Sustainability and Risk Management of Meat Supply Chains in a COVID-19 World

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Introduction

- The COVID-19 pandemic
  - has adversely affected every aspect of the food supply chain
  - is expected to have a large impact on and reshape the food sectors in long-lasting ways
- Such events are not infrequent in modern economies, for example,
  - the Starlink gene in maize (Carter and Smith 2007)
  - Bovine Spongiform Encephalopathy (BSE)
  - recurrent food safety recalls in the US (Shang and Tonsor 2017)
  - a breakdown in feedstuffs and meat markets caused by dioxin contamination in Western Europe in 1999 (Malisch 2017)

Overall Objectives

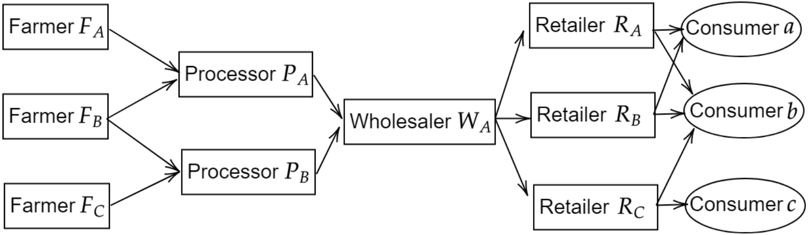
- To understand the underlying structure and vulnerability of food supply chains as well as the economics of supply chain formation
- To quantify the consequences of the COVID-19 crisis, and related crises, and
- to facilitate the design of sound policy responses

Data and Methods

We mainly employ the Commodity Flow Survey (CFS), which provides details of individual shipment records of commodities, including, date, value, weight, source, and destination, to:

1. construct supply chain networks (SCNs) for selected meat products, e.g., beef, pork, poultry, and seafood,
2. estimate the characteristics of the constructed supply chain networks as well as their changes over time to better understand vulnerabilities to supply chain crises,
3. apply theoretical and empirical economic methods to understand the economics of supply chain formation,
4. simulate how meat supply chains are affected by spatial spread of disease, and
5. study how different communities are affected by supply chain disruptions.

Background: SCN of Beef



- In a SCN, pieces and players are interconnected in complicated ways and their dynamics are continuously changing
- Concentrated production and distribution create hubs and heavy flows and leave the system vulnerable to unexpected shocks
- Diversified demand calls for differentiated products in small volume

Supply Chain Network Construction

- Using 2017 CFS, we start with poultry
  - Standard Classification of Transported Good (SCTG) codes
  - fresh or chilled (SCTG 05121)
  - frozen (SCTG 05122)
- Challenge: Source (establishment) $\Rightarrow$ Destination (zip code)
- Solution: construct vertically linked industrial sectors for specific commodities, including, for example,
  - based on the North American Industry Classification System (NAICS)
  - Food manufacturing (NAICS 311)
  - Grocery and related product wholesalers (4244)
  - Grocery stores (4451)

Structure of NAICS, 2017

Sector	Description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining, Quarrying, and Oil and Gas Extraction
22	Utilities
31-33	Manufacturing
42	Wholesale Trade
44-45	Retail Trade
48-49	Transportation and Warehousing
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Admistrative and Support and Waste Management

Supply Chain Network Construction (cont'd)

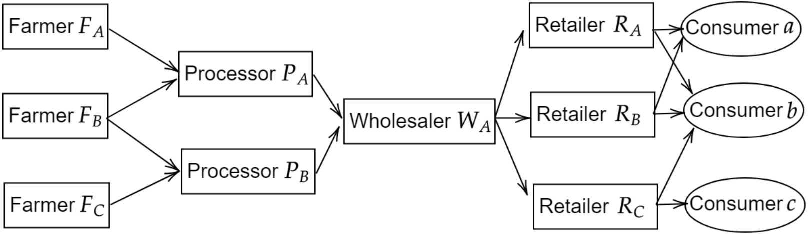
- Follow the method in Atalay et al. (AER; 2014) "Vertical Integration and Input Flows", we first construct vertically linked sectors
  - Industries I and J are vertically linked if 5% of I's sales are sent to establishments in J
  - The fraction of sales from I to J is constructed by using the information from the BEA Input-Output tables, CFS, Annual Wholesale Trade Surveys, and Annual Retail Trade Surveys
- Destination zip code + vertically linked sectors $\Rightarrow$ upstream/downstream establishments along the supply chain network by using the information in the Longitudinal Business Database

Network Measures

- A directed and weighted (shipment values) supply chain network for poultry in 2017
- Aggregate network measures (numbers will be disclosed after approval)
  - small mean degree (average of links a node has)
  - the degree distribution is fat-tailed
  - low edge density (proportion of edges over all possible edges)
  - mean distance (average number of edges between any two nodes)
  - Centrality measures are used to identify key players
    1. degree centrality (how many edges each node has)
    2. closeness centrality (distance between two nodes)
    3. betweenness centrality (importance of nodes in the flow)
    4. eigenvector centrality (takes into account alters' power)

Implications of Network Structure

- Propagation of shocks partially depends on the structure of interconnections
- A small number of participants may play a disproportionately important role in the SCN, for example, wholesaler W_A



Model of Supply Chain Network Formation

- Following the literature, e.g., Holmes and Stevens (2014), we model the driving forces of the SCN's formation
- We assume that meat product flows from region r_O to r_D are determined by:
    1. cost efficiency factor ω_O at the source region r_O
    2. distance adjustment factor $a_{r_O,r_D} \equiv f(d_{r_O,r_D})$, where d_{r_O,r_D} is the physical distance between the regions, and $f(\cdot)$ is a parametric or non-parametric function
- The competitiveness of what is produced in r_O is quantified by the function $g(a_{r_O,r_D}, \omega_O)$

Model of SCN Formation (continued)

- Assume a perfectly competitive market with no transportation constraints, the probability that region r_O's product has a positive market share in the destination r_D is:

$$p_{r_O,r_D} = \frac{g(a_{r_O,r_D}, \omega_O)}{\sum_{i=1}^{I} g(a_{r_O,r_D}, \omega_O)},$$

  where $\sum_{i=1}^{I} g(a_{r_O,r_D}, \omega_O)$ is the summed competitiveness of all other source regions ($i \in \{1, 2, \ldots, I\}$ in r_D
- p_{r_O,r_D} can be measured by the market share s_{r_O,r_D}
- With the total sales of x_{r_D}, total revenue for r_O from region r_D is: $y_{r_O,r_D} = s_{r_O,r_D} \times x_{r_D}$.
- Total revenue for the meat produced at r_O for all destination regions is: $y_{R_O} = \sum_{i=1}^{I} s_{r_O,r_i} \times x_{r_i}$.

Model of SCN Formation (continued)

- For a specific meat product, let $W = \{\omega_1, \omega_2, \dots, \omega_t\}$ be the cost efficiency matrix of all regions considered, and $\Theta = \{\beta_f, \beta_g\}$ be the vector of all distance adjustment function f and competitiveness function g parameters
- Given the market share data of all source-destination pairs, $S = \{s_{r_i, r_j} : i, i \in \{1, \dots, I\}\}$, W and Θ will be estimated by:
    1. for a given set of Θ, solve for W to match predicted regional sales $Y = \{y_{r_i}, i \in \{1, \dots, I\}\}$ with actual sales, and
    2. The probability of shipment between r_O and r_D can be written as $p_{r_O, r_D} = \frac{y_{r_O, r_D}}{\sum_{i=1}^{I} y_{r_O, r_D}}$. The parameters in Θ will be estimated by maximizing the likelihood of the observed destinations in CFS

Simulation of Market Shocks

The impact of supply disruption along the SCN will be simulated in the following steps:

1. Changing the distances between contaminated regions and the destination regions to infinity. Doing this will alter the potential competitiveness of all producing regions, the source-destination pairs, and consequently the flows of targeted meat products,
2. Simulate the resulting commodity flow shares using the estimated model, and
3. Assuming all production facilities in uncontaminated regions reach their capacities, quantify the regional market shortages by comparing predicted sales to historical sales in certain regions

Simulation of Market Shocks (continued)

Simulation outcomes will be used:

- to understand which communities are most vulnerable to shocks at particular nodes,
- to provide an overall assessment of comparative vulnerability to shocks across the entire SCN, and
- to evaluate potential policies and strategies to enhance the sustainability of the SCNs.

Thank You

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