complete SNA dataset can be prohibitive, and data sets can become too large to be handled by conventional data management tools. Second, the primary emphasis placed on the ties between actors tends to be limiting. By focusing only on ties, important data on the attributes of individual actors is sometimes overlooked. Finally, SNA is criticized for its weak theoretical grounding. The importance placed on mathematical relationships tends to overshadow the efforts to develop and test hypotheses about the underlying nature of these interactions.

SNA's application to developing-country agriculture

Several studies that use SNA to examine smallholder innovation systems and processes illustrate the tool's value. Raini et al. (2006) used SNA as a tool to detect disparities in information flows among Kenyan smallholders, agrochemical firms, nongovernmental organizations, governmental agencies, international development agencies, and universities in the development and application of integrated pest management (IPM) techniques to tomato cultivation. Within the social relations underlying the networks they studied, the researchers found significant differences that influenced the interaction behavior among IPM users.

Similarly, Clark (2006) used SNA to study the introduction of information and communication technologies in supply chains for chilies, coffee, and peaches in Bolivia. The study identified key actors, information flows, and supply chain bottlenecks, and recommends ways of improving supply chain efficiency and market access for network actors. In conjunction with that study, Douthwaite et al. (2006) used SNA to develop an interactive tool for use with farmer groups in Colombia to improve members' understanding of the importance of network relationships and to strengthen their capacity to manage their networks more effectively. Conley and Udry (2001) used SNA to map networks of 450 individuals in four clusters of villages in eastern Ghana to demonstrate how farmers' social learning processes were based on communications conducted through social networks that were not determined by geographic proximity. Similarly, Giuliani and Bell (2005) used SNA to examine clusters of wine producers in Chile to show that knowledge flows and connections, instead of being influenced by geographic proximity, were influenced by firm-level absorptive capabilities (measured in terms of human resources, experience, and experimentation) such that information tended to flow through a core group of firms with advanced absorptive capabilities and a similar knowledge base. Hoang et al. (2006) used SNA to study the influence of ethnicity, gender, socioeconomic status, and power relations in rice farming communities in northern Vietnam; the influence of social networks on access to information; and the benefits of agricultural research. Darr and Pretzsch (2006) applied SNA to the study of smallholder networks within agroforestry projects. Their study, based on an analysis of data from four sample sites in rural Ethiopia and Kenya composed of approximately 200 households each, revealed that group cohesiveness, group activity, and member motivation were positively related to technology adoption, in addition to persuasive interventions from the public extension system.

However, questions remain as to whether an increasing diversity of actors within an innovation system has an impact on the capacity of smallholders and rural communities to beneficially participate in innovation processes, and how such changes can be leveraged to promote pro-poor processes of rural innovation. This question can be partly answered by examining innovation network heterogeneity and integration, or the relationships among different types of actors that form the core and periphery structures of a network. More specifically, by examining such measurable indicators as the coreness, centrality, and tie strength associated with a group of similar actors (for example, public sector institutions or private market agents), we can better understand the extent to which a given network is heterogeneous in its composition or integrated in its structure. This allows us to interpret the extent to which these characteristics contribute to, or detract from, innovativeness within smallholder networks. Thus, this study provides a descriptive analysis of the inherent characteristics, measurable relationships, and implications of the relationships among actors within smallholder innovation networks.

Results

Overview of findings

The first set of findings is drawn from the focus group interviews and semi-structured interviews conducted in the 10 enumeration areas. These are examined in the context of three specific enumeration areas using SNA in the subsequent sections, but are generally applicable across all 10 areas.

First, findings suggest that smallholder innovation processes combine a diversity of public, private, and civil society organizations, the extent of which is illustrated in Fig. 3. The ties in this figure indicate interactions in relation to the exchange of production knowledge and information, inputs and materials, credit and finance, or market links and price information. Necessarily, this is not a nationally representative figure in any sense, nor is it an empirical illustration of any one site at any one time. Rather, it is a synthesis of key actors and interactions present in smallholder innovation systems based on the combined findings from this study. The point is to characterize the entire range of possibilities in an innovation system based on composite data before breaking it down into site-specific networks.

Second, findings show that public service providers play what might be termed the most prominent role in smallholder innovation processes, at least within the localities and communities examined here. BoARDs and their development agents, *woreda* and *kebele* administrations, government-backed credit and savings institutions, and farmer cooperatives—all public, quasi-public, or state-supported rural service providers—are closely linked with smallholders, with each other, and with the process of promoting and financing the use of information and technology. This finding is not surprising in itself, but the magnitude and consistency with which these service providers are linked into smallholder networks draws attention to their role. Simply stated, extension and related public services are compelling forces in rural Ethiopia. This has important implications for how innovation networks can interact.

Third, findings suggest that although these actors are key providers of information, inputs, and credit related to improving smallholder output and productivity, their role is far less evident with respect to developing marketing links or transmitting price information to smallholders. Of course, this finding is again limited to the localities and communities examined here, but nonetheless consistent with findings from several studies cited earlier. Fourth, findings show that within these localities and communities, private sector actors—market traders, brokers, moneylenders, and private companies—were also somewhat

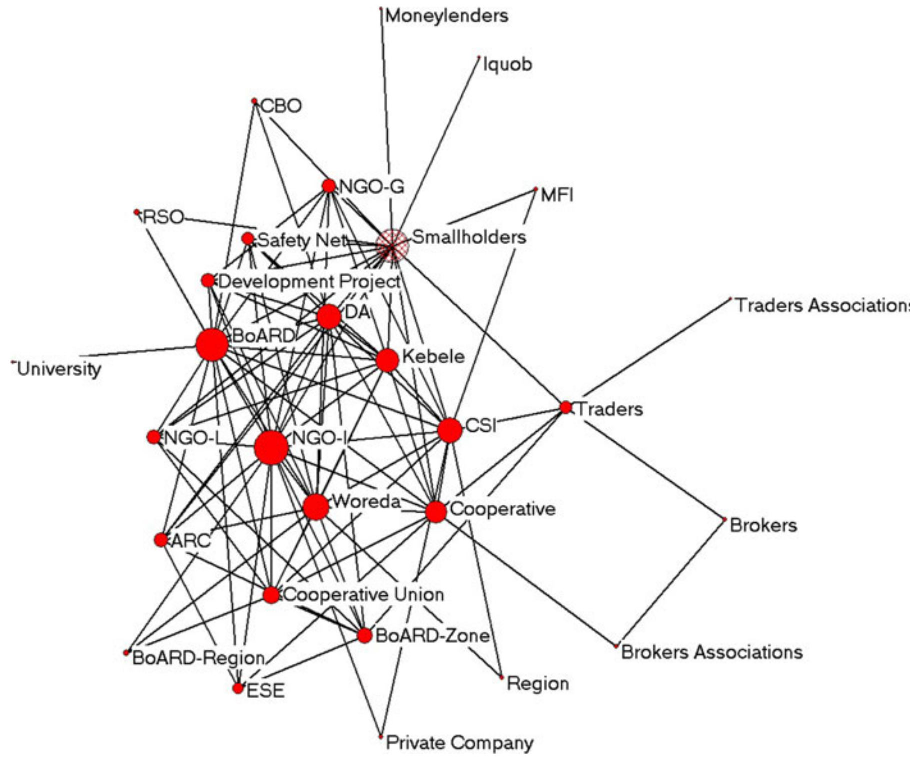

Fig. 3 Hypothetical innovators' social network. *Source*: Authors. *Note*: ARC: Agricultural Research Center; BoARD: Bureau of Agriculture and Rural Development; CBO: community-based organization; CSI: credit and savings institution; DA: development agent; ESE: Ethiopian Seed Enterprise; Iquob: rotating savings and credit association; Kebele: *kebele* administration; MFI: microfinance institution; NGO-G: government-associated NGO; NGO-I: international NGO; NGO-L: Local NGO; RSO: Religious or social organization

peripheral to smallholder innovation networks. In the case study sites where market actors actively operated, their ties to smallholders, public sector service providers, and civil society organizations were typically weak or nonexistent. Thus the government is unlikely to adequately meet its goal of commercializing smallholder productions while market actors remain peripheral to networks.

Finally, findings suggest that in those case study sites where civil society organizations operated, their ties to these same actors were relatively stronger. This finding applies to various organizations, including local and international nongovernmental organizations (NGOs), NGOs more closely associated with the government of Ethiopia, and community-based organizations established under the auspices of NGO activities. Moreover, NGOs were often tied not only to local public sector service providers but also to a range of other actors beyond the immediate locality, such as research institutes and universities. While many of the government actors were central to the network core and form cliques and have high centrality, these NGOs had far-reaching ties that are much more likely to bring new information and opportunities to innovation networks. This is consistent with the notion of "the strength of weak ties" described by Granovetter (1973).

Findings from these 10 cases demonstrated that differences exist among smallholder innovation networks, both within and between communities, with respect to such elements as network size, network density, and distance from different nodes and with respect to the influence that these networks have on smallholder innovation. Thus, we dig deeper into these findings with several site-specific cases in the subsections that follow. The three cases below were chosen for illustrative purposes only, that is, because they capture different types of smallholder innovation systems with different SNA attributes.

Wemberma: the importance of being core

The *woreda* of Wemberma is a highland district in the Amhara region where surpluses of maize and wheat are grown. Wemberma illustrates how innovation processes in the *woreda* combine technological changes (adoption of improved seed-fertilizer packages for maize and diversification into new crops/technologies such as onions and apiculture) with organizational changes (close strategic coordination among public service providers of inputs and credit) and institutional changes (individual marketing of crop surpluses through local market actors and collective marketing through cooperatives). Wemberma also illustrates how smallholders (both innovators and non-innovators) depend on a small number of key nodes for production inputs, credit, and information—namely, the local BoARD, the local cooperative and the Amhara Credit and Savings Institution (CSI), as shown in Fig. 4. These three institutions, along with the kebele administration, operate as a closely tied network for the smallholder: access to inputs from the BoARD requires access to credit from the cooperative or CSI, which in turn depends on a

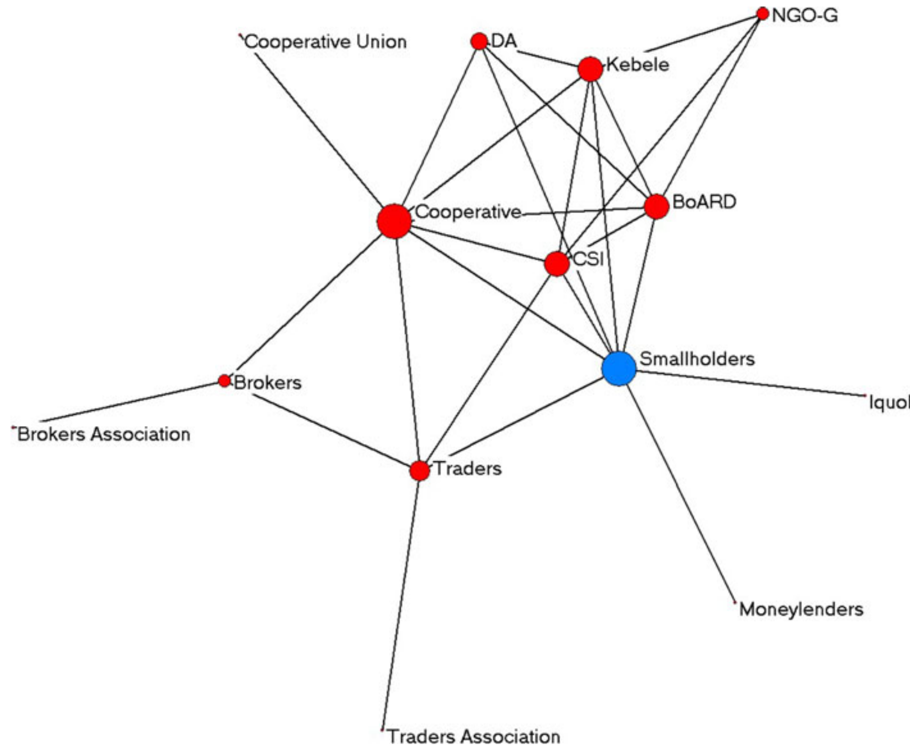

Fig. 4 Map of Wemberma *woreda's* innovation network. *Source* Authors. *Note* The size of each node is determined by the node's degree centrality, or the number of ties that the node has relative to the total number of ties in the network as a whole. BoARD: Bureau of Agriculture and Rural Development; CSI: credit and savings institution; DA: development agent; Iquob: rotating savings and credit association; Kebele: *kebele* administration; NGO-G: government-associated NGO

referral from the kebele administration. At the same time, smallholders in Wemberma depend on an even smaller number of key nodes for market information and links—nodes that are almost entirely delinked from the production-related network.

One way of representing this phenomenon is to examine the network structure in Wemberma in terms of cliques. An analysis of subgroups within the Wemberma network shows that three cliques exist, each with a minimum network size of four, and each revolving around the provision of key agricultural inputs (seed, fertilizer, and credit) with some degree of redundancy:

1. Smallholders, BoARD, development agent, cooperative, and *kebele* administration.
2. Smallholders, BoARD, CSI, and *kebele* administration.
3. BoARD, CSI, government-associated NGO, and *kebele* administration.

The BoARD and *kebele* administration are the closest actors to each other in the sense that they share membership in all three cliques. However, market-related actors (traders, brokers, and their associations) do not share any membership with these actors, indicating that market actors are relatively unconnected to other network actors.

Another way of representing this phenomenon is with an analysis of coreness in the network. Since core membership (described earlier) is identified by the core size of x nodes that generates the highest correlation score, Table 4 provides measures of those nodes that belong to the network core in Wemberma. Here, smallholders, the *kebele* administration, and the BoARD (all of which are nodes found in the network's three cliques) are closest to the network core, followed by cooperatives, the CSI, and the development agent. This implies that core membership in the network is satisfied by the presence of six nodes (all of which are denoted by asterisks). Interestingly, all of these actors are public sector organizations, implying that market-related actors can be viewed as peripheral to the network. In numeric terms, these market-related actors are represented by low coreness scores ranging from 0.006 to 0.213, while the public sector organizations are represented by higher coreness scores ranging from 0.306 to 0.419. Implicitly, we may conclude that smallholder innovativeness in this network is driven by public sector organizations rather than private market actors.

Another finding from Wemberma is that innovation networks vary within communities. Closer examination of networks associated with the two focus groups studied in Wemberma reveals important differences (Fig. 5, panels a and b). First, innovators have more ties to a larger number of actors than non-innovators. Because these ties are not inter-connected themselves, this makes the innovators networks larger but less dense than non-innovators. This is denoted in Table 4 with an ego density score for the innovator's network of 35.71 (out of a possible 100) compared to 66.67 for the non-innovator's network. Second, innovators' networks are more centralized and closer, denoting greater proximity (shorter walks) to other actors.

Table 4 Key network measures, Wemberma

Actor	Normalized coreness score	Possible core size	Correlation score
Smallholders*	0.468	1	0.441
*Kebele**	0.419	2	0.586
BoARD*	0.419	3	0.723
Cooperative*	0.361	4	0.802
CSI*	0.319	5	0.853
DA*	0.306	6	0.910
Traders	0.213	7	0.899
Government-associated NGO	0.201	8	0.896
Moneylenders	0.078	9	0.798
Iquob	0.078	10	0.712
Cooperative union	0.060	11	0.616
Brokers	0.037	12	0.495
Traders association	0.036	13	0.362
Brokers association	0.006	–	–

Measure[a]	Innovators	Non-innovators
Ego network size (no. of nodes)	8 (13)	6 (11)
Ego density	35.71 (100)	66.67 (100)
Network centralization (%)	39.74 (100)	23.64 (100)
Freeman's normalized closeness centrality	68.42 (100)	64.71 (100)
Normalized degree centrality	61.54 (100)	54.55 (100)

*Network core and clique members

[a] Highest possible value for each measure is given in parentheses

Note: BoARD: Bureau of Agriculture and Rural Development; CSI: credit and savings institution; DA: development agent; *Iquob*: rotating savings and credit association; *Kebele*: *kebele* administration

This is denoted in Table 4 as higher scores for network centralization, Freeman's normalized closeness, and normalized degree centrality for the innovators' networks. This suggests that innovators have greater access to sources of knowledge/information, inputs/materials, credit/finance, and market links/price information, and that access gives them a potentially greater number of livelihood options and opportunities than possessed by non-innovators. Third, non-innovators have fewer ties to traditional or informal institutions (such as *iquob*—funeral groups—or local moneylenders) compared with innovators, as shown in Fig. 5. This suggests that non-innovators have less access to informal sources of credit, finance, and risk management.

The implications of the findings to smallholder innovation networks in Wemberma are (a) public service providers are key nodes with respect to the provision of production information and resources, (b) market actors are largely peripheral, and (c) within-community variations exist in terms of the structure and role of innovation networks. In a surplus output *woreda* such as Wemberma, those findings suggest that the network may be insufficiently configured to provide smallholders with ties to the marketing side: neither market links nor price information are transmitted through the subnetwork of public service providers to any significant extent, and the subnetwork of private market actors is relatively disconnected from other actors relevant to smallholders. As a result, smallholders operate with little access to market-related information. The core—periphery structure suggested by a marketing network that is largely separated from the tightly linked production network can potentially constrain the ability of smallholders to innovate effectively—to change their on-farm practices and strategies—in response to changes in the market.

Soro: a case of diversified networking in action

The Soro *woreda* in Southern Nations, Nationalities, and People's Region (SNNPR) is a major enset (false banana, or *Ensete ventricosum*) growing region. Food staple crops such as wheat, teff, and maize are also cultivated in the *woreda*. In recent years, Soro's BoARD has introduced several improved varieties of these cereals, along with higher-value crops such as oilseed and potatoes, and new water-harvesting techniques.

Findings from Soro indicate that its innovation network is more diverse than that of Wemberma in terms of the number and types of actors, with public service providers playing a less central role in the network (Fig. 6). Soro's network includes additional research-oriented actors (ARC1, ARC2 and ARC3) and NGOs which add heterogeneity in a manner that is not present in Wemberma. And

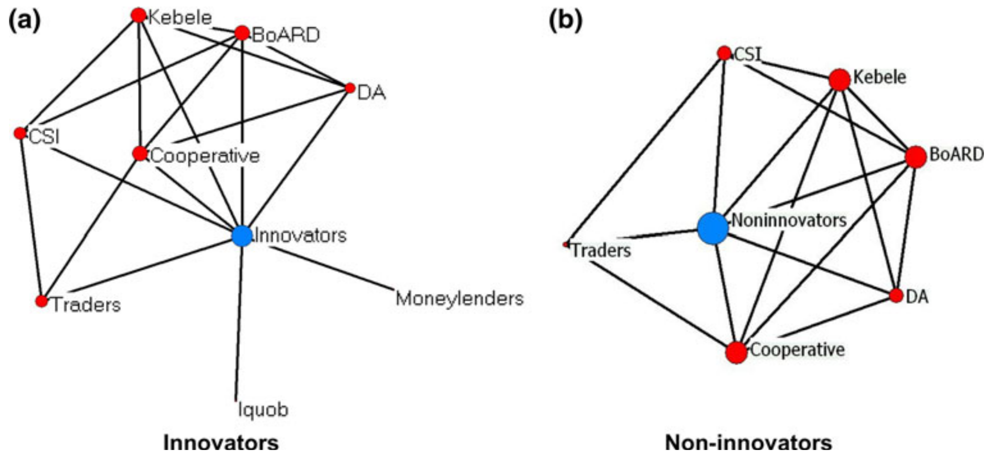

Fig. 5 Ego network of innovators (*panel a*) and non-innovators (*panel b*), Wemberma. *Source*: Authors. *Note*: The size of each node is determined by the node's degree centrality, or the number of ties that the node has relative to the total number of ties in the network as a whole. BoARD: Bureau of Agriculture and Rural Development; CSI: credit and savings institution; DA: development agent; Iquob: rotating savings and credit association; Kebele: *kebele* administration

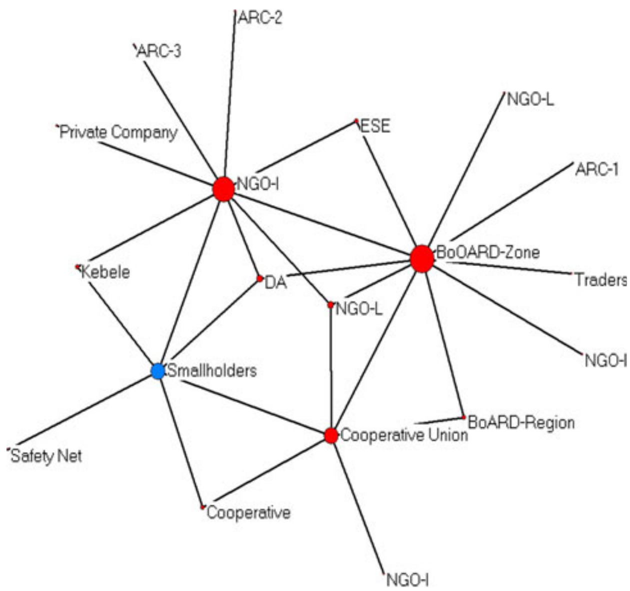

Fig. 6 A map of Soro *woreda's* innovation network. *Source* Authors. *Note* Ties indicate relationships between nodes. Node size is calculated based on degree centrality. ARC-1/ARC-2/ARC-3: three agricultural research centers active in the Soro network; BoARD-Region: Regional Bureau of Agriculture and Rural Development; BoARD-Zone: Zonal Bureau of Agriculture and Rural Development; CBO: community-based organization; DA: development agent; Kebele: *kebele* administration; NGO-G: government-associated NGO; NGO-I: international NGO; NGO-L: local NGO

although smallholders in Soro still depend on the BoARD for access to production information and inputs, it is the local and international NGOs and market-related actors who are particularly active in this network. Interestingly, this may apply to both innovators and non-innovators, both of whom exhibit similar social network characteristics in terms of their scores for ego density, network centralization, Freeman's normalized closeness, and normalized degree centrality given in Table 5.

One way of illustrating these differences using SNA is to examine how key nodes form "bridges" between core

Table 5 Structural holes and brokerage measures in Soro *woreda* network

Actor	Effective size	Broker measure
BoARD-Zone	9.00	40
NGO-I (World Vision)	7.89	31
Cooperative union	5.17	12
Smallholders	5.00	12
NGO-L	1.68	1
DA	1.68	1
Cooperative	1.00	0
Kebele	1.00	0
Safety net	1.00	0
NGO-I	1.00	0
NGO-I	1.00	0
NGO-L	1.00	0
ESE	1.00	0
BoARD-Region	1.00	0
Private company	1.00	0
ARC-1/ARC-2/ARC-3	1.00	0
Traders	1.00	0

Measure[a]	Innovators	Non-innovators
Ego network size (no. of nodes)	5 (10)	5 (9)
Ego density	20.00 (100)	20.00 (100)
Network centralization (%)	45.10 (100)	39.54 (100)
Freeman's normalized closeness centrality	48.64 (100)	51.54 (100)
Normalized degree centrality	27.78 (100)	27.78 (100)

[a] Highest possible value for each measure is given in parentheses

Note: ARC-1/ARC-2/ARC-3: three agricultural research centers active in the Soro network; BoARD-Region: Regional Bureau of Agriculture and Rural Development; BoARD-Zone: Zonal Bureau of Agriculture and Rural Development; CBO: community-based organization; DA: development agent; Kebele: kebele administration; NGO-G: government-associated NGO; NGO-I: international NGO; NGO-L: local NGO network actors and more peripheral actors. In Soro, the bridges include an international NGO (World Vision), the BoARD, and the cooperative union. Without those bridges, the Soro network would break into separate networks. This implies that structural holes exist within the network, where single nodes lie along the *only* walks between one part of the network and another. Implicitly, this means that information and resources from peripheral actors (e.g., regional agricultural research centers) must pass through these bridges to reach smallholders.

Measurement of the network's effective size (described earlier) provides a test for the existence of structural holes in a network. In the case of Soro, World Vision and the BoARD both have a relatively high number of ties compared with their alters (see Table 5). This indicates high effective sizes of their ego networks, suggesting that their locations are structural holes in the network. If World Vision and the BoARD were removed from the network, numerous other actors would also be lost. Another way of testing this is to examine brokerage measures for these bridging actors. The zonal BoARD, World Vision (NGO-I), the cooperative union, and smallholders show relatively high brokerage scores, implying that they play a relatively larger role in connecting other nodes compared with other actors (Table 5).

The Soro case illustrates how a heterogeneous network provides smallholders with a greater diversity of options in accessing information, inputs, credit, or other resources, and how certain actors play critical bridging functions in making those options available to smallholders. Soro also illustrates how networks may be characterized not only by a greater variety and number of actors but also by more integration—that is, fewer separate subnetworks and less of a core-periphery structure. This heterogeneity potentially translates into a greater number of livelihood options and opportunities for smallholders in Soro, whereas integration can bring about greater stability in the network. And while context specificity makes it difficult to justify comparisons between sites (or to generalize to Ethiopia more generally), the Soro case suggests that heterogeneous and integrated networks, all else being equal, provide farmers with greater livelihood options.

Ambo: a case of both strong and weak ties

Ambo is a highland *woreda* in Oromia Region west of Addis Ababa, where teff is grown as the main crop, alongside improved varieties of wheat, barley, maize, linseed, and potatoes. The *woreda's* innovation network is relatively large and diverse compared to other *woredas* covered in the study, which could be due in part to its relative proximity to Addis Ababa, Ethiopia's commercial center. In addition to the usual public service providers, the network includes local and international NGOs, agricultural research centers, a private company, and several banks operating within the *woreda*. This case offers an opportunity to examine how valued SNA data can be used to describe the strength of ties among network actors and with respect to the transmission of specific types of information or resources. Data gathered from the PRA exercise described earlier provide values for tie strength as follows: 1 = not so important, 2 = somewhat important, and 3 = very important.

With respect to the provision of production knowledge and information, innovators in Ambo view their ties with the Oromia Credit and Savings Share Company (CSI) as stronger than other ties relating to the same services (see Fig. 7, panels a and b). The importance placed on the role of the Oromia CSI in Ambo is, according to feedback from smallholders interviewed for this study, a result of the share company's intensive engagement in the *woreda*. The company does more than disburse loans for purchasing oxen, seed, and fertilizer; fattening livestock; renting land for commercial cultivation; or engaging in petty trade. It also operates a training program to educate farmers on the company's various savings and loan programs, and on how to use loans effectively (e.g., how to engage in profitable livestock fattening). In short, the company provides both financial and training services in Ambo.

This finding is an interesting contrast to the observation at other sites that few smallholders, when asked about their key sources of production knowledge/information, consider their local credit and savings institutions as important as the BoARD or other public service providers. Thus, by examining individual actors' perceptions of the strength of ties, the study of the Ambo *woreda* shows that the roles played by actors in a network can vary. The provision of information and resources from farmers need not follow a set pattern that is consistent from site to site. Rather, different actors can play different, possibly overlapping or complementary, roles that may nonetheless contribute to increasing the number of livelihood options and opportunities for smallholders.

Conclusions

This study asks whether changes in Ethiopia's agricultural sector are improving the ability of smallholders to innovate, and thus improve their own welfare. The study presents an analysis of smallholder innovation networks in rural Ethiopia. Using tools drawn from social network analysis (SNA) within an innovation systems conceptual framework, it examines how various types of networks relate to the innovation practices of smallholders in case studies conducted in 10 localities across Ethiopia. Findings

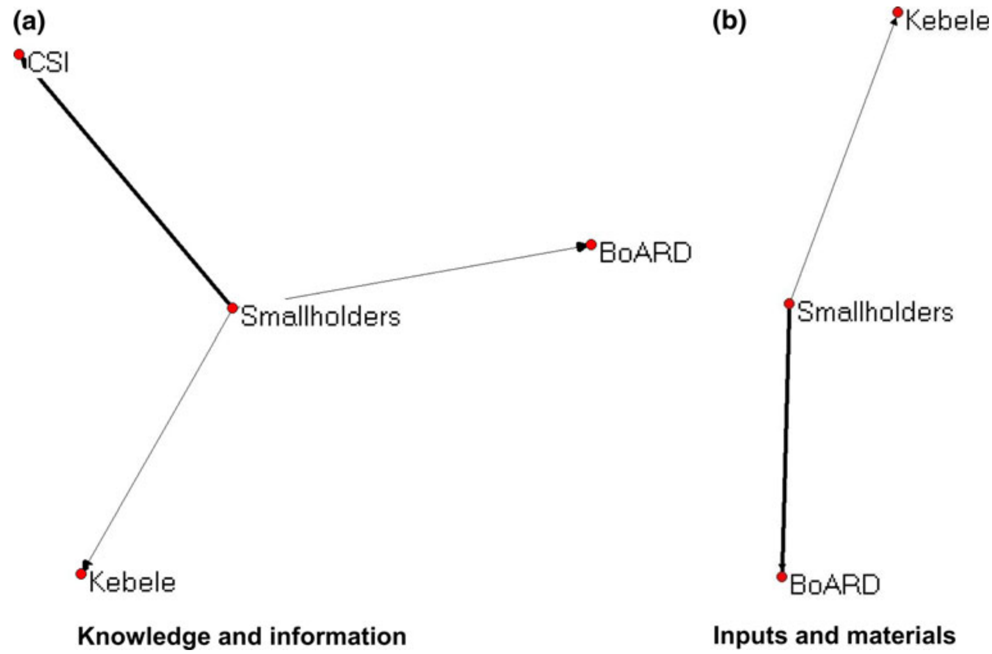

Fig. 7 Smallholder ego network for knowledge and information (*panel a*) and inputs and materials (*panel b*), Ambo. *Source* Authors. *Note* Line thickness denotes the strength of tie on a scale of 1–3. BoARD: Bureau of Agriculture and Rural Development; CSI: credit and savings institution; Kebele: *kebele* administration

offer several insights with respect to development theory and methodology, on the one hand, and development policy and practice, on the other.

From a theoretical and methodological perspective, the study demonstrates the potential contribution of the innovation systems approach to understanding how innovation occurs in developing-country agriculture, and how smallholder innovation networks are central to these systems. The study adds to this by demonstrating the utility of social network analysis in analyzing the relations between innovation system actors, visually, mathematically, and through descriptive analysis.

By applying SNA within an innovation systems approach, this study has provided some novel perspectives and tools for future investigations of rural innovation, knowledge flows, and access to resources. SNA concepts such as centrality, brokerage, coreness, and cliques provide unique insights into rural innovation networks are critical to such investigations. This study also illustrates the need for new tools that allow researchers to (a) compare different network architectures and (b) test hypotheses relating to the relationships between different architectures and their impacts on innovation. While the present study does not fully address this topic, it raises obvious questions that could open the door for further methodological development.

From a policy perspective, the study reveals the central role played by interconnected public organizations in Ethiopia's smallholder innovation system, and the peripheral role played by market and civil society actors, at least in the localities and communities examined in the 10 enumeration sites. While these observations are not nationally representative, they do suggest the need for further study on the role of non-state actors in the agricultural sector, particularly in light of the government's strategic emphasis on smallholder commercialization as a means of enhancing productivity and reducing poverty.

In summary, SNA provides useful insights into the inherent characteristics, measurable indicators, and implications of possible means to enhance smallholder innovation networks in Ethiopia. This form of analysis may also offer insights that can be useful in developing policies to strengthen smallholder innovation processes in Ethiopia, and to develop a more dynamic and competitive agricultural sector in the country.

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