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Article

Structure of the cattle market network in Mexico, 2017-2021

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Abstract:

Cattle ranching, transportation, and utilization are issues associated with resource endowment, distance traveled, and types of markets. The structure of the livestock mobilization network by market at the municipal and state level in Mexico during the 2017-2021 period was investigated. The data were analyzed using measures of economic structure and Social Network Analysis. During the period under analysis, an annual average of 8.9 million heads of cattle were moved in Mexico: 57.9 % interstate and 42.1 % intrastate. The most important markets were for slaughter and fattening, the rest corresponded to beef breeding, reproduction, fairs, and shows. The average market and state specialization were low, with a higher specialization in the entertainment market. The structure of the state network of all markets showed a high degree of average market and density, but low centrality of output and input. These measures mean that, on average, states can connect in 1.2 steps to the national network and in 1.7 steps to the network per purpose. The authors conclude that the state structure of the livestock market in Mexico is composed of 32 origins, 32 destinations, six markets, and major interstate mobilization from the south to the north of the country.

Keywords: Regional localization, Regional specialization, Network analysis, Interstate commerce, Intrastate trade.

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Introduction

Research on cattle production and marketing has been carried out in Mexico, but other important zootechnical objectives or market niches such as breeding, fattening, and entertainment have not been addressed. Livestock mobility consists of moving live animals from one place to another according to the laws of the market and the government[1], while the social structure of markets is a refutation of the asocial market conceptualizations that dominate the economic theory and policy[2].

Research of this type has been carried out in the U.S.[3], Argentina[4], Germany[5], Brazil[6], France[7], Chile[8], Ecuador[9], Ireland[10], and Uruguay[11]; they all agree on the importance of the studies for resource allocation, improved market efficiency, and animal health management.

Canada has an effective animal identification system, and its provinces are moving towards a fully traceable system; however, the U.S. and Mexico have made little or no progress in this sense[12]. In the U.S., lack of traceability causes annual economic losses of up to US$83 billion, and in the case of low- and middle-income countries, of up to US$95 billion; 80% of these losses are related to food and water consumption[13]. In addition to the disruptions in the U.S. beef cattle supply chain and the drop in cattle prices across the board caused by the COVID-19 pandemic[14], the epidemiological phenomenon led to a historical increase in the difference between the price of cattle and the wholesale price of meat[15], with losses estimated at US$ 13.6 billion[16].

In Mexico, the supply of cattle is important in terms of inventory, volume produced, value of production, and spread throughout the national territory[17]. The national inventory in the year 2020 was 35.6 million heads of cattle: 92.7 % beef, and 7.3 % milk. 36.3 % were concentrated in the states of Veracruz, Jalisco, Chiapas, and Chihuahua[18]; the first three states are characterized by the breeding of Zebu cattle, and the fourth, by raising European breeds[19].

The development of information and communication technologies has given rise to theories that form the basis of the current regional economic development. The network theory is a tool for analyzing the structure of a market for any economic activity or productive sector[20]. The structural characteristics of social networks describe how actors are connected to form a network or value chain[21]; network measurements can be calculated at node and network-wide level[22].

Faced with the problem of providing solutions for livestock production and distribution, the objective of the research was to analyze the structure of the livestock mobilization network in Mexico during the 2017-2021 period, through measures of economic location, centrality and density of the networks by type of market motive.

Material and methods

The database used in the research considered 100 % of the daily records of all types of cattle (milk, beef, rodeo, bullfight) legally moved by the quarantine stations of the National Service for Agriculture and Food Health, Safety, and Quality (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria, SENASICA) in Mexico for six purposes or markets (slaughter, fattening, beef breeding, reproduction, fairs, and entertainment) for the 2017-2021 period. The information was used with the express authorization of SENASICA, and its analysis was performed in Microsoft Office® Excel.

A comprehensive data collection method[23] was used for the research. Municipal mobilization records were grouped by state and by market. This grouping was done to form municipal, state, and federal matrices in accordance with the method and techniques utilized to estimate the indicators of the structure of the livestock market network in Mexico. A total of 1,374 source municipalities (Ms), 1,842 municipalities of destination (Md), and 44.7 million heads of cattle moved during the analysis period were analyzed. By market, 951 municipalities moved cattle for slaughter, 900 for fattening, 652 for beef breeding, 676 for reproduction, 391 for entertainment, and 484 for fairs; the municipalities of destination were 853 for slaughter, 1,119 for fattening, 1,086 for beef breeding, 1,355 for reproduction, 916 for entertainment, and 548 for fairs.

Municipal data were analyzed by state, with $N_i = 32$ source municipalities (X_i) and $N_j = 32$ municipalities of destination (X_j); this amounts to 1,024 exchange relationships. The economic importance and networks were measured based on the number of cattle moved across Mexican territory (X_{ij}). Two theories —the spatial location theory[24] and social network analysis— were used in the analysis of the network structure[25].

For the analysis of the regional economic structure, the livestock movement data were arranged in two matrices, one for the sector-region of origin, and the other one, for the sector-region of destination. The sectors were the six types of livestock movements (V_i), and the regions, the states of origin and destination of the livestock (V_j). The variable of analysis was the number of mobilized heads of cattle (V_{ij}).

The participation of the sector in the region of origin (P_{ji1}) and the sector in the region of destination (P_{ji2}) represents interregional specialization; this data was obtained by dividing the percentage of region *j* within the activity of sector *i*. The location coefficient (Q_{ij}) shows the proportion of each region within each sector and is a measure of interregional sector distribution and absolute concentration; it is calculated based on the share of sector *i* in region *j* and the share of the same sector in the national total. Finally, the specialization coefficient (*Qr*) shows the degree of similarity of the regional economic

structure with the economic structure of the country and is used as a measure of regional specialization[26].

$$Q_r = 0.5 \sum_i \left| \frac{V_{ij}}{\sum_i V_{ij}} - \sum_j \frac{V_{ij}}{\sum_i \sum_j V_{ij}} \right| ; 0 \geq Q_r \leq 1$$

For the analysis of the network, the information was organized in a matrix format (X_{ij}). The rows correspond to the mobilized livestock by origin (X_i), and the columns, to those received by destination (X_j). The main diagonal of the matrix was also considered because it represents mobilization within a state, or intrastate (X_{ii}). The matrix elements were transformed to binary form, assigning a value of 1 to livestock mobilization ($X_{ij}>0$) and of 0 to an absence of mobilization ($X_{ij}=0$). A total of seven networks were analyzed, one for all the purposes of livestock movement and one for each purpose. Likewise, all analyses were performed for the period from 2017 to 2021.

The method used was Social Network Analysis (SNA)[25]. The total structure and purpose of livestock movement were analyzed using measures of density and centrality. Density is a measure of cohesion among the elements of a network[27], and centrality measures the importance of a particular element in the network[25].

The degree of centralization of the network measures the number of livestock movements from origin to destination ($GC_{ij} = \sum_{i,j} GC_{ij} = \sum_{j,i} X_{ji}$); density measures the number of livestock movements carried out divided by the number of possible movements ($D_{ij} = N_{ij}/N$); the outbound grade measures the number of connections between each source and destination ($G_i = \sum_i X_{ij}$), and the degree of entry measures the number of connections between each destination and origin ($G_j = \sum_j X_{ji}$). The eigenvector centralization measures the qualitative aspect of a vertex's connections, based on the premise that connections to more influential vertices are more important than connections to less influential vertices, and it also considers the centrality of neighbors.

The eigenvector centrality measures the influence of a node on the network, assigning a relative score to each node based on the principle that the links of important nodes (measured by the degree of centrality) are worth more than the links of unimportant nodes[8].

Homophily is an intrastate measure of livestock and is calculated based on the sum of the elements of the main diagonal of the matrix ($Tr = \sum x_{ii}$). Homophily is the tendency of states and municipalities to form groups for the purpose of selling or buying cattle.

Finally, social capital (SC) is a measure of social relationships and can represent an advantage created by the location of a person with a relationship structure; it can take three forms: 1) Obligations and expectations, 2) Information channels, and 3) Social norms[28]. Likewise, social capital consists of the information and reciprocity resources that individuals can obtain from the structure of social networks[29]. The social capital was

estimated through the closure measure, which quantifies the preference of the origin for a specific destination, that is, a particular origin always prefers a particular destination and vice versa.

Results

The exploratory analysis made it possible to identify the dynamics of live cattle movement in Mexico; mapping its geographical distribution was the basis for showing the state structure during the 2017-2021 period. At the national level, an annual average of 8.9 ± 0.3 million livestock heads were moved for all reasons, with an average annual increase of 3.4 %.

The structure of the livestock moved consisted of six markets: slaughter, fattening, beef breeding, reproduction, fairs, and entertainment. The two most important markets were slaughter and fattening, with 53.5 % and 44.35 % of the cattle moved, respectively; the remaining markets represented 1.1 % for slaughter, 0.5 % for beef breeding, 0.3 % for fairs, and 0.2 % for entertainment. In addition, the structure by sex was higher in males (65.8 %) than in females (34.2 %); however, during the period of analysis, the mobilization of males decreased 16.9 % in that period (72.6 % in 2017 to 60.3 % in 2021), and in females, it increased 44.9 % (27.4 % in 2017 to 39.7 % in 2021).

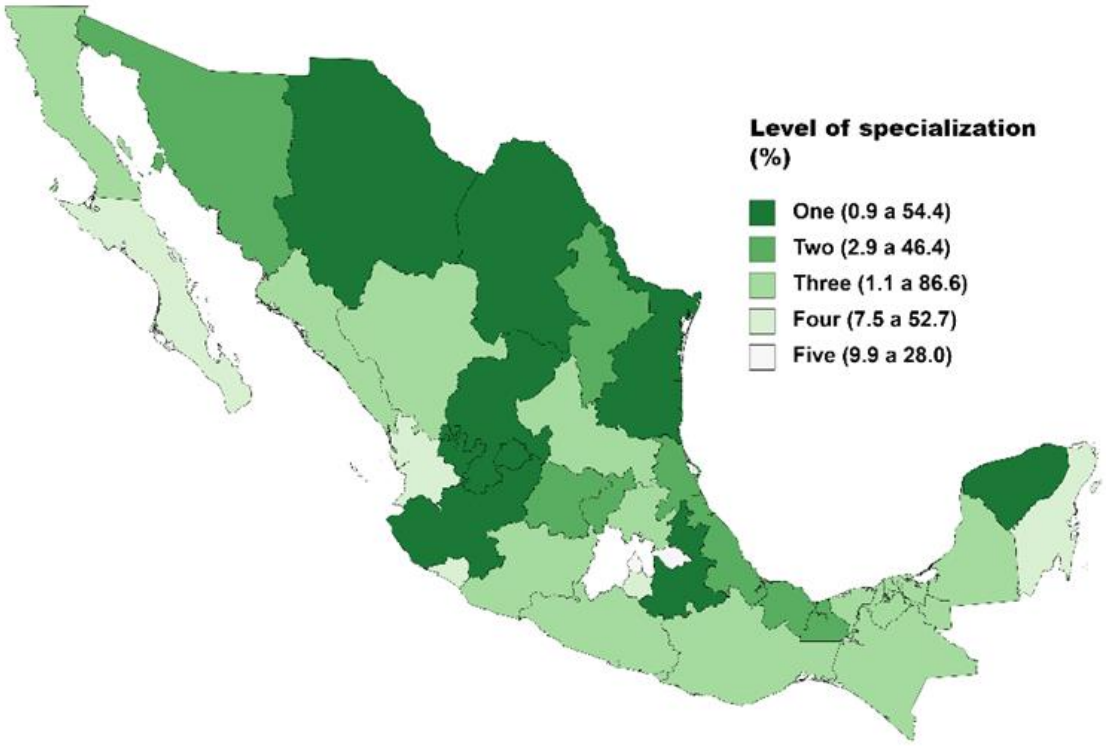
The proportion of cattle in intrastate markets was lower (42.2 %) than in interstate markets (57.9 %). However, intrastate participation by market was 30.9 %; it was higher for the slaughter market (71.8 %) and lower for the entertainment market (5.8 %). By state, the most important intrastate markets were San Luis Potosí (7.2 %), Veracruz (5.7 %), and Durango (5.2 %), and the interstate markets were Chiapas-San Luis Potosí (33 %), Chiapas-Querétaro (2.3 %), and Chiapas-Veracruz (1.7 %).

Supply

The economic structure of livestock movement could be explained through measures of interregional specialization. The average market specialization (0.39) was higher than for the regions (0.33). The markets for entertainment and slaughter were the most and least specialized, with values of 0.57 and 0.28, respectively; by state, Mexico City and Aguascalientes were the most and least specialized, with 0.99 and 0.01, respectively. By state, in one market 25.0 %, in two markets 18.8 %, in three markets 34.4 %, in four markets 15.6 %, in five markets 6.3 % and none in the six markets. The specialization rate by market was 43.8 % for the states specialized in slaughter, 46.9 % for those

specialized in fattening, 43.8 % for beef breeding, 50.0 % for reproduction, 34.4 % for fairs, and 40.6 % for entertainment (Figure 1).

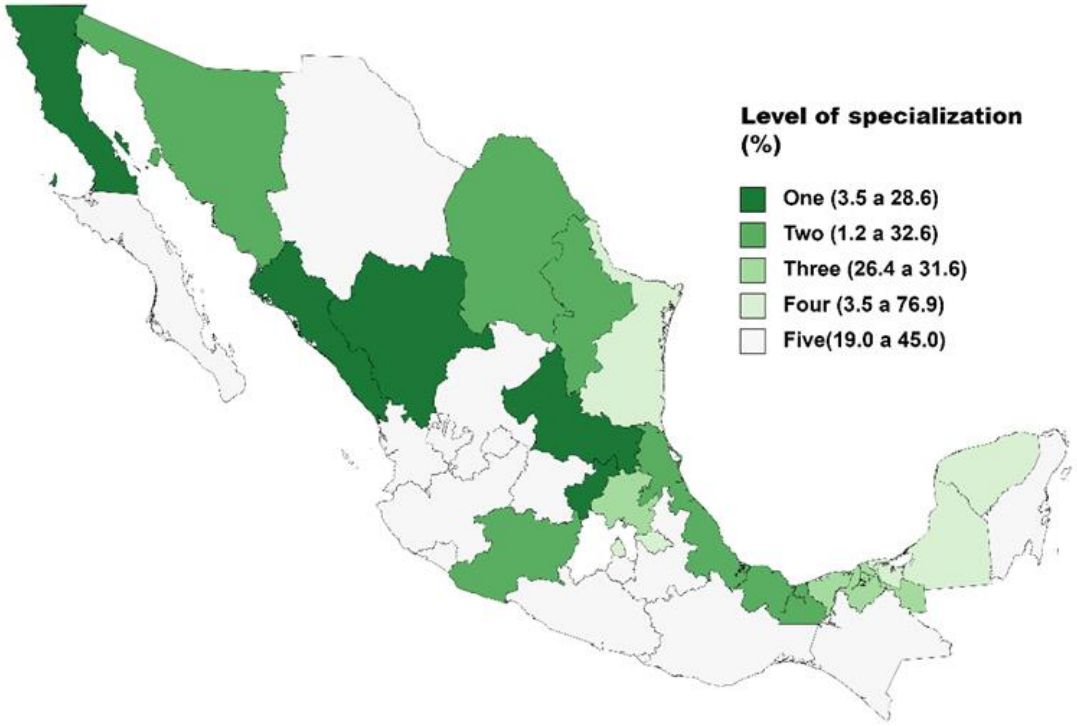
Figure 1: Geographic specialization of bovine livestock supply in Mexico, 2017-2021



Demand

In the economic structure of demand, none of the states specialized in any of the six purposes. The average specialization by purpose was higher than the specialization by state, 0.40 and 0.27, respectively. The fair market was the most specialized (0.58), while the market for slaughter was the least specialized (0.11). Specialization by state shows a specialization rate of 15.6 % in one market, of 18.8 % in two markets, of 6.3 % in three markets, of 43.8 % in five markets 43.8 %, and of 0 % in all six markets. Specialization by market shows that 71.9 % of the states specialized in cattle for breeding, 65.6 % in entertainment, 62.5 % in fairs, 62.5 % in beef breeding, 46.9 % in slaughter, and 43.8 % in fattening (Figure 2).

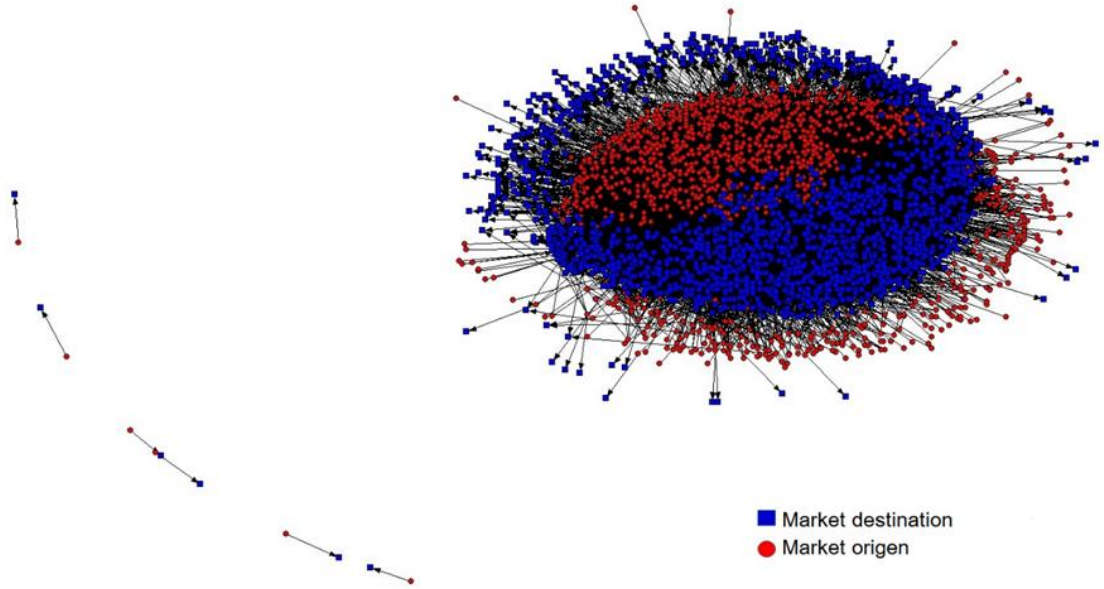
Figure 2: Geographic specialization of the cattle demand in Mexico, 2017-2021



Network analysis

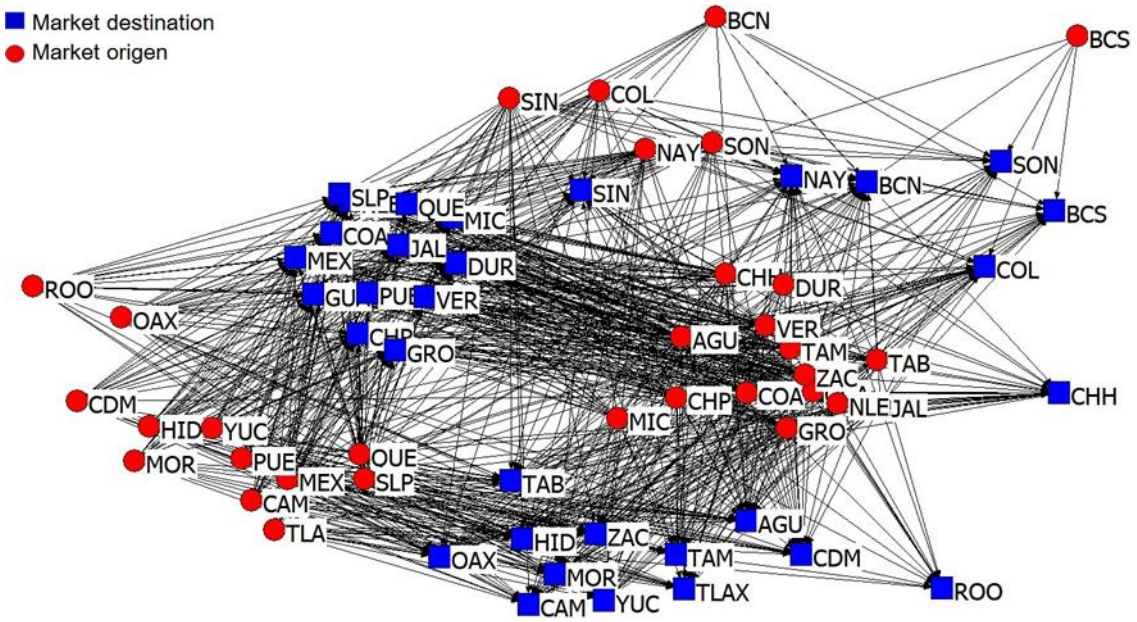
The municipal cattle movement network in Mexico was composed of 1,374 source municipalities (red points), 1,842 municipalities of destination (blue points), and 39,068 commercial links (edges). The measures of the structure of the entire network were low; the density was 0.04, and the average grade, 52.4. However, the measures of centralization were high: the degree of centralization was 0.34, for both outward centralization and inward centrality. The average network density and degree measures by market were lower than for the entire network; however, the centrality measures were higher, amounting to twice as much in the market for shows (Figure 3).

Figure 3: Mexico's municipal network for the mobilization of live cattle, 2017-2021



The state cattle movement network in Mexico consisted of 32 states of origin (red nodes), 32 states of destination (blue nodes), as well as of 856 commercial relationships out of 1,024 potential ones. The average density and degree measures for the entire network were high, 0.84 and 25.9, respectively; however, the centrality measures were low: the degree of centrality was 0.02; the output centrality, 0.17, and the input centrality, 0.14 (Figure 4).

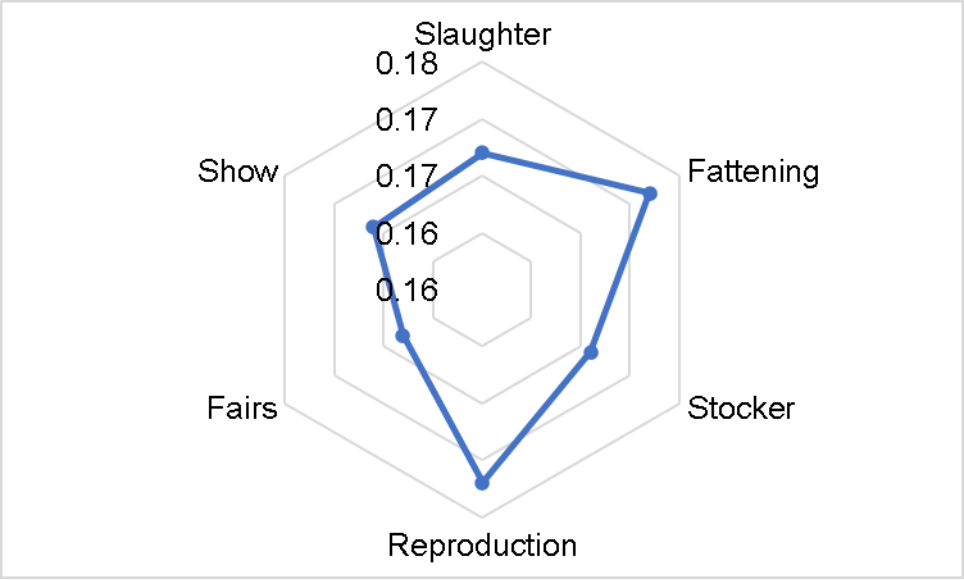
Figure 4: Mexico's state network for the mobilization of live cattle, 2017-2021



The market nets had low average density and degree measures relative to the total net, of 0.50 and 15.0, respectively; the highest average density and degree values were for the fattening and breeding nets (0.60 and 18.6), and the lowest one was for fairs (0.38 and 11.8). However, the degree of market centrality was 11.5 times higher than for the entire network, and the origin and destination centralities were 2.5 times higher.

A measure of centrality that considers the relative importance of the network elements is the eigenvector. The total network had an eigenvalue of 0.18, which is higher than that of the markets (Figure 5). In the national network, the first eigenvector accounted for 80.8 % of the variation of all markets. In the total network, 28.1 % of the states had the maximum eigenvalue (0.19). Jalisco was the most important state in market networks for slaughter (0.24), fattening (0.21), beef breeding (0.24), reproduction (0.22), and fairs (0.28), and the states of Michoacán and San Luis Potosí, for entertainment (0.28) (0.24).

Figure 5: Eigenvector by market network 2017-2021



Finally, measures of homophily and social capital (closure) robustly support the structure of the cattle network in Mexico. The average homophily for the whole network was higher (0.69) than per market (0.31), with the highest homophily for reproduction and the lowest for beef breeding. Likewise, the average network social capital for all markets was higher (0.90) than per market (0.71). The highest capital stock was in the fattening market network (0.79), and the lowest, in the fairs (0.68).

Discussion

Mexico's cattle market moved on average one third of the national inventory annually. slaughter and feedlot markets accounted for the largest proportion of livestock moved, breeding and finishing activities are carried out in the same production unit, but not for

the fair, breeding and show markets (Table 1). Given that the slaughter and fattening markets accounted for the largest proportion of livestock moved, beef breeding and reproduction activities are carried out in the same production unit, unlike for the fair, reproduction, and entertainment markets.

Table 1: Main cattle supply and demand states in Mexico, 2017-2021 (%)

State	S^1	D^{1a}	S^2	D^{2a}	S^3	D^{3a}	S^4	D^{4a}	S^5	D^{5a}	S^6	D^{6a}
Chiapas	0.9	0.7	28.6	1.3	20.1	17.4	10.8	10.1	24.2	24.4	1.5	1.5
Coahuila	4.3	4.4	3.6	3.1	7.0	18.4	2.6	2.7	0.8	0.4	0.5	1.3
Durango	13.7	10.2	1.8	15.7	8.6	11.9	1.9	3.3	1.1	0.8	0.3	2.0
Guerrero	0.1	0.1	3.4	0.0	0.3	0.3	1.7	2.1	0.7	0.3	22.5	2.5
Jalisco	4.5	1.3	6.5	3.0	4.4	6.5	9.5	9.0	10.3	9.5	7.8	9.4
State of Mexico	0.3	9.5	0.2	1.8	0.5	0.9	0.2	1.5	0.2	0.1	4.8	10.0
Michoacán	7.5	11.4	1.5	5.9	0.7	1.2	2.3	5.2	1.1	3.8	4.5	9.7
Nuevo León	7.9	8.8	2.1	8.6	1.9	3.3	10.2	4.1	12.3	8.9	0.7	1.8
San Luis Potosí	13.8	13.8	1.7	15.3	1.2	0.7	0.9	1.6	3.0	4.0	9.9	2.5
Tabasco	0.3	0.3	7.8	0.4	9.4	9.0	7.4	8.1	8.1	7.0	0.4	0.3
Tamaulipas	2.1	1.9	1.7	2.1	3.5	2.6	10.9	6.0	10.9	8.6	1.0	0.6
Tlaxcala	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.3	0.0	0.0	16.4	1.1
Veracruz	9.1	7.4	14.5	10.9	5.6	5.4	8.9	10.9	9.4	8.1	0.8	2.9

1= slaughtering supply 1ª= slaughtering demand, 2= fattening supply, 2a= fattening demand, 3= beef breeding supply, 3a= beef breeding demand, 4= reproduction supply, 4a= reproduction demand, 5= supply for fairs and shows, 5a= demand for fairs and shows, 6= entertainment supply, 6a= entertainment demand.

Productive resources and fuel costs have allowed for greater market specialization; in 2021, the cost per kilometer traveled for land transportation was 0.52 US$ km^{-1} and represented 43.8 % of the total cost[30]. The southeastern states of the country have specialized in the breeding and grazing markets due to the relative abundance of climate, land, water and forage; Mexico's humid tropics are characterized by rainfall of up to 1,300 mm per year (Jaramillo, 1994, cited in Enríquez-Quiroz *et al*., 2021)[31], allowing a maximum of 1.79 UA ha^{-1}[32]. The northern and central states specialize in fattening and slaughtering to supply the large meat consumer markets of the central metropolis, and the central markets, in fairs and entertainment events that are important for regional cultures.

The analysis of the regional economic structure and by livestock market in Mexico indicates that, on average, livestock markets and regions in Mexico have a low level of specialization, since both measures are less than 40 %. The most specialized markets (fairs and entertainment) are related to the supply of fighting bulls and rodeo, while the least specialized is related to the slaughter of cull animals (cows and bulls). The specialization of cattle breeding in the northern states of the country is in the production of calves for export; Chihuahua's cattle breeding activity is oriented to the export of calves[33].

The measure of average specialization by market and by state indicates that cattle farming in Mexico has a low level of specialization, although it was higher by market than by state. The average supply specialization for the states was not statistically different from the average demand specialization for the states (P>005); the same was true for the average market specialization (P>005). However, it was found that there are different degrees of specialization in the markets; it was higher in the entertainment market and lower in the slaughter market. Low specialization is explained by the diversity of production scales, resource allocation, and reduced knowledge of the markets by the suppliers (producers) and demanders (consumers).

Given the large number of municipalities and the dispersion and distance between these, the average degree and centrality of the municipal livestock network in Mexico are considered very low. A higher proportion of Mexico's municipalities participate in livestock markets; 56.2 % of the municipalities participated in the markets of origin, and 73.3 %, in the markets of destination. 41.4 % of the municipalities participated in the slaughter market of origin, and 58.9 %, in the destination market for breeding. The market with the lowest participation of source municipalities was entertainment (16.4 %), and in the destination municipalities, it was the fairs market (23.2 %).

The cost of transporting livestock between municipalities is high. The distance between the two most important municipalities in the mobilization of livestock (Ezequiel Montes Querétaro and La Paz Estado de México) is 224.9 km, but the distance to the second market (Benemérito de las Américas, Chiapas, and Tamuín, San Luis Potosí) is 1,341.9 km, and the longest distance was from Matamoros, Coahuila, to Mexicali, Northern Baja California, of 1,714 km. Livestock mobilization occurs in all Mexican states, but its importance differs by market of origin and destination; the southeastern states were the main origin of cattle for the reproduction, beef breeding, and fattening markets; the northern markets are the main destination of cattle for fattening (Table 1).

Density is a measure of network connectedness and social capital. High density in the national network is associated with the number of markets (six), the number of slaughterhouses (1,175), and the availability of resources, while low centrality is associated with low scales of production. The density by market is lower than for the entire network due to the specialization of both origins and destinations, while the centrality by market is higher because it is associated with the preference or social capital of origins and destinations. The states obtain market information for an average of 26.8±6 states, but these represent only 3.1 % of the cattle moved.

The eigenvector is a measure of network centrality; the network pattern is represented by 80.8 % of the states. The eigenvalue of the states of origin and destination indicate that the national cattle market in Mexico has a high stability. The degree of inequality of the states is only 1.8 % of the potential maximum.

The most important source states are related to the most important destination states, and vice versa, while individual markets have 3.3 times more instability. The breeding and fair markets had the highest and lowest stability, representing 2.3 and 4.2 times the national stability. Special cases are weaned calves; stabilizing their replacement is the basis for stabilizing the beef breeding, fattening, and slaughter markets. The instability of the fairs is more associated with the economic stability of the country and events such as the Covid-19 pandemic in 2021.

Conclusions and implications

This research is the first in Mexico to analyze the structure of the six cattle markets at the municipal level. Maps of specialization of supply and demand were constructed, the economic index of specialization was estimated, the graph of the national livestock movement network by market was presented, and measures of density and centrality of the network were estimated. By knowing the origin, destination and quantity of livestock moved in the country, it is possible to establish a system of sanitary surveillance and registration of market information to improve the productivity of cattle production and marketing systems in Mexico. The cattle market in Mexico is important because it mobilizes on average more than one third of the national inventory, mainly for slaughter and fattening. However, the markets present a low specialization due to variables such as the large number of municipalities in the country. As a result, only a fourth of the states of origin and a seventh of the states of destination specialize in the fattening and slaughter markets. Likewise, the national mobilization structure presents a high degree of density, with a low degree of centrality; whereas, by market, the density is lower, but with higher centrality. Therefore, with homophily representing almost half of the market, the social capital is high. These aspects allow an average of 1.2 states to connect to the entire national network, and up to 1.7 states, to the network by purpose.

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