Food Supply Chains with Vertical Integration

SOM 822 Research Paper

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Introduction

- Food Supply chains are becoming increasingly complex networks.
- Differentiation and concerns with food safety are promoting vertical integration of agents in different tiers of food chains.
- Barkena and Drabenstott (1995) claim that contracts are quickly taking the place of spot markets on the production and distribution of agricultural commodities. They also claim that as the preparation of foods moves from households to industries the need for coordination among different agents in the food chain will further increase.

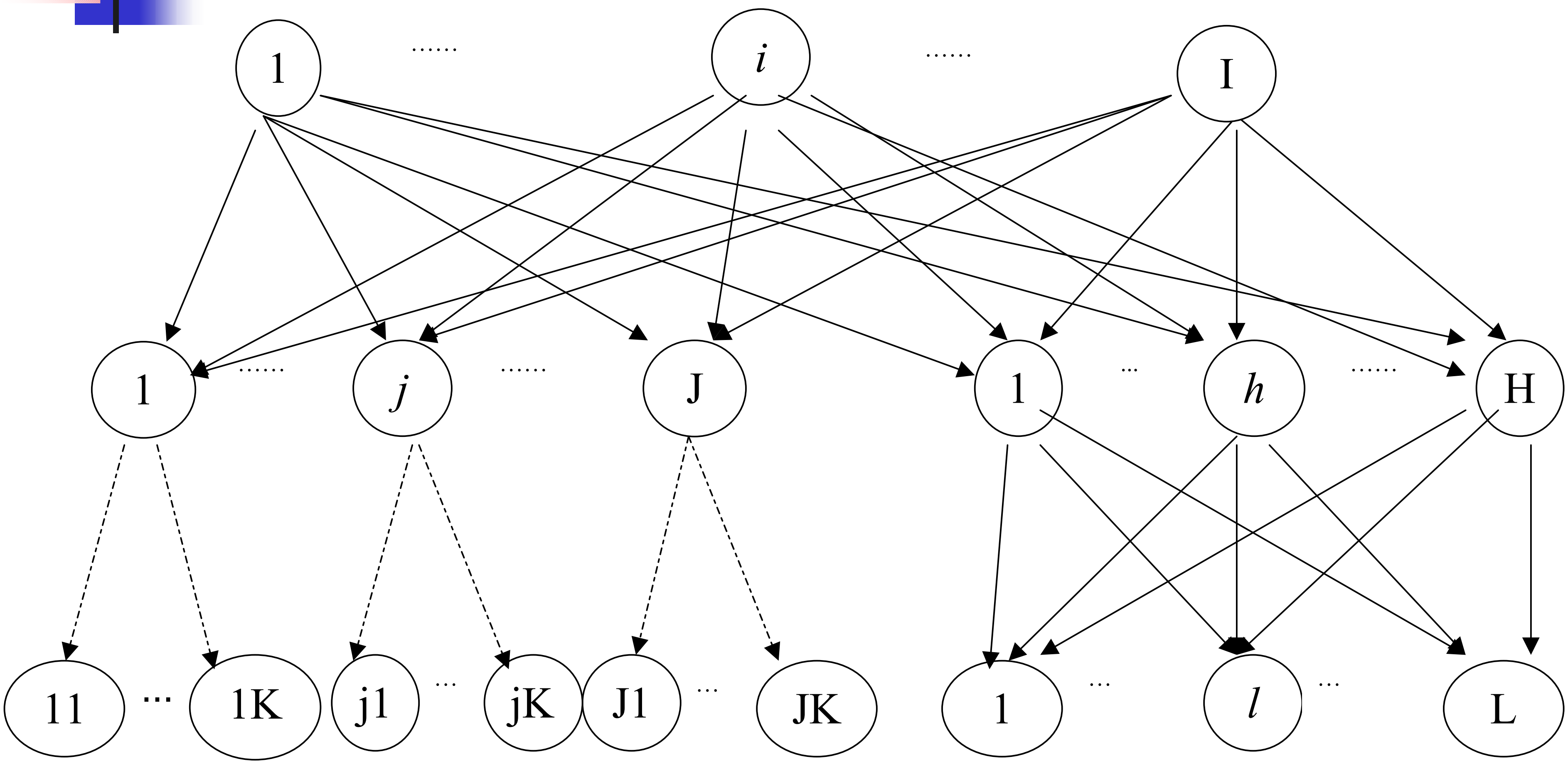
Objectives

- Model vertical integrations of wholesalers and retailers on food supply chain using variational inequalities.
- Verify the conditions in which there are differences in flows of commodities between vertically integrated and classic wholesaler supply chains.
- Understand how such structures influence flows on food supply chain networks.

Food Supply Chains

- Food supply chains are multi-tiered networks.
- Some food chains involve over 5 tiers, from input suppliers to final points of consumption.
- However food products that are consumed in a raw state, like fruits, have more simple supply chains.
- In our model we assume the existence of three tiers:
  - Processors
  - Wholesalers
  - Retailers

Structure of a Food Supply Chain with Vertical Integration



Processors Behavior and Optimization Conditions

- Max $$\pi^i = \sum_{j=1}^{J} t_{ij}.\rho_{1j} + \sum_{h=1}^{H} t_{ih}.\rho_{1h} - f^i(q_i) - c_j^i - c_h^i \quad (5)$$
- Subject to: $t_{ij} \geq 0$ and $t_{ih} \geq 0$ for all *i, j* and *h* (6)
- The associated variational inequality is given by:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}[\frac{\partial f^i}{\partial t_{ij}} + \frac{\partial c_j^i}{\partial t_{ij}} - \rho_{1j}].[t_{\mathrm{ij}} - t_{ij}^*] +$$

$$\sum_{i=1}^{I}\sum_{h=1}^{H}[\frac{\partial f^i}{\partial t_{ihk}} + \frac{\partial c_h^i}{\partial t_{ihk}} - \rho_{ih}].[t_{\mathrm{ih}} - t_{ih}^*] \geq 0, \ \forall (Q^1, Q^2) \in \Re_+^{IJH} \quad (7)$$

Vertically Integrated Wholesalers Behavior and Optimization Conditions

- Max $\pi^{j} = \sum_{k=1}^{K} t_{jk}.\rho_{3k} - \sum_{i=1}^{I} t_{ij}.\rho_{1j} - \sum_{i=1}^{I} c_{j}^{i}(t_{ij}) - f^{j}(d_{j}) - c_{k}^{j}$ (11)

Subject to : $\sum_{k=1}^{K} t_{jk} \leq \sum_{i=1}^{I} t_{ij}$ (12)

and the non-negative constraints that $t_{jk} \geq 0$ for all j and k and $t_{ij} \geq 0$ for all i and j.

Vertically Integrated Wholesalers Behavior and Optimization Conditions

- The corresponding VI is given by:

$$\sum_{j=1}^{J}\sum_{k=1}^{K}[\frac{\partial f^{j}}{\partial t_{jk}}+\frac{\partial c_{k}^{j}}{\partial t_{jk}}+\lambda_{j}-\rho_{3k}].[t_{\mathrm{jk}}-t_{jk}^{*}]+$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}[\rho_{1j}-\lambda_{j}].[t_{\mathrm{ij}}-t_{ij}^{*}]+ \qquad (13)$$

$$[\sum_{j=1}^{J}\sum_{k=1}^{K}t_{jk}-\sum_{i=1}^{I}\sum_{j=1}^{J}t_{ij}].[\lambda_{j}-\lambda_{j}^{*}]\geq 0,\ \forall(Q^{1},Q^{3},\lambda)\in\Re_{+}^{J(K+I+1)}$$

Classic Wholesalers Behavior and Optimization Conditions

- Max $$\pi^h = \sum_{l=1}^{L} t_{hl} . \rho_{2l} - \sum_{i=1}^{I} t_{ih} \rho_{1h} - f^h(d_h) \quad (16)$$

  Subject: $$\sum_{h=1}^{H} \sum_{l=1}^{L} t_{hl} \le \sum_{i=1}^{I} \sum_{h=1}^{H} t_{ih} \quad (17)$$
- and non-negative constraint $t_{ih} \geq 0$ for all *i* and *h* and $t_{hl} \geq 0$ and for all *h* and *l*

Classic Wholesalers Behavior and Optimization Conditions

- The corresponding VI is given by:

$$\sum_{h=1}^{H}\sum_{l=1}^{L}[\frac{\partial f^h}{\partial t_{hl}}+\gamma_h-\rho_{2l}].[t_{hl}-t_{hl}^*]+$$

$$\sum_{i=1}^{I}\sum_{h=1}^{H}[\rho_{1h}-\gamma_h].[t_{\mathrm{ih}}-t_{ih}^*]+ \qquad (18)$$

$$[\sum_{h=1}^{H}\sum_{l=1}^{L}t_{hl}-\sum_{i=1}^{I}\sum_{h=1}^{H}t_{ih}].[\gamma_h-\gamma_h^*]\geq 0,\ \forall(Q^2,Q^4,\gamma)\in\Re_+^{HL+IH+H}$$

Independent Retailers Behavior and Optimization Conditions

- Max $\pi^l = \sum_{n=1}^{N} t_{\ln} \cdot \rho_{3l} - \sum_{h=1}^{H} t_{hl} \cdot \rho_{2l} - f^l(d_l) - c_l(\sum_{h=1}^{H} t_{hl})$ (22)

  Subject: $\sum_{l=1}^{L} \sum_{n=1}^{N} t_{\ln} \leq \sum_{h=1}^{H} \sum_{l=1}^{L} t_{hl}$ (23)

- and the non-negative constraints that $t_{ln} \geq 0$, for all *l* and *n* and $t_{hl} \geq 0$, for all *h* and *l*.

Independent Retailers Behavior and Optimization Conditions

- The corresponding VI is given by:

$$\sum_{l=1}^{L}\sum_{n=1}^{N}[\frac{\partial f^l}{\partial t_{\ln}}+\eta_l - \rho_{31}].[t_{\ln}-t_{\ln}^*]+$$

$$\sum_{l=1}^{L}\sum_{h=1}^{H}[\rho_{2l}+\frac{\partial c_l}{\partial t_{hl}}-\eta_l].[t_{\mathrm{hl}}-t_{hl}^*]+ \qquad (24)$$

$$[\sum_{l=1}^{L}\sum_{n=1}^{N}t_{\ln}-\sum_{h=1}^{H}\sum_{l=1}^{L}t_{hl}].[\eta_l-\eta_l^*]\geq 0,\ \forall(Q^4,Q^5,\eta)\in\Re_+^{LN+LH+L}$$

Market Equilibrium Conditions

- The following market equilibrium condition determines the price charged by the vertical integrated structure

$$d_j(\rho_{3k}^*)\begin{cases} = \sum_{i=1}^{I} t_{ij} & \text{if } \rho_{3k}^* > 0 \\ \leq \sum_{i=1}^{I} t_{ij} & \text{if } \rho_{3k}^* = 0 \end{cases} \qquad (27)$$

- This is equivalent to the VI below:

$$\sum_{j=1}^{J}\left[\sum_{i=1}^{I} t_{ij} - d_j(\rho_{3k}^*)\right].\left[\rho_{3k} - \rho_{3k}^*\right] \geq 0 \; \forall \rho_{3k} \in \Re_+^{IJ} \qquad (28)$$

Market Equilibrium Conditions

- The following market equilibrium condition determines the price charged by independent retailers:

$$d_l(\rho_{3l}^*)\begin{cases} = \sum_{h=1}^{H} t_{hl} \text{ if } \rho_{3l}^* > 0 \\ \leq \sum_{h=1}^{H} t_{hl} \text{ if } \rho_{3l}^* = 0 \end{cases} \quad (31)$$

- This is equivalent to the VI below:

$$\sum_{l=1}^{L}[\sum_{h=1}^{H} t_{hl} - d_l(\rho_{3l}^*)].[\rho_{3l} - \rho_{3l}^*] \geq 0 \;\; \forall \rho_{3l} \in \Re_{+}^{HL} \quad (32)$$

Food Supply Chain Equilibrium

$$\sum_{i=1}^{I}\sum_{j=1}^{J}[\frac{\partial f^i}{\partial t_{ij}}+\frac{\partial c_j^i}{\partial t_{ij}}-\lambda_j].[t_{\mathrm{ij}}-t_{ij}^*]+\sum_{i=1}^{I}\sum_{h=1}^{H}[\frac{\partial f^i}{\partial t_{ih}}+\frac{\partial c_h^i}{\partial t_{ih}}-\gamma_h].[t_{\mathrm{ih}}-t_{ih}^*]+$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K}[\frac{\partial f^j}{\partial t_{jk}}+\frac{\partial c_k^j}{\partial t_{jk}}+\lambda_j-\rho_{3k}].[t_{\mathrm{jk}}-t_{jk}^*]+[\sum_{j=1}^{J}\sum_{k=1}^{K}t_{jk}-\sum_{i=1}^{I}\sum_{j=1}^{J}t_{ij}].[\lambda_j-\lambda_j^*]+$$

$$\sum_{h=1}^{H}\sum_{l=1}^{L}[\frac{\partial f^h}{\partial t_{hl}}+\gamma_h+\frac{\partial c_l}{\partial t_{hl}}-\eta_l].[t_{hl}-t_{hl}^*]+[\sum_{h=1}^{H}\sum_{l=1}^{L}t_{hl}-\sum_{i=1}^{I}\sum_{h=1}^{H}t_{ih}].[\gamma_h-\gamma_h^*]+$$

$$\sum_{l=1}^{L}\sum_{n=1}^{N}[\frac{\partial f^l}{\partial t_{\ln}}+\eta_l - \rho_{31}].[t_{\ln}-t_{\ln}^*]+[\sum_{l=1}^{L}\sum_{n=1}^{N}t_{\ln}-\sum_{h=1}^{H}\sum_{l=1}^{L}t_{hl}].[\eta_l-\eta_l^*]$$

$$+\sum_{j=1}^{J}[\sum_{i=1}^{I}t_{ij}-d_j(\rho_{3k}^*)].[\rho_{3k}-\rho_{3k}^*]+\sum_{l=1}^{L}[\sum_{h=1}^{H}t_{hl}-d_l(\rho_{3l}^*)].[\rho_{3l}-\rho_{3l}^*]\geq 0$$

$$\forall(Q^1,Q^2,Q^3,Q^4,Q^5,\rho_3,\lambda,\gamma,\eta)\in \mathrm{K}$$

Food Supply Chain Equilibrium

- In the previous slide Variational Inequality:
  - The first row reflects the optimization conditions for processors
  - The second row the optimization of vertically integrated wholesalers
  - The third has the optimal conditions of retailers
  - The last defines the prices charged to consumers

Conclusions and Extensions

- Using equation (37) we can analyze the conditions under which the flows through the vertically integrated structure equate those on the non-integrated one.
- This can be done by comparing the shadow prices of processor, demand prices and transaction costs between processors, wholesalers and retailers.
- The main result is that we are able to compare market prices with internal transactions costs, hence being able to test the hypothesis of institutional design based on transaction costs proposed by Williamson (1989).

Conclusions and Extensions

- An obvious extension is to find the adequate algorithm to solve this model.
- Another is to determine to what extent the vertically integrated structure influences the dynamics of flows in the model.
- Finally, we could use it as base for important questions relating to what happens if different quality levels are admitted and how to introduce both food safety, and commercial risk to the model

References

- Barkema, A and Drabenstott, M. 1995. **The Many Paths of Vertical Coordination: Structural Implications for the US Food System.** *Agribusiness.* **11(5)**, 483-492.
- Cotteril, R. 2003. **Fluid Milk Market Channel Pricing: Monopolistic Pricing by Retailers Hurts Processors, Farmers, Consumers, and Federal Market Order Pricing** Food Marketing Policy Center. Issue Paper No.**40**. University of Connecticut.
- Fearne, A. Hornibrook, S. and Dedman, S. 2001. **The Management of Perceived Risk in the Food Supply Chain: A Comparative Study of Retailer-led Beef Quality Assurance Schemes in Italy and Germany.** *International Food and Agribusiness Management Review,* **4**, 19-36.
- Golan, E, B. Krissoff, F. Kuchler, K. Nelson, G. Price, and L. Calvin. 2004. **Traceability in the U.S. Food Supply: Economic Theory and Industry Studies**. Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report No. **830**. March 2004
- Hornibrook, S. and Fearne, A. 2001. **Managing Perceived Risk: A Multi-tier Case Study of a UK Retail Beef Supply Chain**. *Journal of Chain and Network Science.* **1 (2)**, 87-100.
- **http://www.jetro.com/. consulted in 30th April 2004**
- Kola, J. and T. Latvala. 2002**. Demand for Credence Characteristics in Beef.** *Selected paper presented at the AAEA-WAEA Annual Meeting.*
- **http://www.makro.com. consulted in 30th April 2004**
- Nagurney, A. 1999. **Network Economics: A Variational Inequality Approach**, second and revised edition. Kluwer Academic Publishers, Dordrecht. The Nederlands
- Nagurney, A., Cruz, J. and Dong, J. 2003. **Global Supply Chain Networks and Risk Management.**

References

- Rogers, R. T. 2001. **Structural Change in the U.S. Food Manufacturing, 1958-1997**. *Agribusiness*. **17(1)**, 3-32.
- Sexton, R. J. and Lavoie, N. 2001. **Food Processing and Distribution: An Industrial Organization Approach.** In: Gardner, B. and G.C. Rausser, eds. *Handbook of Agricultural Economics,* North-Holland, Amsterdam. The Netherlands*.*
- Zhang, D., Dong, J. and Nagurney, A. 2003. **A Supply Chain Network Economy: Modeling and Qualitative Analysis**. Financial and Economic Networks, Anna Nagurney Editor. Edward Elgar Publishers. Chelthenham, England.
- Williamson, O. E. 1989. **Transaction Cost Economics**. In: R. Schmalensee and R.D. Willig eds. *Handbook of Industrial Organization, Volume I*, Elsevier Science Publishers B.V.