Innovation of Agriculture and Food Systems through Supply Chain Analytics & Sensing

MIT Sloan Reunion Weekend
June 2023
Presenting

Retsef Levi
Management Science
J. Spencer Standish (1945)
Professor of Management

Yanchong (Karen) Zheng
Management Science
George M. Bunker Professor,
Associate Professor of Operations Management
01 Motivation

Food Supply Chain Analytics & Sensing
Initiative scope of work (examples)
  • Projects in China, India, & Indonesia

03 Discussion
Why through Illustrative Numbers

7.5 to 10 billion people
Global demand for safe & nutritious food is expected to grow by 2050 (protein, fruits, and vegetables)

40% of the earth’s surface
Is occupied by agriculture (70% of global water use; 11% of global GHG emissions)

More than 800M people
World hunger is again on the rise

570M farms
And millions in food related jobs, many of whom live in severe poverty

420K die; 600M fall ill
Each year after eating contaminated food
FSAS Team

LEADERSHIP

Retsef Levi
Management Science
J. Spencer Standish (1945)
Professor of Management

Stacy Springs
Executive Director, Food Supply Chain Analytics and Sensing (FSAS) Initiative

FACULTY

Yasheng Huang
Behavioral and Policy Sciences
Epoch Foundation Professor of International Management

Georgia Perakis
Management Science
William F. Pounds Professor of Management and Associate Dean, SERC

Y. Karen Zheng
Management Science
George M. Bunker Professor

Joann de Zegher
Management Science
Maurice F. Strong Career Development Professor

Anthony Sinskey
Biology
Professor of Biology
## Supply Chain & Market design Optimization

### Farmer and Consumer Welfare

**Agriculture Practices**
- Improving smallholder farmers’ welfare with digital technologies and policy intervention
- Technology interventions to optimize & digitize smallholder supply chains

### Management of Human Health Risks in Food Supply Chains

**Predictive Risk Models & Tools**
- Food Safety & Adulteration Risks in China’s Food Supply Chain
- Local Regulatory Strength in China’s Food System
- Wholesale Market Management in China

### Access to Healthy Food

**Testing Technologies**
- Fresh Fruit & Vegetable Consumption: The impact of access and value
- Optimal Interventions for Increasing Healthy Food Consumption Among Low Income Households

## Access to Fresh Produce

**Food Waste**
Systemic Risk Management of Food Supply Chains in China

**Pls: Huang, Levi, Sinskey, Springs, Strano, Zheng**

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>David Byun</td>
<td>Associate Dir. of Data Science</td>
</tr>
<tr>
<td>Lu Chen</td>
<td>Associate Dir. of Research Collaborations</td>
</tr>
<tr>
<td>Duc Tuyen Do</td>
<td>Data Engineer</td>
</tr>
<tr>
<td>Jennifer Gao</td>
<td>Research Associate, Director of Strategy</td>
</tr>
<tr>
<td>Flora Keumurian</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Yanzhe Ma</td>
<td>Research Assistant</td>
</tr>
<tr>
<td>Victoria Pu</td>
<td>PhD student</td>
</tr>
<tr>
<td>Nicholas Renegar</td>
<td>PhD student (graduated)</td>
</tr>
<tr>
<td>Stacy Springs</td>
<td>co-PI and Executive Director</td>
</tr>
<tr>
<td>El Ghali Zerhouni</td>
<td>PhD student</td>
</tr>
<tr>
<td>UROPs</td>
<td></td>
</tr>
</tbody>
</table>

Supported by: [Walmart Foundation](https://www.walmart.com)
Collaboration Structure

- Map fresh water shrimp and fish SC
- Map regulatory environment
- Develop analytics risk models

- Visualization of SC mapping tool and risk models
- Environmental data integration

- Map WS markets
- Risk drivers related to WS markets

- Test high-risk adulterants and freshwater fish types
- Map fresh water shrimp and fish supply chain
- Analyze surveys

Supported by:
Walmart Foundation
On the Ground
CFDA Data Integration

Joint work with Ben Batorsky, David Byun, Jennifer Gao, Chris Muir, Nick Renegar, and Jack Zhao

- Automated processing (in legal compliance with robots.txt and copyrights)

- Integrated central data, all provinces & 310/334 prefectures

- 10.6M+ tests, 110k files (PDF/HTML/Excel/Word), 30k unique data table structures

Example Notice

Extensive text analytics needed!
SC Risk source Analysis of Fresh Water Aquatics

Joint work with Cangyu Jin, Qiao Liang, Nick Renegar, Stacy Springs, Jiehong Zhou and Weihua Zhou

8% of Risk
Environment

46% of Risk
Manufacturers

39% of Risk
Farming
Feed
Supplies
Practices
Breeding

7% of Risk
Retail Adulterant Risk Sources

46%
39%
8%
7%

Retail Stores
Manufacturers
Wholesale Markets
Brokers
Breeding
Farming
Feed
Supplies
Practices
Circulation

Secondary WSMs & Wet Markets
Restaurants
High-risk Manufacturer Visualization Tool

https://foodsafetyinchina.azurewebsites.net/
• Wholesale markets are a consolidation point of the SC (70% of supply through 4,500 large markets)
Wholesale and Wet Market Food Safety Risk Scores
Sensor Development

Accomplishments

- Discovered fluorescent nanosensors for heavy metal ion detection in fish tissue and water
- Developed a machine algorithm for the discovery of nanosensors against metal ions and antibiotics
- Built a portable detector device prototype capable of reading nanosensors deposited sensor strips
- Discovered and engineered a nanobody capable of binding chloramphenicol, a common antibiotic adulterant
  - Currently being tested with various sensing technologies for field detection
  - Screening platform developed to discover nanobodies against additional targets
ZOONOTIC DISEASES IN WHOLESALE/WET MARKETS IN CHINA

Wholesale and wet markets are associated with zoonotic diseases outbreaks (COVID-19, SARS, Avian/Swine Flu)

Strong association between province-level food safety risk scores and zoonotic flu cases (controlling for multiple potential confounding)
Understanding the dynamics within a live animal market

Farm 1

Farm 2

Farm 3

Direct infection from infected poultry

Infection from the environment

Cage surfaces

Wastewater

Feathers

Feces and Residuals
Infected poultry leave residuals

Understanding the dynamics within a live animal market
Understanding the dynamics within a live animal market

Farm 1

Farm 2

Farm 3

Market

Infection from the environment

Direct infection from infected poultry
Understanding the dynamics within a live animal market

Infected poultry leave residuals

Farm 1

Farm 2

Farm 3
<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>METHODOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map detailed structure, operations and regulatory environment of live animal markets in China</td>
<td>Field survey of wet markets and wholesale markets in China</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PILOT</th>
<th>NEXT STEPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey of 2 markets in Guangzhou, and 2 markets in Foshan</td>
<td>Initial results indicate significant volume of poultry staying overnight, and significant volume of dead poultry in the market. The survey will expand to multiple cities starting by Guangdong province.</td>
</tr>
</tbody>
</table>
On the Ground – Surveying Live animal Markets
Antimicrobial Resistance (AMR) in China

China is one of the largest hotspots of animal-associated burden of AMR

Multiple first emergences of AMR to last-resort antimicrobials

Wholesale and live poultry markets are a major source

WHO - top 10 threats to global health (700K deaths annually)!
Alignment with Government Policy Priorities

• Food Safety Policy (Chinese Central Government, released May 2019):
  • By 2020, Establish a risk analysis and supply chain management based food safety regulatory system
  • Urge the transition toward smart digital management of WSM
Concluding Comments

- Analytics & AI based decision support tools to guide risk-based sampling at the SC source:
  - High-risk Companies
  - High risk SC locations
  - High risk products

- Focus on Wholesale Markets!
  Leveraging technology (testing & digital platforms) to create rapid monitoring and transparency in the supply chain

- Managing food safety AND zoonotic disease AND AMR risks!
Market Design in India

Pls: Levi, Zheng

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>X. Lily Liu</td>
<td>PhD student</td>
</tr>
<tr>
<td>Wen Hong Pay</td>
<td>SM student (graduated)</td>
</tr>
<tr>
<td>Morgan McCombs</td>
<td>SM student (graduated)</td>
</tr>
<tr>
<td>Somya Singhvi</td>
<td>PhD student (graduated)</td>
</tr>
<tr>
<td>MBAn students</td>
<td></td>
</tr>
<tr>
<td>UROPs</td>
<td></td>
</tr>
</tbody>
</table>
Agricultural Supply Chains in Developing Countries

Large number of small household farms → An opaque network of middlemen → Manufacturers/Retailers → Consumers

India
- 70% < 2.5 acres land holding
- 52% total workforce (vs. 0.7% in the U.S., 28% in China)

Sources: 2011 India census, The World Poverty Clock, FAO of the UN
Key Challenges

- Low Productivity (~50% vs. developed)
- High Poverty (78% world’s poor)
- Food Safety & Security (global & local)
- Environmental Sustainability

Interventions
Digital/mobile platforms to improve market & info access for better decisions
Collaboration Rooted on the Ground

Objective

Improve efficiency and social welfare in food and agri-systems (current focus in India)

- Impact assessment & auction design of UMP
- Market intelligence for produce farmers
- Tech adoption in rural communities
- Optimizing government procurement programs
- In-depth farmer interviews
- Active conversation with CII & central government

Supported by:
- MIT Sloan School
- Operations Research Center
- TATA Center Technology + Design
- MIT CBI Center for Biomedical Innovation
- Biology
- ChemE
Field Visits in Rural Regions
Impact in Practice

**Impact Assessment**

First impact assessment of the State of Karnataka digital agri-platform

Policy recommendations on platform and supply chain design

**Publications**


Improving Farmers’ Income on Online Agri-platforms: Evidence from the Field.

**Implementation**

Field implementation in Karnataka

- USD $19M commodities traded since Feb 2019
- **3.6% price gain** (up to 94% profit gain) for 20K+ lentils farmers
- Government plans to expand implementation across the state
Launch of UMP in Karnataka

• 162 regulated mandis are now integrated on the UMP
  • By Nov. 2019, 62.8M tons (US$21.7B) of commodities traded

• Objective:
  • What is the impact of UMP on farmers’ revenue?
  • How can we further enhance the impact of UMP?
    • Improve the auction design on UMP to benefit farmers
Average Impact of UMP on Modal Prices

- **80%-300% profit gain for 2M+ farmers**

- **Limited in-market competition is a barrier for lentils**

- **Optimize auction design**

### Average Impact of UMP on Modal Prices

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Impact</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddy</td>
<td>7%</td>
<td>0.014***</td>
</tr>
<tr>
<td>Groundnut</td>
<td>4%</td>
<td>0.020**</td>
</tr>
<tr>
<td>Maize</td>
<td>3%</td>
<td>0.008**</td>
</tr>
<tr>
<td>Green</td>
<td>1%</td>
<td>0.022</td>
</tr>
<tr>
<td>Cotton</td>
<td>1%</td>
<td>0.013</td>
</tr>
<tr>
<td>Tur (Arhar)</td>
<td>0%</td>
<td>0.88</td>
</tr>
</tbody>
</table>

***: $p < 0.01$; **: $p < 0.05$. Percentages are estimates of price increase, standard errors in parentheses.

Green (red) bars represent statistically significant (nonsignificant) impact.
Auction Design Process

Operational Feasibility
- Participation constraints of market participants
- Resource constraints

Select potential auction mechanism

Traders’ Bidding Behavior
- Semi-structured interviews with traders
- A behavioral auction model

Determine when new auction will benefit

Field Implementation
- Empirical impact assessment
- Model validation based on auction and interview data
Two-Stage Auction for UMP

• Current design is a first-price, sealed-bid auction

• Increase competition by introducing a qualification round
  • Stage 1: Everyone submits sealed bids
  • Top k bidders qualify and informed of top bid
  • Stage 2: Qualified bidders bid again (cannot decrease)
  • Highest bidder is declared the winner

• Launched the field trial for Tur in February 2019
Results: Average Weekly Price for Tur

**Impacts**

- **3.6% increase** in average price
- **55%-94% profit gain** (~11% increase in monthly income) for 20K+ farmers
- Impact **persists** in 2020 season
Transparency, analytics & sustainability in smallholder supply chains

Pls: de Zegher, Zheng

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olumurejiwa Fatunde</td>
<td>PhD student</td>
</tr>
<tr>
<td>Aufar Kari</td>
<td>SM student (graduated)</td>
</tr>
<tr>
<td>Irene Lo</td>
<td>Research Collaborator (Stanford)</td>
</tr>
<tr>
<td>Yuan Shi</td>
<td>PhD student</td>
</tr>
<tr>
<td>Ravi Sojitra</td>
<td>PhD student (Stanford)</td>
</tr>
</tbody>
</table>
Smallholder Supply Chains & Environmental Sustainability

• Typically untraceable, very poor, coexist with most threatened landscapes

• Nearly 20% of humanity’s yearly carbon footprint can be sequestered by farmers through sustainable agricultural practices

• **Research efforts**
  • Platform technologies to optimize & digitize the “first mile”
  • Create holistic, scalable approaches to traceability – enable implementation of incentives for sustainability, quality, ...
  • Design **carbon reward scheme** to motivate large-scale adoption of sustainable practices while maintaining agricultural productivity
On the Ground
CONCLUSION

01 Digital platforms & tools hold tremendous potential to improve efficiency, welfare, & sustainability in Ag-food systems

02 Technologies are a means to an end; need systems approach that accounts for operational and supply chain processes

03 Field based, behavior centric, and data driven approach is key to enable impact in practice
# Future Directions

## Supply Chain & Market design
- **Optimization**

## Management of Human Health Risks in Food Supply Chains
- **Predictive Risk Models & Tools**
- **Testing Technologies**
  - Expanding efforts in food safety in **China**

## Access to Healthy Food
- **Access to Fresh Produce**
- **Food Waste**
  - Using Advanced Data-Science to Increase Healthy Food Consumption in **US** Underserved Populations via Enhanced Personalization and Resilience

## Farmer and Consumer Welfare
- **Agriculture Practices**
  - Water, agriculture, and food efforts in **Thailand**, addressing water scarcity, water allocation, flooding, and contamination as they relate to agriculture
Questions?
Contact

Retsef Levi retsef@mit.edu
Y. Karen Zheng yanchong@mit.edu
Stacy Springs ssprings@mit.edu

FSAS: mit-fsas@mit.edu