A Social Network Analysis of a Regional Automated Wood Pellet Heating Industry in Pursuing Homeowner Satisfaction

Tian Guo Jessica Leahy Emily Silver Huff
Cecilia Danks Maura Adams

Abstract

Our study examined relationships among pellet mills, bulk delivery companies, and high-efficiency pellet boiler equipment firms in northern New England as they relate to homeowner satisfaction, using social network analysis and the concept of supply chain management. The continual growth of supply and demand for automated pellet heating requires a careful match between innovative technologies and homeowner needs; these involve multiple factors and require collaboration among firms. Using interview data with managers from pellet mills, bulk delivery companies, and equipment firms in Maine, New Hampshire, and Vermont, we found 15 firms that are connected through both a transaction network and an informal business interaction network. The networks were characterized by short paths and no obvious sign of centralization. Network statistics reported for each network included density, clustering coefficient, and degree, closeness, and betweenness centrality. Most firms in the supply networks shared customer satisfaction information (average number of information sending ties = 3) and considered collaboration in customer services important (mean = 4.4, on a 5-point scale). However, equipment firms initiated more information sharing than other types, and bulk delivery companies were in the best position in the supply network to promote collaborative customer services. Opportunities exist to improve communication between pellet mills and equipment firms, leading to a robust automated pellet heating supply chain, strong demand, and subsequent homeowner satisfaction.

Recent developments in technology and environmental innovation, including the invention of automated bulk-fed, high-efficiency pellet boilers and conveying systems, allow private households to be heated with wood pellets as the sole central fuel source (Thomson and Liddell 2015). Compared with traditional wood pellet stoves, automated pellet heating systems feed fuel directly to the boiler from a storage unit when the thermostat indicates the need for heat (Northern Forest Center n.d.). Less maintenance than with traditional wood pellet stoves is required, including less ash removal and fuel feeding. Pellets are delivered to homes through professional bulk delivery services.

While wood pellets have been manufactured in the United States since the 1930s (Lu and Rice 2011), these modern technologies were introduced to the United States from Europe in the mid-2000s. In northern New England, the focus of our research, the technologies have spread throughout communities along with a growing supply of boilers and bulk delivery services. Approximately 1,000 automated pellet heating systems have been installed in the region since 2012. New forest product companies have emerged to import and sell automated pellet systems and to provide bulk pellet delivery services there. Collectively, pellet manufacturers and bulk delivery and equipment firms help fulfill household heating needs where infrastructure such as natural gas pipelines is not available, especially in rural areas. These systems also contribute to the local forest-based economy (Woodall et al. 2011; Brandeis and Guo 2016), decrease net carbon emissions compared with oil and

The authors are, respectively, Postdoctoral Research Fellow, Univ. of Michigan, Ann Arbor (tianguo@umich.edu [corresponding author]); Professor of Human Dimensions of Natural Resources, Univ. of Maine, Orono (jessica.leahy@main.edu); Assistant Professor, Michigan State Univ., East Lansing (ehuff@msu.edu); Associate Professor, Univ. of Vermont, Burlington (cecilia.danks@uvm.edu); and Program Director, Northern Forest Center, South Portland, Maine (madams@northernforest.org). This is paper 3547of the Main Agric. and Forestry Experiment Sta. This paper was received for publication in October 2017. Article no. 17-00055.

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propane (Buchholz and Gunn 2016), and reduce regional dependence on foreign fossil fuels (Pa et al. 2013).

To promote continual diffusion of these modern wood heating technologies, it is crucial to ensure that customers, including the private homeowners, are satisfied. For any new technologies, early adopters are a major information source for potential customers (Rogers 1995). Compared with oil heating, which tends to be the default option for residential heating in the Northeast, automated pellet heating technology faces low customer awareness, and this makes word of mouth even more important. Homeowners' experiences directly determine their willingness to recommend automated pellet boiler systems to others (Thomson and Liddell 2015). Occasional user problems, such as an unintentional shutdown, may lead homeowners to question the reliability of the entire technological concept, rather than attributing these problems to the quality of a specific product. Quick and coordinated responses from equipment and pellet suppliers are essential to maintain satisfaction among homeowners. As an industry leader once commented about automated pellet heating technologies, ''Everybody says all the time: we are a new industry. We cannot afford to get a black eye.''

Guided by a social network analysis framework, we address three research questions:

1. How do pellet mills, bulk delivery companies, and equipment firms relate to one another in a supply network?
2. What role do individual firms play in the supply network?
3. How do firms share homeowner satisfaction information within the supply network?

Relationships between pellet manufacturers, bulk delivery companies, and equipment firms often go unrecognized, yet these social networks play a key role in meeting homeowners' needs. A wood pellet burner can malfunction or shut down if pellets are damaged or contain significant fines. Multiple factors affect the reliability of automated wood pellet heating systems, including pellets' ash content and durability, potential damage to pellets during bulk delivery, and the design of pellet storage, conveyance, and combustion systems (Thomson and Liddell 2015). These factors are intertwined, but are often controlled by separate pellet mills, bulk delivery companies, and equipment firms, which results in interdependence among these companies to ensure homeowner satisfaction. For example, when a technical problem arises, such as excessive ash or a system shut down (Thomson and Liddell 2015), a slow response from any firm that finds fault with another part of the supply chain may adversely impact the perceived reliability of automated pellet heating, thus damaging the overall image of the technology. It may be difficult to determine whether the problem is because of issues with the pellets, the delivery process, the equipment, or a combination of all of them. Coordination among firms may shorten the time needed to diagnose and solve such problems and thereby enhance positive user experiences.

Thus, our study was designed to understand the complex relations among pellet manufacturers, delivery companies, and equipment firms as they relate to homeowner satisfaction. Although there is substantial information available about the traditional wood pellet and the biofuel industries (Wolfsmayr and Rauch 2014), little is known about how individual firms interact to serve homeowner needs. We drew upon social network analysis theory. Our recommendations suggest ways to facilitate the wood pellet industry's continued collaborative capacity.

Social Network Analysis

The interactions among pellet manufacturers, equipment firms, and bulk delivery companies may be characterized as social networks. Social network analysis (SNA) examines the complex Web-like connections among companies (Lazzarini et al. 2001, Hearnshaw and Wilson 2013, Basole and Bellamy 2014). SNA views a system as a set of interrelated actors or nodes (Borgatti and Li 2009, Borgatti et al. 2013; see Table 1 for definition for basic SNA concepts). Actors connect with others through ties, which may be interactions (e.g., the activities of participants), or flows (e.g., the movement of materials or information). Using SNA, a system can be visualized in Web-like graphs and described by various statistics (Scott 1991, Wasserman and Faust 1994). Galaskiewicz (2011) noted that ''social network analysis is relevant for the management of interorganizational relations as firms attempt to share information, coordinate their schedules, and develop products and service together'' (p. 5). Lazzarini et al. (2001) elaborated the concept of netchains and emphasized that companies in supply chains are sequentially arranged based on vertical ties that reflect the sequence of the chain, while at the same time they are grouped through horizontal ties that represent the tiers of the chain.

An important proposition of SNA theory is that network characteristics influence actor and system performance (Borgatti and Li 2009, Galaskiewicz 2011, Hearnshaw and Wilson 2013). For example, Hearnshaw and Wilson proposed three network characteristics that influence supply chain management, including how many ties are required to connect any two firms in a network (named characteristic path length), how concentrated the ties are among actors (connectivity distribution), and how pairs of companies share ties to other companies (clustering coefficient). Each of the network characteristics can be captured by a few SNA measures (Table 2).

Empirical studies have just begun to examine SNA in the context of supply chain management research. Kim et al. (2011) studied the materials flow and contractual relations in an automobile manufacturing supply network. They used measures that included degree, closeness, and betweenness centrality, and compared the SNA results with case-based interpretations. Their results supported the usefulness of SNA to understand supply chains. Sloane and O'Reilly (2013) used betweenness centrality at node level and were able to describe key actors in food production networks. However, little research on empirical SNA studies of forest products has been published. Michael and Massey (1997) used SNA to model the communication within a sawmill to measure network closeness and betweenness. Anbumozhi et al. (2010) qualitatively described the interfirm network in a wood biomass industrial cluster to illustrate the complex interactions within the forest products network. Nybakk et al. (2013) found network size positively influenced the performance of firewood producers; however, they treated network size as a property of the individual firms rather than conducting an SNA. Nevertheless, these studies suggest that SNA is a promising tool to study the supply side of the

Table 1.—Social network analysis terms and descriptions.

Concept	Description[a]	Examples in this study
Node	An entity that make up the system; it is often referred to as an actor in the network	Firms
Tie	Relations among actors; they could be shared membership, interactions, and flows	Sell product to, share information
Sociogram	A Web-like graph that visualizes nodes and their relations	Figs. 2 and 3

[a] Definitions adapted from Borgatti et al. (2013) and Ashton (2008).

automated pellet heating industry in northern New England while concurrently considering demand side issues.

Methods

We examined the social networks of firms in Maine, Vermont, and New Hampshire that constitute part of the suppliers of residential automated pellet heating and studied their collaborative customer satisfaction activities.

Study context

The forest products industry has a long history in northern New England, including Maine, Vermont, and New Hampshire, but is facing severe challenges from recent pulp and paper mill closures and decreasing lumber demand. The wood pellet manufacturing industry in the region has been remarkably resilient despite low oil prices (Lu and Rice 2011). Nine pellet facilities in Maine, New Hampshire, Vermont, and New York produced about 490,000 metric tons of pellets in 2014 (Buchholz and Gunn 2016). Nearly 56 percent of total feedstock consumption by pellet mills came from forest harvesting operations, followed by almost 44 percent from sawmill residues, with less than 1 percent from other sources, such as municipal waste and yard and landscaping trimmings (Buchholz and Gunn 2016). The great majority of the forest harvesting inputs are classified as pulpwood (76%) or small-diameter trees (22%).

The region is well acquainted with wood heating. About 1.1 million households in New England use wood for space heating, including wood pellets, cord wood, and wood chips (Energy Information Administration 2015). Despite the existing wood heating market, about 80 percent of all households in Maine still use fuel oil as their primary heating source, followed by 58.6 percent for Vermont and 58.1 percent for New Hampshire (US Census Bureau Housing and Household Economic Statistics Division 2011), among the highest rates in the nation. Maine, Vermont, and New Hampshire all have policies and support programs to reduce dependence on fossil fuels. Increasing energy use from biomass sources such as wood pellets has been part of this effort. The Northern Forest Center is a nonprofit organization that actively advances innovative strategies in modern wood heat. The center has a community-based education and incentive program, named the model neighborhood project (MNP), to promote automated pellet heating in the three states. During the program, the center observed that pellet mills, bulk delivery companies, and companies that sell automated pellet boilers were the key actors in ensuring homeowner satisfaction, especially after occasional incidents of pellet boilers malfunctioning. Based on this field knowledge, we focused on these three groups of firms and the issue of homeowner satisfaction.

Table 2.—Descriptions of network characteristics and corresponding measures in UCINET.

	Descriptions[a]	Actor level measure	Network-level measure
Geodesic distance	Shortest path length between two nodes; measure characteristic path length	Smallest number of ties to connect two nodes	—
Density	To what extent an actor is connected with all other actors in the network	—	Ratio of number of ties to number of pairs in the network
Closeness centrality	How close an actor is to the other actors in the network, considering geodesic distance; measure connectivity distribution	Degree of individual node divided by the lengths of the geodesics to every other node	The sum of the difference between maximum closeness centrality among nodes and an individual node's closeness centrality, and then divided by the maximum value possible
Betweenness centrality	How often the interactions between two actors might depend on other actors; measure connectivity distribution	The sum of a node's proportion of times the node lies on the shortest path between each pair of other nodes	The sum of the difference between maximum individual node betweenness centrality and each node's betweenness centrality, and then divided by the maximum value possible
Broker	Individual actor that links components of a network together	The number of ties a node has on the shortest path between two other nodes	—
Degree centrality	To what extent ties are centralized to a small number of actors; measure connectivity distribution	Node's degree divided by the maximum possible degree expressed as a percentage	The sum of differences between individual node degree centrality and each node degree centrality, then divided by the maximum value possible
Clustering coefficient	To what extent clusters of nodes exist in a network	The density of its open neighborhood	Weighted mean of the clustering coefficient of all nodes with each one weighted by its degree

[a] Descriptions adopted from Wasserman and Faust (1994) and Borgatti et al. (2002).

Network specification

We defined our network boundary to include active pellet mills, bulk delivery companies, and equipment firms located in Maine, Vermont, and New Hampshire. To identify potential members within these boundaries, we conducted four scoping interviews in depth with community representatives from the center who have worked on the MNP and are knowledgeable about the supply and demand of automated pellet heating. We also interviewed the leader of a regional wood pellet trade association. We identified all pellet mills, equipment firms, and major bulk delivery companies located in the study region based on these interviews, and we focused our research on them. We consider these three to be related but fundamentally different types of companies. Independent boiler system installers and sawmills that provide raw materials to pellet mills were also identified in the scoping interviews. There are also delivery companies out of the study region that serve the three states. To set a boundary for the SNA, we did not include them in this study.

We focused on two types of ties that give rise to two multiactor supply networks. They are first, regular and current product transactions, and next, other informal business interactions. Transactions are strong ties among firms, the first layer of the automated pellet heating supply network. Firms with transaction ties are naturally bounded in serving homeowners, such as through quality assurance or user problem diagnosis. Firms in the supply network also interact on other occasions, such as through casual information sharing among managers, equipment parts exchange, and interaction through branches of business that are not directly related to automated pellet heating. Compared with transaction ties, these business-related interactions tend to be informal and spontaneous. We grouped them together as a type consisting of weak ties. We assumed both the transactional and other business-related interaction ties are symmetric (they flow both directions among actors). We focused on the binary values of the ties (i.e., 1 signifies that a tie is present, and 0 that it is absent).

We also studied information sharing among participants regarding homeowner satisfaction. Firms need to engage their supply chain partners in customer service in order to collectively pursue homeowner satisfaction. The activity could also be among firms of the same type, even when they may be competitors. For example, a bulk delivery company may go to a competitor to check whether instances of homeowner dissatisfaction with a certain batch of wood pellets were common or not. It is worth noting that a recipient in one pair of customer information sharing ties does not necessarily offer to send back any information, which results in nonreciprocal and asymmetric customer information sharing relations.

Data collection

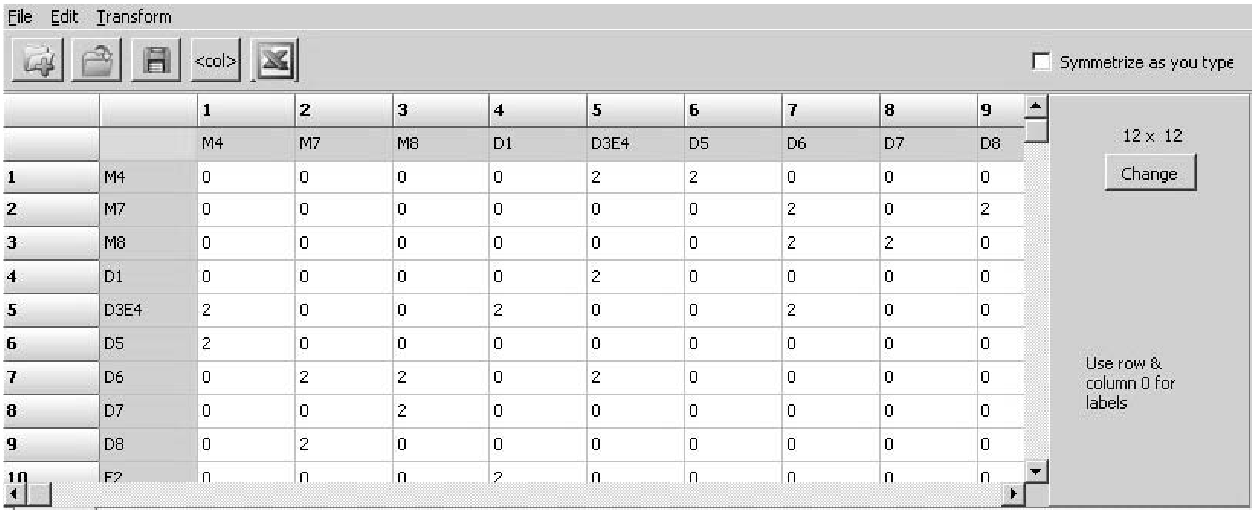
Data were collected using semistructured interviews in depth. Managers from companies were contacted through e-mail and phone. Two pellet mills were not in operation during data collection and were excluded from the study. Two additional pellet mills, newly established after 2015, had not yet sold pellets to any automated pellet heating customers. Although their managers expressed interest in the automated pellet heating market during the interviews, they were excluded from the analyses. The final population list included 15 firms located in Maine, New Hampshire, and Vermont. Among these firms, one chose not to participate because of a lack of interest. Managers from one pellet mill and two bulk delivery companies could not be reached after multiple attempts within the data collection time frame. Therefore, our effective response rate was 80 percent, which provides strong coverage of the wood pellet industry in northern New England. Another bulk delivery company based in Massachusetts and a pellet mill in New York also serve some automated pellet heating customers in Vermont and New Hampshire; they were not included in this study because they primarily serviced customers outside our geographic region of interest.

We developed an interview guide based on the literature and refined the guide through pilot interviews with the center and the regional trade association. To measure relations among actors, each participant was presented with the member list, and asked if their company: (1) buys any products from firms on the list; (2) sells any products to these firms; (3) has any other business relations with firms on the list; and (4) shares customer satisfaction information with these firms. Participants were asked to rate how frequently they collaborate with other companies in the industry on customer service and how important they rate collaborative customer service, using a 5-point scale. The interview guide also included open-ended questions that asked how respondents perceived collaborations within the industry and what specific challenges they faced. On average, an interview lasted 78 minutes. The first author conducted all the interviews at locations selected by the participants, which generally took place in their offices, and completed field notes after each interview. Interviews were recorded and transcribed verbatim.

Data analysis

Raw social network data were entered as four symmetric matrices from field notes and cross-referenced with interview transcripts (Fig. 1). We compared and merged the buying and selling matrices into a nondirectional matrix that recorded transaction ties. Missing data were filled with existing data.

To give an overview of firm relationships, we first visualized the networks using NetDraw and then conducted analyses using UCINET 6.632 (Borgatti et al. 2013). For the first research question, which concerned the relationships between pellet mills, bulk delivery companies, and equipment firms, we conducted network-level analyses, including descriptive analysis to summarize the number of firms with ties, average degrees, average geodesic distance, and density. We then analyzed the network structural properties using four statistics: degree centrality, clustering coefficient, closeness centrality, and betweenness centrality. These statistics all have values that range from 0 to 1. It is worth noting that these statistics tend to be used in comparison rather than with an absolute cut-off value. Because we did not have an automated pellet heating supply network to use as a reference for comparison, we interpreted the data jointly with the sociograms. A connected network is required to calculate network-level closeness and betweenness statistics (Wasserman and Faust 1994). Thus, following the example from Wasserman and Faust, we removed unconnected nodes and obtained closeness and betweenness centrality for a reduced network using actors that connect to at least one other member of the network. For the second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Symmetrize as you type

		1	2	3	4	5	6	7	8	9
		M4	M7	M8	D1	D3E4	D5	D6	D7	D8
1	M4	0	0	0	0	2	2	0	0	0
2	M7	0	0	0	0	0	0	2	0	2
3	M8	0	0	0	0	0	0	2	2	0
4	D1	0	0	0	0	2	0	0	0	0
5	D3E4	2	0	0	2	0	0	2	0	0
6	D5	2	0	0	0	0	0	0	0	0
7	D6	0	2	2	0	2	0	0	0	0
8	D7	0	0	2	0	0	0	0	0	0
9	D8	0	2	0	0	0	0	0	0	0
10	F2	0	0	0	2	0	0	0	0	0

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Figure 1.—Illustration of social network analysis data matrix in UCINET.

research question concerning the role of individual firms in the supply network, we conducted analyses at the node level, including ranking the betweenness and closeness of individual actors. For the third research question concerning how firms share homeowner satisfaction information within the supply network, we used descriptive analyses to assess the customer satisfaction activities of sharing firms that participated in the study. Qualitative interview data were used to interpret the quantitative results.

Results

When considering the use of wood pellets for residential heating, the automated pellet heating supply network in Maine, New Hampshire, and Vermont included five pellet mills, six bulk delivery firms, three equipment firms, and one firm that provided both equipment and bulk delivery. Most pellet mills in the sample were established before 2009. The production capacity of these mills ranges from 16,600 to 105,000 metric tons. Most pellet mill managers reported that bagged pellets are their major distribution channel, but they also supply bulk delivery companies. Bulk delivery companies are diverse; some specialize in automated pellet heating, while others deliver oil fuels as well. Three bulk delivery companies also sell and install automated pellet heating systems, and one company recently entered the bulk delivery business to integrate its tree service business. The four equipment firms all import pellet burners from Europe. They sell products to customers directly and through dealers.

Supply network configurations

Pellet mills, bulk delivery companies, and equipment firms are related through transactions. Interviews revealed that bulk delivery companies buy from pellet mills and equipment firms sell boiler systems to bulk delivery companies that also do installation. Figure 2 shows the overall pattern of transaction ties among 15 firms. To gain insights about the meaning of the structure, we arranged actors by their types and were able to obtain a sequence-like sociogram of the transaction network. Four bulk delivery companies (BD4, BD5, BD6, BD7EF4) had transactions with both pellet mills and equipment firms. BD7EF4 is one company that both delivers bulk pellets and sells equipment. Three of five pellet mills in the sample (PM1, PM4, PM5) reported transactions with more than one bulk delivery company. Bulk delivery companies, except BD4, reported transactions with one mill in the sample. Note that bulk delivery companies may procure pellets from mills outside the study region, e.g., from Canada or New York. The results did not reflect how many suppliers are used by individual bulk delivery companies. As expected, no transactions were found between pellet mills and equipment firms or within the same type of firm. One pellet mill (PM3) was considered by participants to be part of the pellet heating industry, but no transactions involving this mill were reported. This mill has the second-smallest production capacity in the sample.

Generally, firms were not densely connected through transactions (density = 0.13; Table 3). Most firms bought products from or sold products to about two other firms in the network (average degree = 2). On average, any firm was able to reach another firm in the transaction network through two other companies (average geodesic distance = 3). Given the small number of firms in the network (n = 15), the

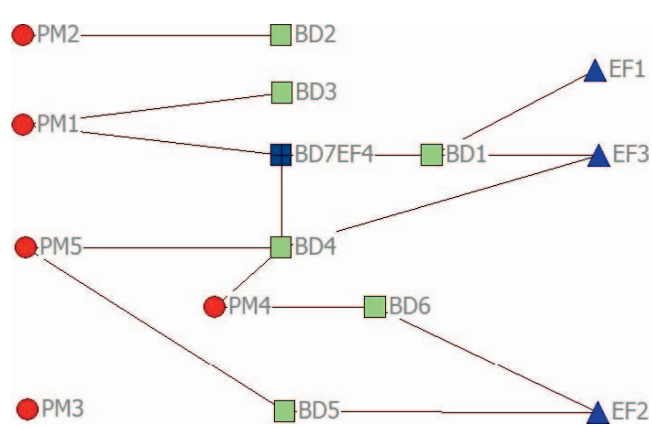

Figure 2.—Sociogram of the transaction network in the pellet heating supply chain. PM = pellet mill; BD = bulk delivery company; and EF = equipment firms. Numbers refer to specific participants. (Color version is available online.)

Table 3.—Descriptive information of central pellet heating supply networks.

Network type	No. of firms with ties	Avg. degree	Avg. geodesic distance	Density
Transaction	14	2	3	0.13
Informal business	11	2	2	0.13

characteristic path of transaction relations was relatively short, confirming the interdependence among members. The transaction network did not show strong signs of a power law connectivity distribution. The degree centrality (18%), closeness centrality (35%), and betweenness centrality (47%), all fell below 50 percent (Table 4). This suggested that there was no single firm with significantly more transaction relations than any other. The sociogram confirmed the relatively balanced connectivity distribution. Most of the triads in the network were open, supported by the low clustering coefficient.

In general, firms that do not have transaction relations may still interact with one another in their operations or through information sharing (Fig. 3). Fewer firms reported informal business relations than the number that reported transaction ties; however, there were more informal business relation ties (density = 0.13). Bulk delivery companies and equipment firms were connected through strong and weak ties. The interviews revealed that the way each brand of pellet heating system set up storage units affected delivery methods. Participants also noted that when technical problems arose, customers were most likely to contact their bulk delivery service or equipment provider. Conversely, pellet mills had few informal business relations with equipment firms except in one case (PM2-EF1). In that instance, the mill bought a pellet boiler from the equipment firm to heat its facility. Because there were no direct transaction ties between equipment firms and mills, pellet mills rarely interacted with equipment firms on a regular basis. Surprisingly, we did not observe many informal business interactions within similar types of companies. One mill-to-mill tie, two ties between equipment firms, and four ties among bulk delivery operations were observed. These accounted for 10, 33, and 19 percent of possible within-group ties, respectively.

The structural properties of informal business interaction networks were somewhat different from the transaction network. Firms were less likely to rely on other companies (closeness centrality = 31%; betweenness centrality = 35%); however, some firms were more active in engaging other companies in informal interactions (degree centrality = 34%).

Table 4.—Characteristics of central pellet heating supply networks.

Network type	Degree centrality (%)	Clustering coefficient	Closeness centrality (%)[a]	Betweenness centrality (%)[a]
Transaction	18	0.00	35	47
Informal business	34	0.26	31	35

[a] After removing nodes that are disconnected from a majority of nodes (Wasserman and Faust 1994).

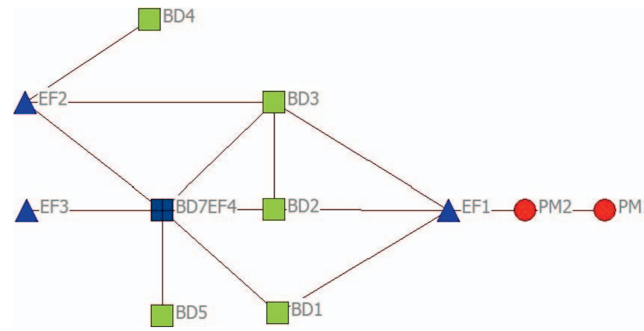

Figure 3.—Sociogram of informal business interaction network in the pellet heating supply chain. PM = pellet mill; BD = bulk delivery company; and EF = equipment firms. Numbers identify participants. (Color version is available online.)

Individual firms in the network

Individual firms differed in their network roles. Some members of the networks are more connected than others. In the transaction network, one delivery company (BD3) could reach any other firm in the network through the least number of transaction partners (closeness = 41). It was followed by two equipment firms (EF1, EF2; closeness = 39). Conversely, a different delivery firm (BD4) was most likely to be the bridging actor (betweenness = 33.5). BD4 was also the broker of the transaction network (broker = 6). In the informal business network, the delivery company (BD3) and the equipment and delivery company (BD7EF4) were the closest to the rest of the actors (closeness = 58.8). The equipment and delivery company (BD7EF4) was also most likely to be the actor bridging other firms in the informal business network (betweenness = 21) as well as being the broker of the operation network (broker = 13). Firms BD2 and BD3 provide delivery services but do not install. Although they did not have transaction relations with equipment firms, they interacted with them informally. In comparison, delivery companies that do system installations (BD4, BD5, and BD7EF4) were more embedded in the automated pellet heating supply network.

Customer service

Individual firms reported that they share customer satisfaction information with other firms in the network. However, firms differed in whether they initiated customer satisfaction information sharing. As information sender, on average, an individual firm shared customer satisfaction information with three firms, with a standard deviation (SD) of 3 (Table 5). An equipment firm reported the most customer information sharing ties with other firms (11), while two pellet mills reported the fewest customer information sharing ties (0). On the recipient end, an individual firm received customer satisfaction information from three firms on average, with an SD of 1.

We observed a discrepancy between initiating and receiving customer satisfaction information. Pellet mills tended to be on the recipient end of this information, while bulk delivery companies and equipment firms tended to initiate customer satisfaction sharing. This is not surprising because bulk delivery companies and equipment firms are more likely to be in direct contact with homeowners. They are located downstream from the automated pellet heating supply chain. Individual delivery companies are most likely

Table 5.—Summary customer satisfaction information sharing ties between individual firms.

	Mean	SD	Min.	Max.	% within-group sharing[a]
Sending					
Whole network	3	3	0	11	—
Pellet mills	1	1	0	2	0
Bulk delivery firms	3	2	1	6	35
Equipment firms	7	3	4	11	14
Receiving					
Whole network	3	1	0	5	—
Pellet mills	3	1	1	4	—
Bulk delivery firms	3	1	2	5	—
Equipment firms	2	2	0	3	—

[a] Average percentage of within-group sharing was calculated as the number of within-group information sharing ties (e.g., information sharing among pellet manufactures) divided by the total number of information sharing ties (i.e., information sharing within and outside the subgroup).

to share customer satisfaction information with other delivery companies. An estimated 35 percent of all information ties of bulk delivery companies were with other such companies, compared with 14 percent that communicated among equipment firms. Pellet mills in our sample did not report any customer satisfaction sharing with other pellet mills in the sample.

Ten of the 15 managers from firms in the sample answered the questions about how frequently they collaborate with other companies in the industry on customer service and how important they rate collaborative customer service. On average, managers occasionally collaborated with other companies in the industry (mean = 2.6, 1 = almost never, 2 = rarely, 3 = occasionally, 4 = frequently, 5 = very frequently), which was consistent with the customer information sharing activities they reported. All managers considered collaborative customer service important or very important (mean = 4.4, 1 = not important at all, 5 = very important). The gap between collaboration frequency and importance perception suggests opportunities for growth.

Discussion

By defining the complex nature of firm-to-firm interactions and connectedness, our analyses revealed that automated pellet heating supply in northern New England is better described as a network than as a linear sequence of firms. Demand for automated wood pellet heating requires supplies of pellets, equipment, and bulk delivery services. We uncovered two types of networks that supported automated pellet heating. There are transactional relations between pellet mills and bulk delivery companies and between bulk delivery companies and equipment firms. These firms are also connected through diverse informal business interactions, such as operational problem solving, and by sharing storage facilities. This finding suggests that communication channels existed beyond formal transaction relations. Compared with the supply network in the automobile industry in Korea (Kim et al. 2011), the automated wood pellet heating supply network has higher density and centrality statistics. However, considering the significantly smaller network size and differences in the industry, the automated wood pellet heating supply network is characterized by an absence of centralized power and relatively short paths among participants. Like the food production network studied by Sloane and O'Reilly (2013), there are brokers in the automated pellet heating network that connect actors. Firms in the networks shared customer satisfaction information, which supported the complex interactions with the forest products network found by Anbumozhi et al. (2010). However, equipment firms were more likely to engage in satisfaction information sharing than others. Finally, all actors in the networks perceived collaboration in customer services as important but infrequent.

Homeowner satisfaction

Interfirm relations result in challenges and opportunities unique to pursuing automated pellet heating homeowner satisfaction. Pellet quality influences automated pellet heating experiences. With bulk delivery, pellet mills do not necessarily connect directly with homeowners. Residential bulk delivery companies may or may not reveal brands to their customers. The tasks of monitoring pellet quality and distributing feedback generally fall on bulk delivery companies. Bulk sale itself is not the major outlet for pellet mills. In addition, most mills in our sample reported they work with two bulk delivery companies. To make bulk pellets price competitive, delivery companies are constrained to select pellet suppliers that are nearby. Therefore, bulk delivery companies do not have much negotiating power with pellet mills. The mills are more likely to be motivated by users of bag pellet, who are more sensitive to pellet quality and who are their primary clientele. Automated wood pellet heating demand has not grown to the point where it can dictate upstream product quality.

Our network analysis did not reveal any regular transaction relations between pellet mills and equipment firms. This has implications for ensuring current homeowner satisfaction and promoting technology advancement. Some technical problems of automated pellet systems relate to pellet durability. Generally, pellets used in automated systems receive more impacts compared with those used by pellet stoves. Pellets that break during delivery and in the conveying process from the storage unit to the burner could clog the system and cause shut downs. Automated systems are designed to be more tolerant of pellet quality. However, when user problems occur (which is to be expected in any heating technology), there is uncertainty whether the problems should be attributed to pellet quality, delivery methods, or equipment design. A potential way to navigate this uncertainty is through collaborations among firms in customer service and technology improvement, particularly between the mills and equipment firms. This approach aligns with supply chain management philosophy (Mentzer et al. 2001). Although most study participants indicated that the pellets for an automated pellet boiler system are the same as those for pellet stoves, the pellet could be adjusted to the specific handling methods in the bulk delivery process and in the design of burners. Two pellet mills reported they adapt their manufacturing process for bulk delivery, but it seems uncommon among other mills. It is worth noting that one pellet mill reported that at one point they imported equipment with the ultimate goal of increasing demand, but they sold out this branch of their business to focus on pellet manufacturing. Although upstream integration of pellet manufacturing and equipment importing may not be efficient, the industry could benefit from more interactions among mills and equipment firms.

Key actors

Residential bulk delivery companies may play a key role in mobilizing interactions within the automated pellet heating supply network. The transaction sociogram revealed that many bulk delivery companies were connected with both pellet mills and equipment firms. At the node level, delivery companies were found to be close to other members of the network and thus more likely to be the bridging actor and broker of the network. They may be more dependent than the others on the performance of equipment firms and pellet mills. A bulk delivery company manager mentioned that they needed to learn pellet boiler mechanisms quickly when their customers called in with a problem and questioned whether it was a fuel quality issue. The technical support from equipment firms to bulk delivery companies is important but insufficiently recognized. Conversely, bulk delivery companies are the frontline of automated pellet heating supply. They are in contact with homeowners on a regular basis and have firsthand understanding of their needs. Bulk delivery companies differed in their interest in the automated pellet heating business. Some companies are traditional oil delivery suppliers and got into the pellet delivery business to diversify their products, while other delivery companies specialized in pellet boiler installation and bulk delivery. These diverse interests influence how much effort an individual bulk delivery company would be willing to invest in the automated pellet heating industry. Some bulk delivery companies are more likely than others to emerge as leaders of the automated pellet heating industry, as are equipment firms.

Despite the promising role delivery companies could play because of their position in the network, equipment firms more often initiate customer information sharing compared with bulk delivery companies. It is not surprising that equipment firms, which introduced automated pellet heating technologies to the market, also carry a greater burden to promote the technologies through ensuring customer satisfaction; their reputation, and thus their longevity, depends on it. It seems their motivation, not their position in the network, compelled them to initiate more customer satisfaction information sharing. This finding aligns with the reasoning of Hearnshaw and Wilson (2013) about efficient supply networks. A supply network could benefit from a firm and its hub of partners that take the lead in improving performance, which in our case is to ensure customer satisfaction. However, the effects may not be evident in the overall network characteristics, especially when the network is relatively small and young in development.

Policy implications

The results have implications for state governments and nonprofit organizations. To achieve diffusion through a community, promotion of wood pellet boiler systems requires careful matching between technologies and pellet supply on one hand and homeowner needs on the other. Policy investment in wood-based sustainable energy development is likely to generate economic impacts in multiple economic sectors, including manufacturing, sales, transportation, and services, because the supply side has grown into a network of firms during the past decade. Promotion of automated pellet heating needs will benefit individual firms and the entire network; it may also create a variety of job opportunities that matches the capacity of existing work forces. Automated pellet heating supply is essentially an energy business. Compared with the oil or natural gas industry, much of the automated pellet heating business, especially for pellet manufacturing and delivery, operates on a local scale. As such, economic benefits are more likely to stay in the immediate region and thus promote a sustainable and vibrant local economy. The network of firms could be leveraged to promote innovation diffusion and augment the economic, social, and environmental benefits. Governments and nonprofits could also use the results to improve programming and diffusion of the automated pellet heating technologies. For example, some study participants reported examples of companies that work together to solve user problems. These examples could be summarized as best practices and used in educational campaigns directed at homeowners to build an industry image that is approachable, innovative, responsive, and reliable. By establishing examples of how good companies operate, such a campaign would also teach potential customers how to select equipment and delivery service providers. It would help separate the performance of an individual company from the performance of the entire technological industry. Finally, most incentive and homeowner education programs have worked with key actors in the network, but more attention could be given to hubs of companies that include pellet mills, delivery companies, and equipment firms to promote best practices that will ensure homeowner satisfaction.

Limitations and future research

This study has a few limitations that are worth noting. We conceptualized ties among firms as binary and symmetric. Such an approach helped to build basic networks that reflect relations among pellet mills, bulk delivery companies, and equipment firms. However, this approach lacks details on how companies interact on a daily basis. We did not collect data on the frequency and number of transactions out of concern that participants would be reluctant to share this information. We were able to use existing data to construct transaction and informal business interaction networks under the symmetric ties assumption. However, for the customer information sharing ties, directionality matters. We were not able to construct a customer information sharing network. The node-level analyses helped to summarize the information. Although the analyses were descriptive, they suit the research questions. Using longitudinal data in the future, we could run advanced statistical analyses on network characteristics and address more complicated questions, such as how the supply network structures influence the activities and performance of firms.

This study could be expanded to include other parts of the forest products industry. It would put the relations among pellet mills, bulk delivery companies, and equipment firms in a larger and more complex network. The results would elucidate how wood pellet demand influences the broader forest economy. Future research could also compare automated wood pellet heating supply in northern New England with other regions in the United States and in other countries. For example, the automated pellet heating technologies were first invented and diffused in European countries, including Austria, Sweden, and Norway. Comparisons of the supply side development processes may help reveal common challenges in dispersing sustainable energy innovation and help advance knowledge about how cultural, natural, economic, and policy environments influence the growth of the sustainable energy industry. Continually tracing development of the automated pellet heating industry in the region will provide valuable longitudinal information that will shed light on the diffusion processes. Future studies could examine how a firm's position in the network influences its customer satisfaction performance.

Conclusions

Automated residential wood pellet heating is an environmental innovation that is diffusing through demand and supply growth. The market success of the technologies relies on homeowner satisfaction, which is influenced by a variety of factors. To this end, pellet mills, bulk delivery companies, and equipment firms need to serve automated pellet heating needs collectively and advance the technology. They relate to one another through transactions and informal business interactions. No obvious centralization was identified in the networks. Most firms in the supply networks shared customer satisfaction information and considered collaboration in customer services to be important. However, equipment firms initiated more information sharing than other types of firms, and bulk delivery companies are in the best position in the supply network to promote collaborative customer services. Opportunities exist to continuously promote communication between pellet mills and equipment firms, leading to a robust automated pellet heating supply and homeowner satisfaction.

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