

The structure and geographic distribution of the live-sheep market in Mexico, 2007-2021

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ABSTRACT

Objective: This study aimed to analyze the structure and geographic distribution of the sheep market mobilized for slaughter, breeding, rearing, fairs, and fattening in Mexico from 2017 to 2021.

Design/methodology/approach: The data on sheep mobilizations between source and destination municipalities were sourced from Mexico's Sistema Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA). Via social network analysis theory, national cohesion and centrality measures were calculated per purpose of sheep mobilization.

Results: Of all sheep mobilized, 98.2% moved between states, with 97.0% of them destined for slaughter. The national livestock mobilization network had 54.0% of possible connections, an average out-degree of 17.3, and an average in-degree of 16.7. The highest out-degree centrality was found in the state of Jalisco, while the highest in-degree centrality was found in the state of Puebla.

Limitations on study/implications: The primary constraint of the study was the failure to consider the mobilizations of sheep not passing through livestock control centers, despite assuming a minimal level.

Findings/conclusions: The sheep mobilization structure in Mexico is determined by the market of sheep destined for slaughter and an interstate mobilization pattern.

Keywords: Network analysis, sheep mobilization, market connectivity, distribution networks.

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INTRODUCTION

Over the past decade, sheep production systems in Mexico have accounted for 12.5% of the national red meat inventory (SIAP, 2023). Although these systems are distributed nationwide, a significant gap in data persists regarding the relationship between production and consumption centers, creating challenges for national planning. In contrast, cattle production systems are found throughout the country but exhibit a highly concentrated mobilization pattern, primarily shaped by slaughter and fattening markets. This structure is characterized by high-density networks, low centrality, significant intra-state movement,



and a low degree of market specialization (Callejas and Salas, 2023). Network Analysis, traditionally employed in epidemiological research, provides a theoretical framework for studying relationship structures involving the exchange of information, products, and services within markets. The role of livestock mobilization in disease transmission has been well documented. In the United Kingdom, sheep movements contributed to the rapid spread of foot-and-mouth disease in 2001 (Kiss *et al.*, 2006), while in Scotland, researchers identified sheep mobilization patterns as a key factor in disease dissemination (Volkova *et al.*, 2010). Similarly, studies conducted in Paraguay demonstrated that cattle movement networks facilitate the spread of foot-and-mouth disease and brucellosis (Avalos *et al.*, 2022). When applied to market dynamics, social network analysis enables the examination of attributes within dyadic relationships as well as structural patterns across entire networks (Borgatti and Everett, 1997). Given the limited availability of information on livestock mobilization in Mexico, this study aimed to analyze the structure and geographic distribution of the live-sheep market mobilization network, specifically for slaughter, breeding, rearing, fairs, and fattening from 2017 to 2021.

MATERIALS Y METHODS

The analysis considered the daily number of sheep mobilized (X_{ij}) from all source municipalities (x_i) to all destination municipalities (x_j) across Mexico between 2017 and 2021. The dataset was derived from official records of sheep mobilization for slaughter (Y_1), breeding (Y_2), rearing (Y_3), fairs (Y_4), and fattening (Y_5), obtained from the Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA).

Given that Mexico comprises 2,476 municipalities across 32 states, state- and municipal-level samples were constructed for analysis. Each sheep mobilization purpose was examined as both a source and destination market (Table 1).

Nationwide mobilization matrices (N_{ij}) were constructed using the daily number of sheep mobilized X_{ij} for each mobilization purpose at both municipal and state levels:

Table 1. Municipal and state samples per source and destination sheep markets, 2017-2021.

Purpose/ source	Percent	Purpose/ destination	Percent
Municipal level			
Slaughter	12.0	Slaughter	15.0
Breeding	5.6	Breeding	15.6
Rearing	4.4	Rearing	9.4
Fairs	4.1	Fairs	3.5
Fattening	0.9	Fattening	1.2
State level			
Slaughter	91.3	Slaughter	93.1
Breeding	87.5	Breeding	122.0
Rearing	80.0	Rearing	92.5
Fairs	67.5	Fairs	73.1
Fattening	35.6	Fattening	39.4

slaughter (Y_{1ij}), breeding (Y_{2ij}), rearing (Y_{3ij}), fairs (Y_{4ij}), and fattening (Y_{5ij}). In each matrix, rows represented the source states of the mobilized sheep, while columns represented the destination states.

Sheep mobilization patterns were analyzed at the municipal level, distinguishing between inter-municipal (M_{ij}) and intra-municipal (M_{ii}) shipments. The former represents shipments from x_i to x_j , while the latter accounts for shipments within the same municipality x_j to x_i . Similarly, the analysis was extended to the state level to evaluate broader movement trends.

To examine the structure and geographic distribution of the sheep market in Mexico, the study applied social network analysis theory (Borgatti *et al.*, 2018). According to these authors, cohesion and centrality measures are particularly effective for assessing network structure, providing insights into connectivity patterns, market integration, and dominant mobilization hubs.

The market network density (ND) measures the proportion of connections between source and destination municipalities or states, indicating the extent of direct and indirect linkages within the network. A fully connected network is considered complete, meaning all nodes are directly or indirectly linked. Higher network density corresponds to a greater number of links, reflecting a more interconnected market.

While ND is a fundamental measure for understanding overall network structure, additional metrics provide deeper insights. Among these, outbound centrality (OC) and inbound centrality (IC) assess the dominance of specific nodes in sheep mobilization. The average degree (AD) measures the mean number of connections per node, while connectivity (CO) evaluates network cohesion. Mutual nodes (MD) identify the reciprocal exchange of sheep between locations, and dyadic reciprocity (DR) quantifies bidirectional transactions within the network. Each node was analyzed using density and centrality measures to determine its role in the national mobilization structure.

To achieve a comprehensive understanding of sheep mobilization networks in Mexico, the study incorporated the theory of spatial location of production systems, particularly focusing on the motivations for mobilization. Following the framework of Lira and Quiroga (2009), the economic structure of each state and the purposes for mobilization were examined using two measures of relative regional specialization.

The localization quotient (R_E) quantifies a state's participation in a specific production system, comparing it to the national level. Here, F_{ij} represents the flow of sheep for purpose i in state j . An $R_E > 1$ indicates relative or interregional specialization, signifying that the state plays a disproportionately large role in that particular aspect of sheep production or trade.

$$R_E = \frac{F_{ij}}{\sum_i F_{ij}} \frac{\sum_j F_{ij}}{\sum_{ij} F_{ij}}$$

The specialization coefficient (R_M) assesses the degree of similarity between a region's economic structure and the national structure. An $R_M \sim 1$ indicates a specialized production system, meaning the region is highly focused on a particular aspect of sheep production or trade. Conversely, an $R_M \sim 0$ suggests a diversified production system, where economic activities are more evenly distributed across multiple production purposes.

$$R_M = 0.5 \sum_i \left| \frac{F_{ij}}{\sum_i F_{ij}} / \frac{\sum_j F_{ij}}{\sum_{ij} F_{ij}} \right|$$

RESULTS AND DISCUSSION

The findings are presented for both the national market (N_{ij}) and per product (Y_{ij}). During 2017-2021, an annual average of 1,114,147 livestock heads were mobilized in Mexico. Five types of markets comprised the sheep market: slaughter, breeding, rearing, fairs, and fattening. All markets showed significant linear correlations ($p < 0.05$), except for fattening with other types and slaughter with fairs.

Of all mobilized sheep in Mexico's markets, 97.0% were destined for slaughter, 1.3% for breeding, 0.9% for rearing, 0.6% for fairs, and 0.2% for fattening. The domestic market grew at an average annual growth rate (AAGR) of 1.5%, increasing from 1.08 million head in 2017 to 1.1 million head in 2021. The slaughter and fattening markets grew at AAGRs of 1.9% and 52.7%, respectively, while the breeding, rearing, and fair markets recorded negative AAGRs of 10.3%, 13.8%, and 9.4%, respectively.

Sheep supply and demand in Mexico were highly concentrated at the state level, with the top quartile of states accounting for 79.6% of the national market. These states mobilized 80.7% of sheep for slaughter, 78.6% for breeding, 64.6% for rearing, 72.3% for fairs, and 74.5% for fattening. Meanwhile, the top quartile of states with the highest demand concentrated 94.1% of the national sheep market, including 95.5% for slaughter, 56.6% for breeding, 59.5% for rearing, 74.6% for fairs, and 73.6% for fattening.

The leading states in national sheep supply were Jalisco (32.6%), San Luis Potosí (10.9%), and Campeche (10.0%). Other significant contributors included Chihuahua, Coahuila, Guanajuato, Zacatecas, and Querétaro. The supply of sheep for slaughter determined the national sheep supply, reflecting the same states and market shares as the national market. The top states for breeding were Hidalgo (25.2%) and Jalisco (21.2%); for slaughter, the State of Mexico (14.4%) and Puebla (11.6%); for fairs, Guanajuato (25.1%) and Jalisco (19.3%); and for fattening, Campeche (25.5%), Colima (20.4%), and Nayarit (10.0%).

During the analyzed period, only 34.4% of the markets exhibited positive AAGRs, with an average growth rate of 1.5%. The most critical period occurred between 2018 and 2019, when the market experienced a 6.3% decline.

The leading sheep market, located in Jalisco, demonstrated a notable average annual growth rate of 9.3%, while the second-largest market recorded a 7.3% decrease. Significant variations were observed in the supply of certain markets with outstanding AAGRs. The market in Coahuila grew at an average rate of 27.0%, Tabasco at 26.2%, and Sinaloa



Figure 1. Average Spatial Distribution of Cattle Supply in Mexico.

at 412.8%. Despite this growth, Tabasco and Sinaloa maintained low market shares, accounting for only 1.4% and 0.2%, respectively.

Regarding national sheep demand, the leading states were the State of Mexico (45.0%), Hidalgo (22.6%), and Puebla (11.7%) in terms of mobilized livestock, followed by Guanajuato, Morelos, Querétaro, Jalisco, and Nuevo León. Similar to sheep supply, the slaughter market dictated national demand, involving the same states but in different proportions. The most significant states in the slaughter market were the State of Mexico (46.2% of all mobilizations), Hidalgo (23.1%), and Puebla (11.8%). In the breeding market, the key states were Querétaro (8.6%), Guanajuato (8.0%), and Veracruz (7.6%). For the rearing market,

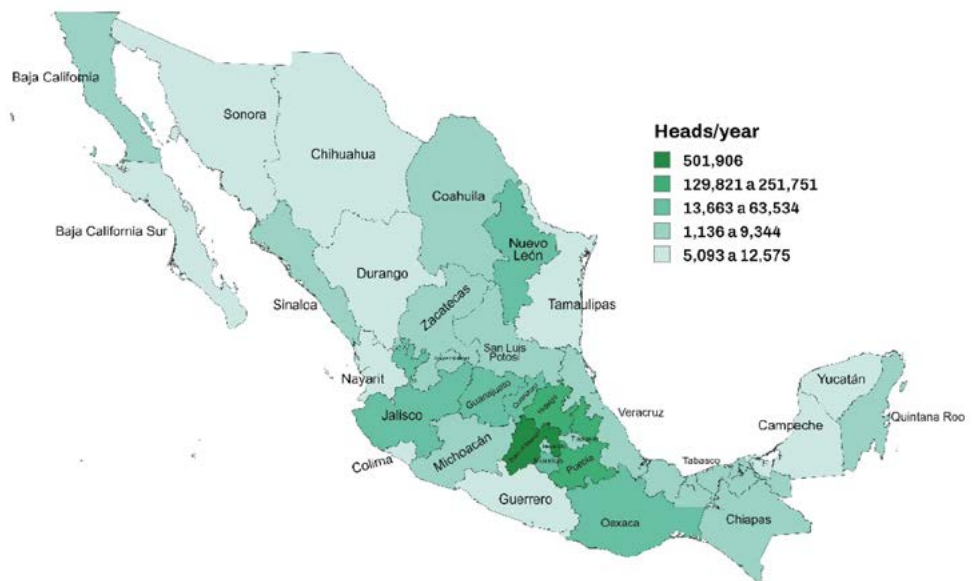


Figure 2. Average spatial distribution of cattle demand in Mexico.

Jalisco was identified as the most central source market, accounting for 96.9% of all sheep mobilizations to destination markets. The State of Mexico was the main destination market, receiving 90.6% of all links. In contrast, Baja California Norte received 9.4% of all shipments, while Baja California Sur sent 18.8% of all shipments.

Analysis

The first analysis of Mexico's sheep market network revealed its large size, driven by significant distances between markets and the country's numerous municipalities. Additionally, intrastate markets were found to be substantial. Mexico's diverse human, monetary, and natural resources sustain five distinct production systems and their respective markets. However, social network analysis indicated a centralization of these production systems and markets. Network centrality was used to identify key elements within the network, revealing that the national network's centrality was lower compared to the per-product networks. Four markets contributed to increased national centrality: Jalisco (supply) and Estado de México, Hidalgo, and Puebla (demand). For slaughter, Jalisco and San Luis Potosí led in supply, while Estado de México and Puebla dominated demand. In breeding, Hidalgo and Jalisco were major suppliers, but no significant demand markets were identified. For fattening, Campeche and Colima served as key suppliers, with Jalisco as the main demand market. No important markets were found for rearing, while in fairs, Guanajuato and Jalisco were key suppliers, and Guanajuato and Querétaro were leading demand markets.

Market cohesion measures belonging and access to information for all source and destination markets within a network. In the national sheep mobilization network, every source and destination market, including the smallest (fattening), exhibited high connectivity. However, the overall network density was low, and even lower in the per-product networks. The states with the highest centrality and market density within the national network were Jalisco, Estado de México, San Luis Potosí, Campeche, Puebla, Colima, and Querétaro. The centrality and cohesion observed in the sheep market network

Table 2. National network and product cohesion metrics (2017-2021).

	Y	Y1	Y2	Y3	Y4	Y5
Possible links	1024	992	1024	992	812	456
Existing links	553	372	377	288	183	82
Avg degree	17.30	10.97	11.13	8.13	5.89	2.88
Deg centrality	0.34	0.48	0.47	0.47	0.45	0.33
Out-degree centrality	0.45	0.53	0.63	0.62	0.43	0.23
In-degree centrality	0.39	0.47	0.26	0.20	0.43	0.19
Density	0.53	0.35	0.36	0.27	0.22	0.13
Transitivity/Closure	0.71	0.65	0.62	0.49	0.44	0.27
Mutual	0.38	0.22	0.19	0.11	0.08	0.03
Null	0.32	0.52	0.47	0.57	0.64	0.78
Arc Reciprocity	0.72	0.63	0.53	0.41	0.36	0.26
Dyad Reciprocity	0.57	0.46	0.36	0.26	0.22	0.15

were attributed to the economic structure of the production systems. At the national level, economic specialization was low (45.0%), primarily due to minimal specialization in slaughter (1.5%). Other systems exhibited higher specialization levels: 64.5% in fattening, 58.3% in rearing, 51.8% in fairs, and 49.3% in breeding. Additionally, 51.3% of sheep-producing states considered themselves specialized overall. Specifically, 40.6% specialized in sheep for slaughter, 65.6% for breeding, 62.5% for rearing, 43.8% for fairs, and 43.8% for fattening.

CONCLUSIONS

The live-sheep mobilization network in Mexico is primarily driven by the slaughter market, while production systems for breeding, fattening, and fairs are nearly non-existent. These production systems are characterized by interstate markets, which are heavily concentrated in the central region of the country. The national state network exhibited high cohesion among states, with strong centrality for both entry and exit. However, the densities for specific mobilization purposes remained low. The national municipal network displayed even lower density and centrality. Jalisco (as an origin) and Puebla (as a destination) were identified as the two best options for disseminating information within the sheep mobilization network. Additionally, sheep production systems in Mexico should be regarded as diversified.

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