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Identifying Vulnerabilities in Multilayer Spatial Networks

A Case Study of Food Flows in The United States

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SPATIAL NETWORKS – NETWORK MEASURES

- Various indices have been used for identifying important nodes (locations) in spatial networks:
  - Degree, betweenness and closeness centrality (Freeman 1977),
  - Entropy (Li et al. 2008, Koylu and Guo 2013),
  - Clustering coefficient (Saramäki et al. 2007),
  - GINI coefficient (Lin, Dang, and Konar 2014)
  - ….

SPATIAL NETWORKS – NETWORK MEASURES

- These measures are often inadequate to identify vulnerabilities in spatial networks because there are often multiple types or categories of interactions between each pair of locations (Kivelä et al. 2014).
- For example, state-to-state food flows include several different types of food such as cereal grains and livestock. A state that is important for sustaining a connected supply-chain network for a certain type of food such as cereal grains may be insignificant for the distribution of another type of food such as meat and livestock

United States® Census Bureau

USDA

AGRICULTURE NASS COUNTS

Freight Analysis Framework

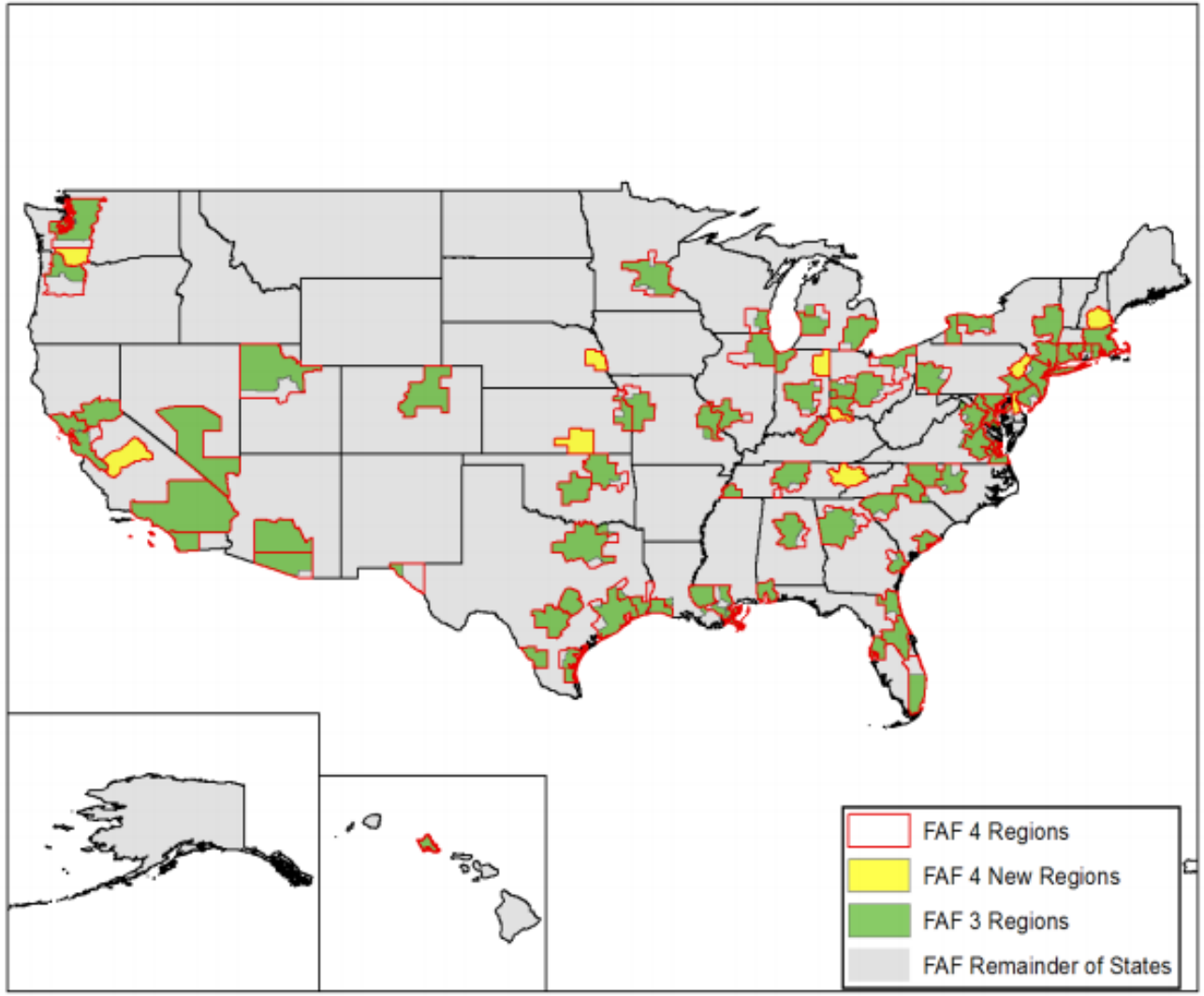
The Freight Analysis Framework (FAF) integrates data from a variety of sources (five for food products) to create a comprehensive national picture of freight movements among states and major metropolitan areas by all modes of transportation.

Modes of transportation: Truck, Rail, Water, Air, Multiple Modes and Mails, Pipeline, Unknown or other

132 FAF zones from Commodity Flow Survey (CFS)

- May change every 5 year
- reflection of changes in regional population or economic activity patterns

Origin, Destination, SCTG, Shipment Value, and Shipment Volume



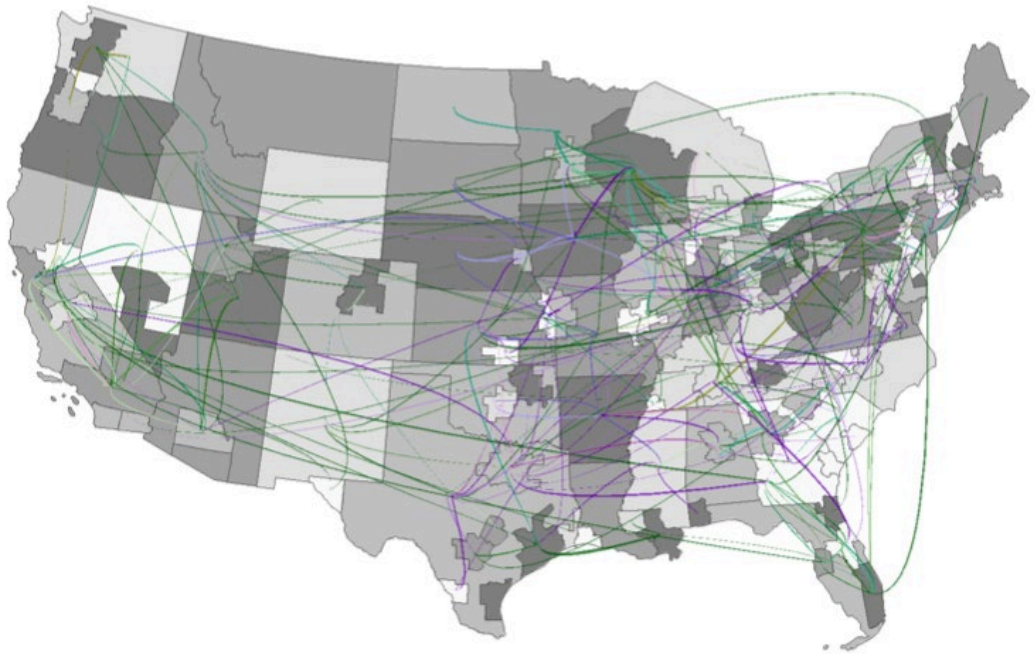
FOOD CATEGORIES IN COMMODITY FLOWS

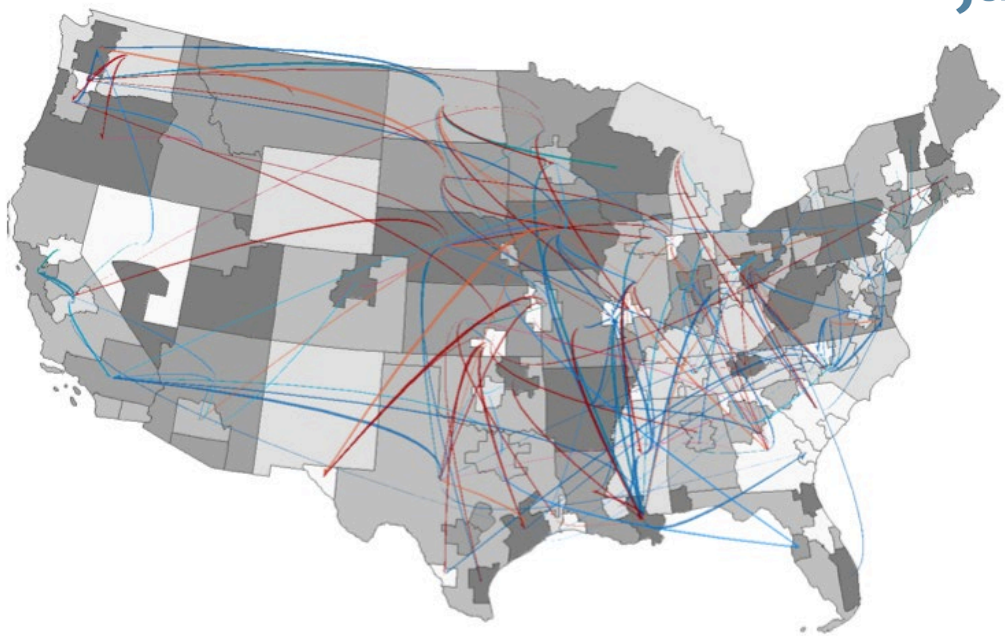
Table 1. List of standard classification of transported goods (SCTG) food categories included in this study.

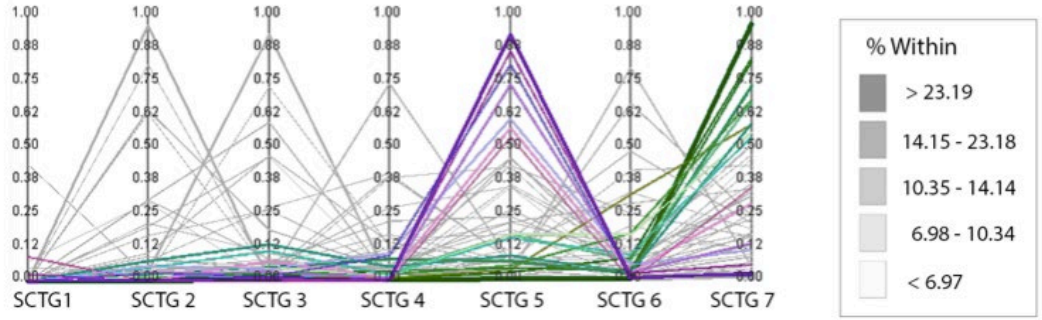
SCTG	Model
1	Animals and fish (live)
2	Cereal grains (includes seed)
3	Agricultural products (excludes animal feed, cereal grains, and forage products)
4	Animal feed, eggs, honey, and other products of animal origin
5	Meat, poultry, fish, seafood, and their preparations
6	Milled grain products and preparations, and bakery products
7	Other prepared foodstuffs, fats and oils

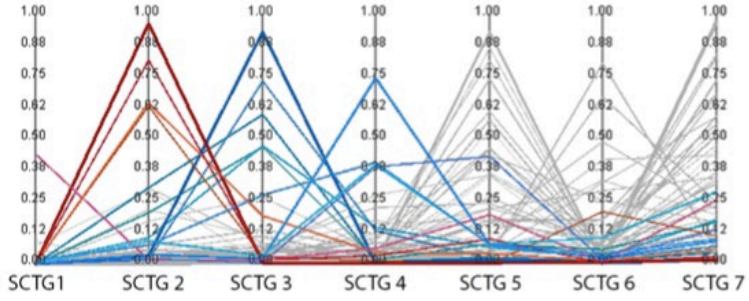
The multivariate clustering of food flows by category (>50% of all flows).

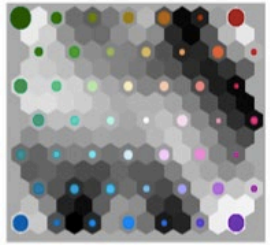
The choropleth base map illustrates the percentage of within flows for FAF regions.











Dr. Caglar Koylu

METHODOLOGY

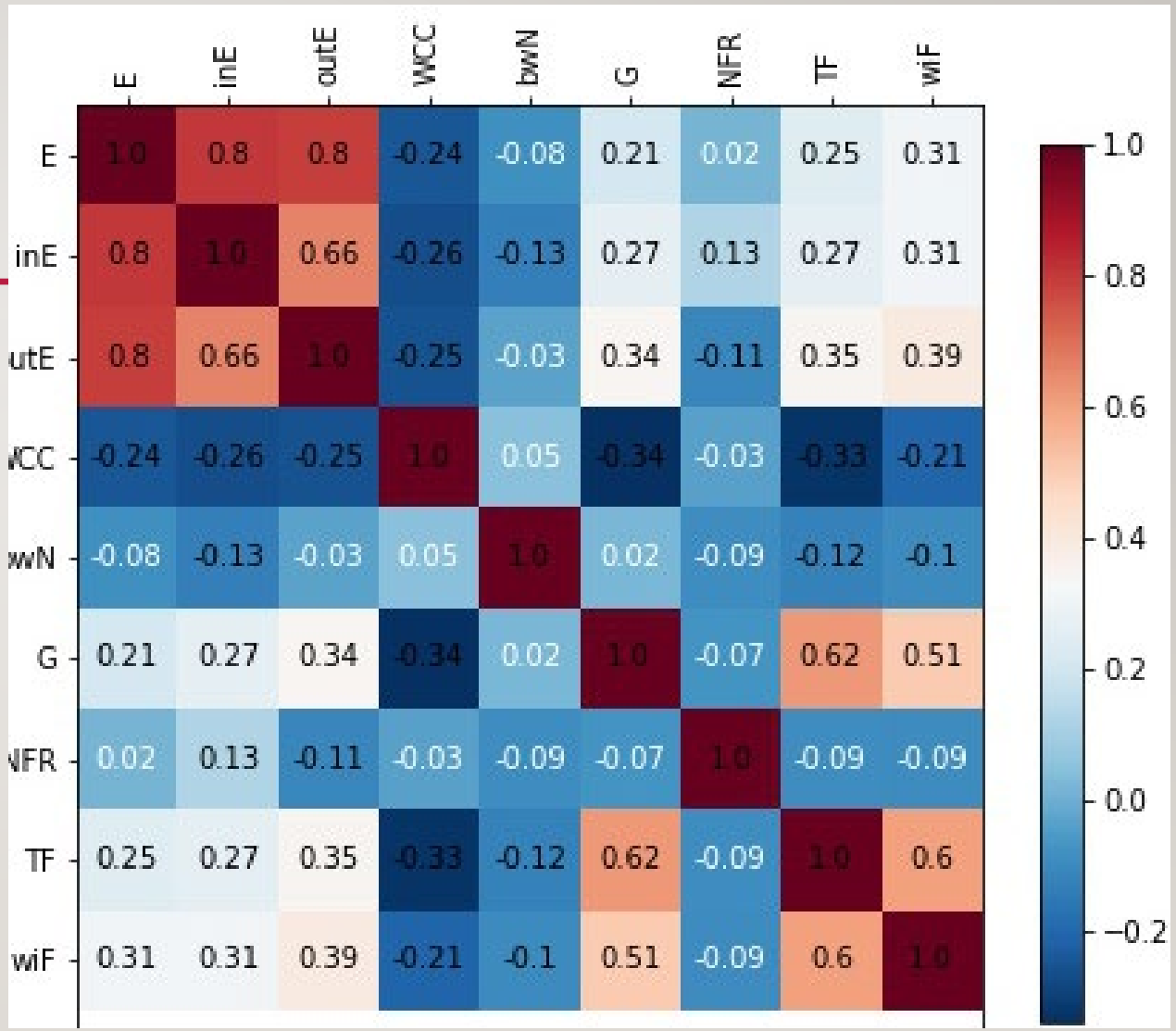
We adopt a series of network measures to identify network characteristics and potential vulnerabilities of locations in the food network using the multilayer network approach.

By calculating the Kendall's Tau coefficients, we perform two evaluations to identify the level of similarity between:

1. the different layers (food flow category) for each measure
2. each pair of network measures for each layer.

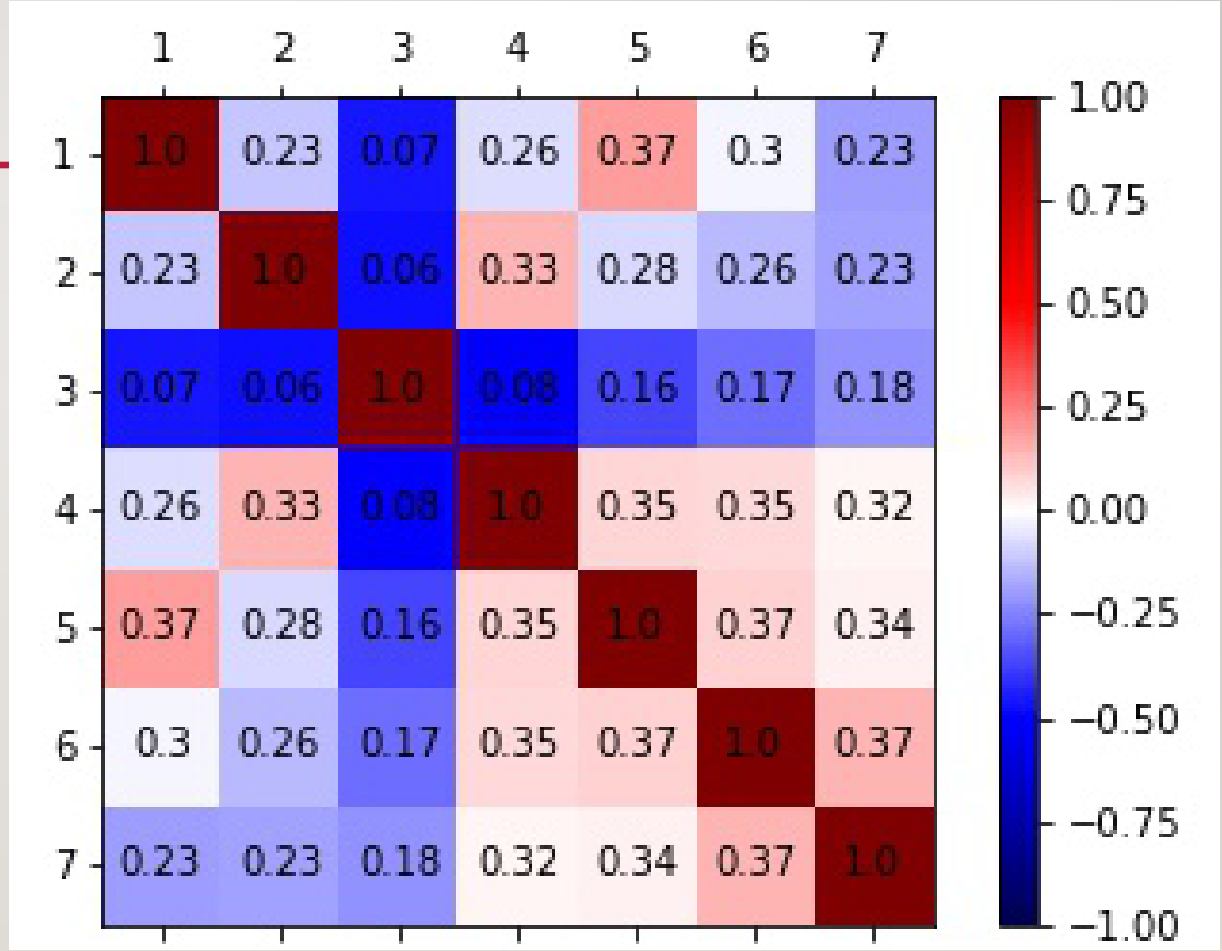
KENDALL'S TAU NETWORK MEASURES

- Entropy
- Inflow Entropy
- Outflow Entropy
- Weighted Clustering Coefficient
- Weighted Betweenness Centrality
- GINI Coefficient
- Netflow Ratio
- Total Flow
- Within Flow

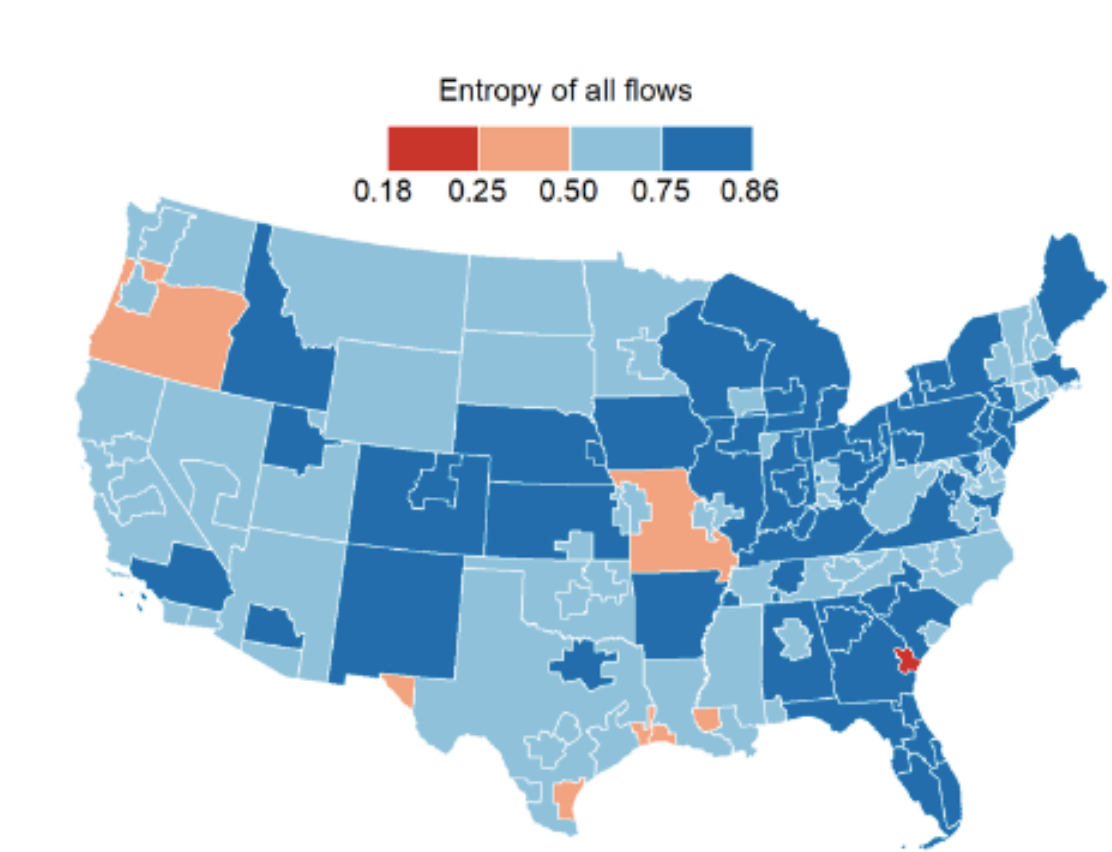


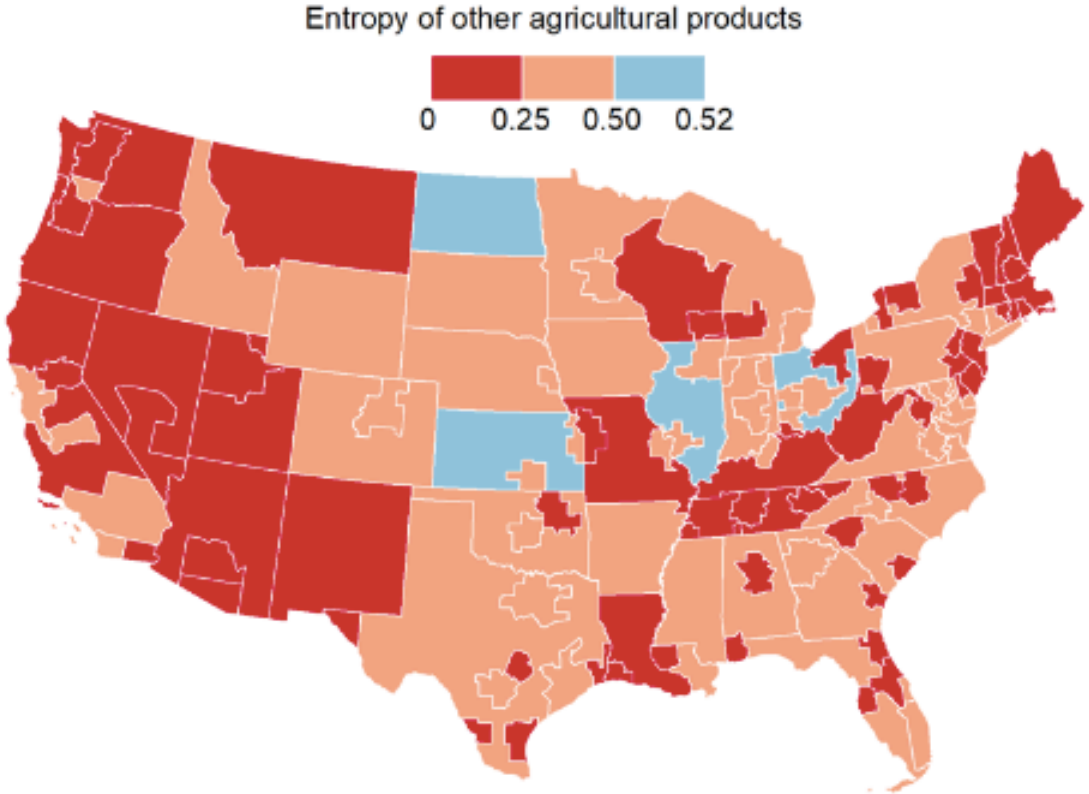
KENDALL'S TAU NETWORK LAYERS

1. live animal/fish
2. cereal grains
3. other agriculture products
4. animal feed
5. meat/seafood
6. milled grain products
7. other foodstuffs.



Entropy: the degree of disorder





CONCLUSION

- It is important to distinguish the measurement of vulnerability in spatial networks into the concepts of system vulnerability and location vulnerability.
  - For example, low values of entropy indicate that a location is sending and receiving flows from only a few locations, while high values of entropy indicates that the location is receiving and sending flows from diverse locations with similar volumes.
- Low values of entropy may indicate high vulnerability for a location in the case of disruptions such as natural disasters effecting those few connections that the location has.
- In contrast, while high entropy means that at location is self-sufficient and robust, this may pose a potential threat to the systems vulnerability because the system becomes highly vulnerable if the location has any disruptions in its distribution of flows.

FUTURE DIRECTIONS

- Develop an indicator based on the average rankings of measures. This would ultimately carry information from each measure, which reflects a different characteristic of for the locations and the network.
- While developing such an indicator, we will remove redundant measures (e.g., measures that highly correlate with each other) to reduce noise and redundancy.
- Analyze the relationship between food flows and the factors such as food production and consumption, population and demographics, and transport hubs in our future studies.