

Exploring the Bangladesh smallholder livestock sector through network analysis: Insights, assessment results, and future directions

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Abstract

Livestock production is a key livelihood strategy in rural Bangladesh, especially for smallholder farmers who often face barriers such as limited access to business services and markets. Increased livestock production is linked to improved household income, nutrition, and health outcomes. This study analyzes the USAID-funded Livestock Production for Improved Nutrition (LPIN) Activity, focusing

on how livestock service providers' (LSPs) access to business service providers—analyzed through networks—affects their performance. We find that LSPs with higher network connectivity have significantly greater sales and serve more clients. LPIN-supported LSPs had higher sales but did not serve more clients compared to non-assisted peers. Barriers such as limited access to quality services, gender gaps, and sector-specific challenges were analyzed.

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Disclosure Statement

The authors report there are no competing interests to declare.

Data Availability Statement

Due to privacy agreement with study participants open access to the dataset is not available.

Youth and female, youth-owned LSPs showed high network centrality, but this did not always translate into better performance. These findings indicate that while connectivity matters, other structural barriers must be addressed to improve outcomes and foster inclusive growth in the livestock sector. Policy efforts that facilitate higher-quality, reliable business service linkages could be particularly advantageous if they are effectively targeted. Our results demonstrate actors' willingness to leverage these services to become leading sector network performers.

Keywords

international development, market access, livestock management, Bangladesh, gender, agriculture, network analysis

Introduction

It is crucial to recognize the significance of supporting small-scale livestock farmers in developing nations by working through key market system actors. These requirements include improving access to veterinary services, quality inputs, and market opportunities—critical components for enhancing food security, expanding information networks, and reducing poverty in rural regions ([CGIAR-IEA], 2016; Wahyono et al., 2023). This manuscript evaluates the effectiveness of a market systems development initiative—the United States Agency for International Development (USAID)-funded Feed the Future Bangladesh Livestock Production for Improved Nutrition Activity (LPIN)—using network analysis to explore how connections influence livestock service providers' (LSPs) performance. The study identifies the key successes and persistent challenges in service delivery and offers practical insights on the use of social network analysis as a tool for assessing development interventions in the livestock sector.

The livestock industry has played an increasingly prominent role in supporting livelihoods across much of Bangladesh over the past 70 years (CGIAR-IEA, 2016; Rahman et al., 2014). The sector supports skilled and unskilled employment, market engagement, and a means of subsistence for many (Shamsuddoha, 2009). Increasingly, the livestock sector in the country stands to benefit tre-

mendously from coordination from stakeholders to inform inclusive agricultural and economic policy decisions (Rahman & Chandra Das, 2021; Rahman et al., 2014; Shamsuddoha, 2009). The LPIN project, activated from 2015 to 2021 and implemented by ACIDI/VOCA, took a market systems approach, enhancing LSP service quality, reach, and profitability. It aimed to sustainably improve livestock productivity, nutrition, and incomes for rural households. The project engaged with LSPs to increase access to livestock services, inputs, information, and markets, providing technical assistance and animal healthcare services to over 180,000 farmers (87% female). The project intentionally integrated gender and social inclusion (GSI) considerations, targeting women's engagement. The LPIN assisted LSPs in the following sectors: milk collector; animal health (AH) worker with an input shop; AH worker without an input shop; alternative fodder seller; artificial insemination (AI) technician (tech); feed retailer and dealer; and food entrepreneur. On average, the LSPs earned 286 USD and served 510 clients monthly. Strengthening the capacities and outreach of LSPs (measured by income, number of clients, and available services) were core elements of LPIN's strategy to achieve its stated objectives of improved livestock productivity, nutrition, and incomes. The project sought to better understand the complex relationships between LSPs and livestock sector market actors that provide capacity-building services.

Prior studies often focus on the number of service or assistance connections as opposed to the number of market actors that provide targeted business support (Stofer et al., 2022; Wahyono et al., 2023). This has resulted in limited relevant sources for comparison and has overlooked factors that are crucial to sustainability and performance. This work seeks to address this research gap. This study was conducted in 2021 with the overarching goals of: a) understanding how LPIN influenced LSPs' networks, and b) making recommendations on how stakeholders may learn from LSP networks to enhance potential initiatives aimed at enhancing their economic capabilities. To do this, the following research questions were formulated: 1) How has the LPIN activity influenced the LSP model

(networks, sales, and clients) and how (if at all) are LSP network metrics related to their sales or client number; 2) Did LSP characteristics influence network access?; and 3) Which market actors are high- or low-performing in terms of access to service providers? The results of this assessment are intended not only to assess the impact of the LPIN activity but also to inform the work of stakeholders in this area.

Literature Review

Agricultural and food system networks have gained increasing attention for their ability to highlight how relationships among actors influence access to resources, information, and markets, particularly in rural and low-resource settings (Palmer et al., 2023; Rocker et al., 2022; Stofer et al., 2022). These networks have practical implications for communities, farmers, and entrepreneurs by shaping participation in economic systems and influencing development outcomes. In this context, social network analysis (SNA) has emerged as a valuable methodological tool to assess how these connections function and where gaps may exist. SNA allows for the identification of central actors, isolated groups, and information flows in agricultural systems, which can help development programs assess their effectiveness (Krebs & Holley, 2002; Rocker et al., 2022). Moreover, network analysis has been widely used in business and entrepreneurship studies, offering insights into the role of social ties in facilitating access to novel information (Burt, 1993), building trust (Uzzi, 1997), and securing start-up resources (Mailfert, 2007; Scott & Richardson, 2021). This interdisciplinary foundation supports our use of network analysis in evaluating the LPIN project, as it provides a means to explore how LSPs interact with business service actors and how these relationships affect their success in the market system.

This work expands upon these efforts in the distinct sociocultural context of Bangladesh and the agro-economic context of the livestock sector. The livestock and dairy sector represents a sector with prominent contributions to community well-being in Asia, aiding with, for example, poverty reduction, increasing incomes, decreasing food insecurity, and public health improvements. The sector makes these contributions through its

potential to enhance the human and social capital of farmers, champion cooperative learning environments, and engage inclusively across local and regional economic scales (Akter & Farrington, 2011; Farouque et al., 2024; Hernandez et al., 2021; Wahyono et al., 2023).

In some areas of Bangladesh, more than 97% of households rely on agricultural activities for their livelihoods (Rahut et al., 2010). Smallholders are prominent actors in the agriculture and livestock market sector in Bangladesh, while noting they face many constraints (farm size, household labor, and income) to enhanced market integration (Gani & Hossain, 2015; Rahut, et al., 2010). Many participatory approaches and stakeholder engagement show the value of including diverse actors in agricultural development (Gerhart & Howard, 2023; Graddy-Lovelace & Roman-Alcalá, 2024; Little et al., 2024; Mujjabi et al., 2024). This is exemplified through the work of Reardon et al. (2012) in classifying inclusive small-scale sectors as contributing to a 'quiet revolution' in the Asian agri-food system, where imminent development takes place led by small-scale farmers and small off-farm entrepreneurs. This demonstrates how social and economic constraints in small-scale value chains, both upstream and downstream, can pose major hurdles to the advancement of the sector and community economic development in Bangladesh (CGIAR-IEA, 2016; Gomes et al., 2024; Hernandez et al., 2021; Rahman et al., 2014; Roborgh et al., 2024).

Women entrepreneurs in Bangladesh have been growing in prominence across many economic sectors, with recent evidence documenting how women face specific barriers (e.g., access to financing, limited training opportunities, awareness of support services, and overt gender discrimination) to economic inclusion (Afroze et al., 2014; Hossain et al., 2021; Shoma, 2019). Women are actively engaged in the livestock sector in Bangladesh, with many exhibiting an enhanced level of empowerment resulting from their involvement in the sector, especially in cattle and poultry production (Mostari et al., 2021; Nath et al., 2024). However, studies have highlighted the economic and social barriers facing women entrepreneurs in Bangladesh, discussing limitations in accessing cap-

ital, information, and business networks (Afroze et al., 2014; Akter & Farrington, 2011; Head et al., 2015; Jost et al., 2016; Nath et al., 2024; Schuler et al., 2010; Shoma, 2019). Exploring strategies for scaling up small-scale farmers to access larger retail markets can provide valuable lessons for market access and profitability in the livestock sector in Bangladesh (Gerhart & Howard, 2023). These themes (scaling-up connections to markets and increased economic engagement by the most isolated and vulnerable individuals) parallel pro-poor economic growth policies that focus on the nature of coordination problems experienced by the poorest individuals and small-scale agricultural practitioners in Asia and Africa (Kydd & Dorward, 2004). Increasing economic involvement and empowerment has been shown to have far-reaching socioeconomic benefits (e.g., poverty alleviation, enhanced women's resilience, and improved access to credit and education) in the country (Akter & Farrington, 2011; Hossain & Matin, 2007; Jost et al., 2016; Shoma, 2019; Sraboni et al., 2014).

Development organizations and scholars have highlighted a lack of information as a critical barrier to addressing women's empowerment and anti-poverty initiatives (Hossain & Matin, 2007). This research seeks to address research gaps in providing information about how the livestock sector socially functions for different populations (e.g., gender differences) in Bangladesh. By identifying the areas where network isolation (a lack in quality and quantity of social connections) may constrain certain actors, we are able to better inform future research and development initiatives.

Methodology

This study was conducted to evaluate the ACIDI/VOCA LPIN activity and gain new insights into the program effectiveness. It sought to employ an innovative methodological strategy using social network analysis paired with traditional metrics of project success.

Study Site

Bangladesh is a densely populated South Asian nation where most of the total working population is engaged in livestock or agricultural production

(Shamsuddoha, 2009). Most of the livestock that are being produced are bovine, sheep and goats, poultry, and fish; their products are key to providing a source of household income across the country (CGIAR-IEA, 2016; Rahman et al., 2014). Over the last 50 years, the livestock sector in Bangladesh has been identified as an area where sustainable development initiatives hold tremendous potential to improve the distribution, growth, and performance of resources if certain technical, institutional, and social barriers are ameliorated (Rahman et al., 2014; Shamsuddoha, 2009).

The LPIN project was a USAID Feed the Future initiative implemented by ACIDI/VOCA from 2015 to 2021 in the Barisal, Dhaka, Khulna, and Chattogram Divisions in Bangladesh. The project sought to impact rural household nutrition by improving engagement and product utilization in the livestock sector (ACIDI/VOCA, 2015). In a separate impact evaluation, the project was found to be successful in raising awareness of livestock and nutrition issues and improving household meat consumption (United States Agency for International Development [USAID], 2021).

Data Collection

To answer the study research questions, we assessed relationships between LPIN and non-LPIN-assisted LSPs with their market system actors, specifically service-providing firms. Sales and clients served were considered as success indicators. In March-April 2020, LPIN staff conducted face-to-face surveys with 230 LSPs. Informed consent was obtained for all participants.

Of the 2,002 total LSPs the project assisted, 115 LSPs were randomly selected using stratified sampling with replacement, ensuring representation across each sector type (e.g., AH worker, feed dealer) and key demographic categories (gender, age group). This method allowed us to capture a diverse and representative subset of the LPIN-assisted population for meaningful comparison with non-assisted LSPs.

Out of the total estimated 3,600 LSPs, 115 non-LPIN assisted LSPs were selected with the assistance of local livestock offices. The sample size was chosen to provide a minimum of 10% margin of error and a 95% confidence level for

accurate statistical representation of the target population. Sample size was proportionally allocated to represent the categories (i.e., the strata) of female adult, female youth, male youth, and male adult. Targeted oversampling of female LSPs was conducted to increase the power needed to examine effects at the level of these strata (Vaughan, 2017). All information collected was LSP self-reported data, although it is important to note that LPIN-assisted LSPs' were made aware of iterative LPIN reporting requirements regarding firm sales and the number of customers when the relationships were first established.

Data was entered directly into the KoboCollect data collection platform (Kobo Toolbox, 2020). Networks were constructed by an enumerator asking LSPs a series of name generator questions to identify the firms in key service areas. The network consisted of two types of actors: LSPs (focal nodes—survey respondents) and service firms (alters—the firms named by the respondents in their network questions). Survey respondents were asked “what is the name of the provider that you primarily use for this service” for a variety of services.¹ The primary focus of the analysis of this report centers around ego-network analysis of the LSPs. Ego-network analysis examines a focal actor (focal node or ego) and the set of actors (non-focal nodes or alters) that are directly connected to the focal actor through a stated network tie (Marsden, 2002). Ego-centric analysis is useful for examining how information is accessible to key network actors and helps identify important sources of information (Haythornwaite, 1996). This was chosen because of the focus on the primary respondents in our research questions (meaning the focal LSP is the center of analysis), as opposed to drawing broad conclusions about the wider networks and ancillary firms. However, whole network (an analysis that plots all of the ego-networks together and connects the networks that named the same firms or alters, as seen in Figure 1) and firm-specific (focusing on only the non-focal nodes or alters that were named as connections by the respondents) analyses were

used to inform the wider findings and calculate some measures of centrality. Analysis used the Kumu network analysis software platform (Kumu Inc., 2021) and the SPSS statistical software for inferential statistical tests.

Analytical Methods

Initially, network measures were examined from the perspective of respondent LSPs, or ego-centric analysis. These measures included degree, closeness, eigenvector centrality, and K-2 reach. A higher degree of centrality and network size demonstrate that project respondents have more local connections and a larger ego network compared to control respondents. Literature suggests that, theoretically, higher closeness centrality means that project respondents are generally better connected to the wider network and are potentially more prominent actors in the network compared to control respondents. Higher eigenvector centrality demonstrates that project respondents are better situated to be leaders in the wider network than control respondents (Newman, 2006). K-2 reach shows that project respondents are better connected to other respondents through an immediate connection compared to control respondents, suggesting more opportunities for market and social interaction (Duxbury, 2020).

To determine whether network metrics, sales, and clients served (i.e., our dependent variables) were significantly different between LSPs with various characteristics (i.e., our independent variables), we used a minimum p -value of $<.05$ for network metrics among the full sample. When examining comparative groups, a p -value of <0.1 was used, due to the reduced sample size for the analytical scope. For instance, a p -value of <0.1 was used for tests involving the sales variable, as sales ranges are notably different for different types of LSPs. Spearman's rho, chi-squared tests, and independent two-sample t -tests were used to examine bivariate relationships. Analysis of variance regression models was used to examine multivariate relationships when examining multiple categories of LSPs.

¹ Services asked about in the survey included training in different milk collection and management processes; linkages to milk collection centers, input suppliers, or other private sector firms; sharing knowledge around vaccinations, animal health, and improved nutrition and food security practices; access to fodder and forage materials; silage processing, and 'other'.

Limitations

Data was collected over the phone due to the COVID-19 pandemic, making it difficult to complete surveys in one call. Information for what service each firm provided to a surveyed LSP was not captured, disallowing analysis of specific types of service gaps. Because of the data collection limitations, detailed information regarding the prominence and specific nature of network ties was not captured.

Therefore, some forms of network statistics were not deployed (Breiger, 1974; Duxbury, 2020; Larremore et al., 2014).

Results

Females made up 18.7% of respondents (Table 1). The average respondent age was 37.8 years old, and 13.5% of the LSPs were owned by someone under the age of 30, referred to as youth ownership. Ninety-seven percent of respondents indicated that their LSP was solely owned. For LSPs with multiple owners, if one of the owners is a female, the LSP is considered female-owned in the analysis. Three percent of the LSPs were owned by a female under the age of 29 (referred to as female youth-owned). The group (female/youth-owned) has been highlighted in the analysis due to the important role that entrepreneurial women play in the Bangladesh livestock sector (Akter & Farrington, 2011; Rahman et al., 2014).

Traditional metrics of LSP success include estimated clients served per year (averaged 680.3) and estimated annual sales (BDT 266,941.7²). The network, represented in Figure 1, can be seen in

the full sociogram representation, where “Respondent” refers to LSPs and “Provider” refers to the service provider firms that the respondents named.

LSP’s differential network statistics, in terms of access to service providers, demonstrate a variety of disparate characteristics between various types of LSP respondents. The average degree of centrality, or number of connections for each LSP, is 2.15

Table 1. Descriptive Statistics for LSP Survey Respondents

	Sample <i>n</i>	Mean	Std. Dev.
Annual sales (in BDT)	230	266,941.7	417,491.3
<i>Project LSPs</i>	115	303,176.5	556,974.7
<i>Control LSPs</i>	115	230,707.0	193,021.1
Clients served annually	230	680.3	1,349.9
<i>Project LSPs</i>	115	647.8	1,281.5
<i>Control LSPs</i>	115	712.8	1,419.9
Business age (in years)	227	7.6	8.6
<i>Project LSPs</i>	112	6.8	10.4
<i>Control LSPs</i>	115	8.4	6.3
Sector entrance (in years)	216	6.1	5.7
<i>Project LSPs</i>	112	4.6	4.1
<i>Control LSPs</i>	104	7.6	6.7
		Yes (1)	No (0)
Yes = LPIN assisted LSP No = control group	230	50.0%	50.0%
Gender (female)	230	18.7%	81.3%
Youth ownership (15-29)	230	13.5%	86.5%
Female youth ownership	230	3.0%	97.0%
Network isolate	230	17.0%	83.0%
Single owned LSP	230	97.4%	2.6%
Sector:	230		
Milk collector		14.4%	85.7%
AH worker w/ input shop		10.9%	89.1%
AH worker w/o input shop		20.4%	79.6%
Alternative fodder seller		12.2%	87.8%
AI tech		17.4%	82.6%
Feed retailer/dealer		10.0%	90.0%
Fodder entrepreneur		14.8%	85.2%

Note: Number of observations differ due to missing values in survey responses.

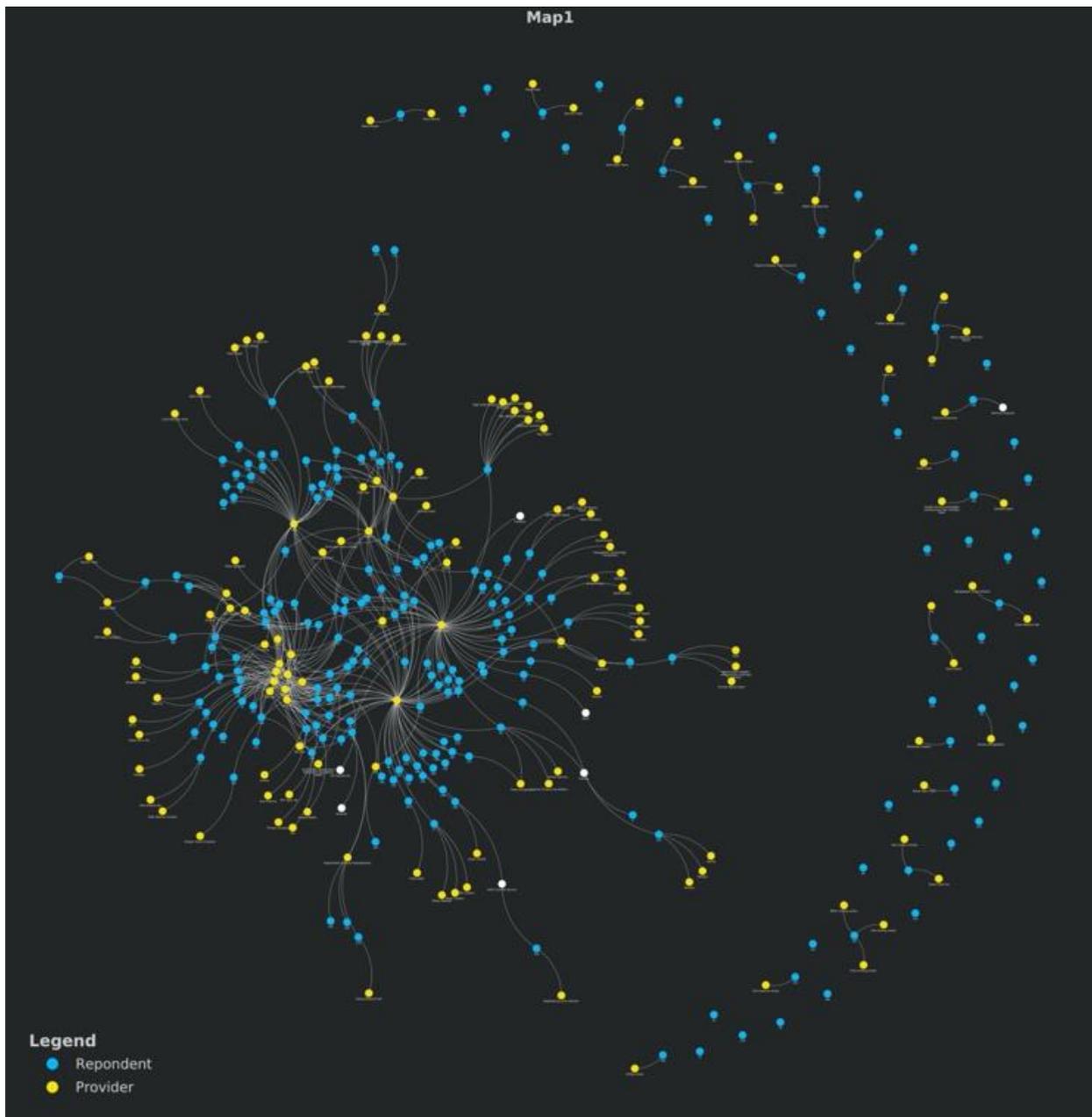
² The average exchange rate between March–April 2020 was 84.7 BDT=1 USD, so the estimated annual sales was equivalent to 3,151 USD during the time of data collection in 2020.

service provider firms. This also means that the average network size is 3.15. The mean value for closeness centrality, a measure of network prominence, is 0.161. Eigenvector centrality, a measure of network leadership, has a mean value of 0.004. K-2 reach, the measure of centrality of reach within two connections away in the network, has a mean of 0.115. Network isolates are LSPs that did not name a single connection.

Networks and Network Relationship to LSP Success

Analysis examined statistically significant relationships between network metrics and success indicators (sales and clients served) (Table 2). Sales presented a positive relationship with degree centrality and size ($p < .001$), but no significant relationship with closeness, eigenvector centrality, or K-2 reach. Project LSPs were found to have significantly

Figure 1. Sociogram Display of All Study LSP Networks



higher sales compared to the control group (see Table 1, $p < .10$). All selected network metrics presented a significant positive relationship with clients served ($p < .05$). Sales did not correlate with clients served. There was no significant difference in clients served noted between project and control LSPs.

There were significant differences across network metrics between the LPIN assisted and non-LPIN assisted LSPs (Table 3). However, LPIN assisted LSPs were allowed to reference ACIDI/VOCA as a service provider in this study. Although not all LSPs included ACIDI/VOCA in their list (since not all LSPs received the same types of assistance or services from ACIDI/VOCA), most did. This contributed to project-assisted LSPs averaging one additional connection (degree centrality of 2.652) compared to the control sample (1.643) and likely influenced all measures of centrality, which were significantly higher for LPIN assisted LSPs. This also demonstrates the prominence of key nongovernmental organizations (NGOs) in providing economic and agricultural assistance to spur community development throughout Bangladesh (Das & Kabir, 2014; Farouque et al., 2024; Roborgh et al., 2024; Shamsuddoha, 2009).

What Role Did LSP Gender and Age Play in Network Results and Performance?

A significant difference was found between LPIN assisted male and female LSP owners for all network measures (Table 4). These differences were not observed for control LSPs. This demonstrates that network access is more limited among female-owned LSPs involved in the LPIN project as compared to men. This gender disparity is consistent with previous studies that demonstrate more limited social and economic network access by women entrepreneurs in the country (Afroze et al., 2014;

Table 2. Network and Success Variables Comparison

Variable	Sales	Clients served
Degree	+***	+**
Closeness		+**
Eigenvector		+**
Reach		+**
Size		+**

Note: $n=230$; ** $p < .05$. *** $p < .001$

Schuler et al., 2010; Shoma, 2019). Male LSPs were found to have significantly greater annual sales compared to female LSPs (Table 5). This disparity was also found among the project sample. No gender disparity was indicated in the number of clients that LSPs served.

When controlling for the LSP sector type, degree centrality/size ($p < .10$) and closeness ($p < .01$) among the project sample were shown to maintain significant gendered differences (male LSPs have greater measures of degree and closeness centrality) in the project sample. For the overall sample, no

Table 3. LPIN Project Sample and Overall Sample Comparison with Network Variables

Variable	Group	Mean	Std. Err.	Std. Dev.
Degree	Control	1.643	0.0146	1.563
	Project	2.652	0.194	2.082
	Total	2.148	0.126	1.905
Closeness	Control	0.130	0.009	0.101
	Project	0.191	0.009	0.096
	Total	0.161	0.007	0.103
Eigenvector	Control	0.002	0.0003	0.003
	Project	0.005	0.0004	0.005
	Total	0.004	0.0003	0.004
Reach	Control	0.075	0.007	0.072
	Project	0.155	0.010	0.103
	Total	0.115	0.006	0.097
Size	Control	2.643	0.146	1.563
	Project	3.652	0.194	2.082
	Total	3.148	0.126	1.905

Note: Control group $n=115$; Project group $n=115$; Total $n=230$; *** = $p < .001$.

Symbols key: < control is significantly smaller than project group; ≠ control is significantly different from project group; > control is significantly greater than project group.

Table 4. Gender Comparison with Network Variables

Variable	Group	Mean	Std. Err.	Std. Dev.	n
Degree (all)	Female	2.047	0.280	1.838	43
	Male	2.171	0.141	1.924	187
Not sig.	Total	2.148	0.126	1.905	230
(Project resp.)	Female	2.139	0.329	1.973	36
	Male	2.886	0.236	2.100	79
<*	Total	2.652	0.194	2.082	115
Closeness (all)	Female	0.154	0.018	0.115	43
	Male	0.162	0.007	0.100	187
Not sig.	Total	0.161	0.007	0.103	230
(Project resp.)	Female	0.159	0.019	0.116	36
	Male	0.206	0.009	0.083	79
<***	Total	0.191	0.009	0.096	115
Eigenvector (all)	Female	0.004	0.0007	0.004	43
	Male	0.004	0.0003	0.004	187
Not sig.	Total	0.004	0.0003	0.004	230
(Project resp.)	Female	0.004	0.001	0.005	36
	Male	0.006	0.0005	0.004	79
<*	Total	0.005	0.0004	0.005	115
Reach (all)	Female	0.125	0.017	0.110	43
	Male	0.112	0.007	0.094	187
Not sig.	Total	0.115	0.006	0.097	230
(Project resp.)	Female	0.131	0.019	0.114	36
	Male	0.166	0.011	0.096	79
<*	Total	0.155	0.010	0.103	115
Size (all)	Female	3.047	0.280	1.838	43
	Male	3.171	0.141	1.924	187
Not sig.	Total	3.148	0.126	1.905	230
(Project resp.)	Female	3.139	0.329	1.973	36
	Male	3.886	0.236	2.100	79
<*	Total	3.652	0.194	2.082	115

Note: * $p < .05$; ** $p < .01$.

Symbols key: < female is significantly smaller than male group.

measures of network centrality maintained significant gender differences. When the scope of the analysis is narrowed to individual sectors, female AH workers without an input shop were found to have greater degree centrality/size ($p < .10$), closeness ($p < .05$), eigenvector ($p < .05$), and K-2 reach ($p < .01$) compared to men. Female milk collector LSPs were shown to have lesser degree centrality/size ($p < .10$) and closeness ($p < .05$) compared to men.

Statistically significant differences were observed between youth-owned and non-youth-

owned LSPs (Table 5). Youth-owned LSPs have greater degree centrality/size, closeness, eigenvector, and K-2 reach compared to non-youth-owned LSPs. Among project LSPs, youth-owned LSPs have greater degree centrality/size, eigenvector, and K-2 reach compared to non-youth-owned LSPs. Youth-owned LSPs were less likely to be network isolates. Youth ownership was not found to have a significant relationship with sales or clients served.

Differences were found in LSPs that are female youth-owned. Female youth-owned LSPs

Table 5. Bivariate Relationships: {x} by {gender; youth-ownership; female youth-ownership}

	Degree/Size	Closeness	Eigenvector	K-2 reach	Sales	Clients served
Gender (overall)	—	—	—	—	>^	—
(project)	>*	>*	>*	>*	>^	—
Youth ownership (overall)	>***	>**	>***	>**	—	—
(project)	>***	—	>***	>*	—	—
Female youth ownership (overall)	—	>^	>**	>**	—	>*
(project)	—	—	—	—	—	—

Note: ^ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$; — indicates no significant difference. Gender: Male reference group compared to female. Youth ownership: Youth owned referenced group compared to non-youth owned. Female youth ownership: Female youth owned referenced group compared to non-female youth owned.

have greater closeness, eigenvector, and K-2 reach compared to other LSPs. In the overall sample, female youth-owned LSPs were found to serve more clients compared to other LSPs. Female youth-owned animal healthcare workers without an input shop had greater closeness ($p < .10$), eigenvector ($p < .01$), and K-2 reach ($p < .01$) compared to all other LSP types. No other statistically significant female youth-owned LSP differences were found within sectors. Controlling for LSP sector, female youth ownership was found to maintain significance in the overall sample for closeness ($p < .10$), eigenvector ($p < .05$), and K-2 reach ($p < .05$). In the overall sample, female youth-owned LSPs were found to serve more clients compared to other LSPs. Pervasive disparities in economic empowerment and access to resources have been noted among differing sectors and demographic groups in Bangladesh (Farouque et al., 2024; Gomes et al., 2024; Hernandez et al., 2021). This provides evidence that is in

conversation with our observed findings relating to differences in network characteristics, sales, and clients served between groups in the livestock sector.

LSP Characteristics Influence on Performance

There are seven different sectors in which surveyed LSPs were engaged in the livestock management field (noted previously). The statistically significant, individual network centrality measure differences that LSP sector types display, when independently examined in relation to all other sector types, can be seen in Table 6. When all LSP sector types are examined simultaneously in a one-way analysis of variance, the models for sector differences are significant for degree centrality, size, and eigenvector centrality, but not for closeness or K-2 reach centrality. There were also significant differences found between specific LSP sector types and different network metrics, suggesting one provider can play multiple network

Table 6. Measures of Network Centrality LSP Sector Relationship

	Degree/size***	Closeness	Eigenvector***	K-2 reach
AH worker with shop	+***	+**	+***	+**
Alternative fodder seller	-*			
AH worker w/o shop	+*	+*	+*	+*
AI tech	-*			
Feed retailer/dealer		+*	+*	+**
Fodder entrepreneur		+*		+*
Milk collector	-*	-***	-***	-***

Note: Top row includes ANOVA model significance; + = sector mean is significantly higher compared with all other sectors; - = sector mean is significantly lower compared with all other sectors; * $p < .05$; ** $p < .01$; *** $p < .001$

roles: AH workers with an input shop were shown to have the most local influence, connections, the largest ego-network, and are best positioned to be network leaders in terms of accessing these business service providers. AH workers without an input shop and feed retailers and dealers were shown to have more local influence, more connections, and larger ego-networks compared to other sectors. AH workers without an input shop and fodder entrepreneurs are better positioned to be network leaders compared to other LSP sectors. Alternative fodder sellers had the least measure of local network influence, the least connections, and the smallest ego-network. Milk collectors were shown to be worst positioned to be network leaders. Milk collectors and artificial insemination technicians were shown to have less local network influence, fewer connections, and smaller ego-networks compared to other LSP sectors. Feed retailers and dealers were shown to be poorly positioned to be network leaders compared to other LSP sectors. Feed retailers and dealers and fodder entrepreneurs were less likely to be network isolates. This suggested that feed retailers and dealers and fodder entrepreneurs operate in the livestock sector with at least one livestock sector network connection. Conversely, milk collectors were more likely to be network isolates. This demonstrates that milk collectors more frequently operated in the livestock sector in network isolation compared to LSPs in other sectors. The reasons for these differences in network measures between the LSP sectors may have been due to the nature of the role they play in the livestock sector or may also have been due to the type of business owners that are drawn to these occupations. We cannot give causal explanations for these differences beyond our hypotheses, and this presents an area for important future research.

The age of the LSP business (mean of 7.6 years) did not have any significant relationships with measures of network centrality or with LSP sales and clients served. Male-owned LSPs were found to be significantly older businesses (8.2 years) compared to female-owned LSPs, at 4.9 years ($p < .05$). It is unsurprising that non-youth-owned LSPs had older businesses (8.0 years) compared to youth-owned LSPs, at 5.2 years

($p < .10$). Businesses with more recent entrance into the livestock sector (mean of 6.1 years) are more prominent actors in the network in terms of business service provider access (greater closeness; $p < .05$), more often network leaders (higher eigenvector; $p < .10$), and have more opportunities for social and market interaction (greater K-2 reach; $p < .05$) when compared to LSPs longer established in the livestock value chain. The year an LSP became active in the livestock sector did not have a significant relationship with LSP sales. More established businesses were associated with serving more clients ($p < .01$). Women-owned LSPs were shown to have entered the livestock sector more recently (4.5 years) compared to male-owned LSPs, at 6.5 years ($p < .05$). Unsurprisingly, youth-owned businesses were shown have entered the livestock sector more recently (4.7 years) compared to non-youth-owned LSPs, 6.3 years ($p < .10$).

Sector types were shown to have significant differences for sales ($p < .001$). When individual LSP sectors were compared with the full sample, feed retailers and dealers had the highest sales ($p < .001$). Alternative fodder sellers had the lowest sales ($p < .01$). Fodder entrepreneurs and AH workers without input shops had significantly lower sales compared to other sectors ($p < .01$ and $p < .05$, respectively). Sector types were shown to have significant differences for clients served ($p < .001$). AH workers with an input shop had the most clients ($p < .001$). Artificial insemination technicians also demonstrated a significantly higher number of clients ($p < .10$). Fodder entrepreneurs have the least clients served ($p < .05$). Alternative fodder sellers and milk collectors also demonstrated significantly lower clients served compared to other sectors ($p < .05$). When controlling for the sector in the overall sample, gender and female youth-ownership retained significant differences in clients served ($p < .001$). Therefore, the characteristics of a given LSP are shown to have distinct impacts on markers of social connectedness and economic success. Partially due to its central livelihood importance, the livestock sector in Bangladesh is especially sensitive to individual differences in business characteristics that impact their efficacy in the wider market (CGIAR-IAE, 2016; Jost et al., 2016; Rahman et al., 2014; Schleiss, 2001).

Identifying High- and Low-Performers Network Actors

By noting the differences between LSPs, we are able to document the actors in the networks that are potentially high- or low-performing. Three LSP types were shown to have significantly higher eigenvector centrality, meaning they are potential market bottlenecks as they are uniquely positioned as network leaders: AH workers with an input shop, AH workers without an input shop, and feed retailers and dealers. Three LSP types were also noted to be more isolated in their immediate network access: milk collectors, alternative fodder sellers, and artificial insemination technicians. Milk collectors are also more likely to be network isolates and the worst positioned sector to be a network leader in regard to business service provider access. LSPs in these sectors are in a vulnerable network position as low performers in the network. Network performers can be broken down as follows:

- High performers:
 - Sectors (in overall sample): AH workers with an input shop (degree/size and eigenvector centrality), AH workers without an input shop (degree/size and eigenvector centrality), feed retailers and dealers (eigenvector centrality and isolates), and fodder entrepreneurs (isolates).
 - Male or non-female-owned LSPs in project sample (all network measures).
 - Youth-owned LSPs in overall (all network measures) and project sample (three network measures).
 - Female youth-owned LSPs in overall sample (three network measures).
- Low performers:
 - Sectors (in overall sample): Milk collectors (three network measures), alternative fodder seller (degree/size), and artificial insemination technician (degree/size).
 - Female-owned LSPs in project sample (all network measures).
 - Non-youth LSPs in overall (all network measures) and project sample (three network measures).
 - Non-female-youth-owned LSPs in overall sample (three network measures).

Discussion and Conclusion

Our findings can be summarized with the following four key points: (1) network centrality regarding business service provider access matters to LSP success indicators (sales and clients served); (2) there are varied effects of LSP characteristics on performance; (3) sector type impacts performance; and (4) this study provides valuable lessons that can be applied in future development initiatives. Results demonstrate that increasing LSP access to business provider services, which is reflected in increased measures of centrality, enhances LSP sales and the number of LSP clients. Essentially, this information supports the value of such firm services in supporting the economic growth of LSPs, as well as the livestock sector overall. This is because, as they grow, LSPs are also reaching more producers and actors (i.e., clients). These findings recommend further implementation and potential scaling-up of activities that facilitate LSP connections to firms as an effective means of aiding performance and sector growth.

Youth-owned LSPs demonstrated higher measures of centrality in terms of access to service providers. However, there was no significant difference between adult and youth-owned firms in terms of sales or number of clients. Similarly, LSPs that more recently entered the livestock market (which tend to be female and youth-owned LSPs in the sample) are also network leaders but have significantly fewer clients than longer established livestock sector businesses. The lack of increased clients or sales for youth-owned or recently established livestock firms, despite these higher network centrality statistics, suggests confounding factors are serving as impediments to their success. In this study, youth cite lack of access to reliable service providers as a key barrier, implying that, although they are accessing services, they might not be of high quality or the ones that they need. Other contributing factors could be time, pricing models, the types of clients they serve, or a lack of access to certain equipment and capital. Future activities should try to identify and address barriers to whole-of-business success as these youth-owned or newly established LSPs demonstrate promise in terms of scaling of impacts, due to current strengths in network

centrality measures, including leadership roles in the network.

Along this same trend, female youth-owned LSPs exhibited high potential in terms of business performance, interacting more prominently with these service firms and positioning themselves as leaders, as compared to female adult-owned LSPs. This is a surprising finding and challenges previous evidence noting the limitations often faced by these populations (Afroze et al., 2014; Hossain et al., 2021; Shoma, 2019). Notably, female youth-owned LSPs had significantly more clients than adult female-owned LSPs. However, overall, female LPIN-assisted LSPs had significantly lower network access than LPIN-assisted male LSPs. The precise reasons for this are uncertain and require further examination but it is suspected there is a gap in female business owners accessing wider livestock sector networks due to cultural and economic customs. To close this gap, it is recommended that future activities note this inequality and intentionally provide additional or more targeted assistance to female LSPs in linking them to helpful firm service providers. Future development activities might choose to champion these female youth LSPs or place them as coaches of adult female LSP actors. The primary barriers female LSPs cited in accessing firm services included transportation and distance and not enough supply. More research should be done to examine these and potentially other barriers facing women-owned businesses and to identify why the age disparity exists between female-owned LSPs.

Results imply that female LSPs are charging, and thus receiving, less per services or product than male LSPs as they had lower sales, but no significant differences in the number of clients served. This also relates to the finding that sales and clients served are not significantly related to each other, meaning that neither measure is a sufficient stand-alone proxy for success. In keeping with this theme, LPIN's gender impact assessment found gender biases influenced customers' willingness to pay female LSPs for their services. Ideally, future research would examine why female LSPs are not able to charge or collect the same amount

for their services and products as male LSPs and if there is a way to change or adjust this pricing model. Each LSP sector type had different strengths and weaknesses, and the influence of LSP owner sex or age on performance varied by LSP type. These results suggest that future activities tailor formative research and interventions by LSP sector type.

This analysis presents a number of areas for research. Targeted analysis is merited to examine why differences exist between sectors. Perhaps there are certain characteristics for each type of business that impact how they interact with others in the livestock sector. Alternatively, there may be something about the people that are attracted to these sectors that influence how they construct their networks and conduct their business. A more gender-centric avenue of research is also needed to examine how these business success and network measures impact potential indicators of empowerment and, ultimately, aspects of everyday livelihood like poverty and food security. Future research would also benefit from including enhanced spatial and socioeconomic status analysis to further understand the nuances in the findings and improve future service delivery.

Finally, this study documents the usefulness of practical applications of social network analysis for market systems actors in an applied development setting. The specific findings are not widely applicable across geographic or cultural contexts, but, rather, the application of the method demonstrates the relevance of this type of scientific analysis for development projects. The results effectively advocate for additional support targeting younger LSP business owners and women-owned businesses.

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