Microeconomic Characterization of Supply Network Integration in a Multi-product Manufacturing Environment

Kobe University ○Jayeola Femi Opadiji, Toshiya Kaihara, Kentaro Sashio

This paper presents a theoretical framework for supply network integration in a multi-product manufacturing economy making use of the walrasian market system. We propose a method of dissolving a supply network into a competitive market and then applying the theory of Computable General Equilibrium (CGE) to find an optimal allocation of resources. Agents in the supply network are represented using the Cobb-Douglas (CD) function with a constant return-to-scale. A simulation program based on Market-Oriented Programming (MOP) was developed to mimic the trading environment in order to search for a pareto-allocation of resources in the network. The experimental results presented reveal that this framework can be adapted for use in drafting a holistic picture of a supply network in a multi-product manufacturing environment.

Keywords: Supply Network, Market-Oriented Programming, Computable General Equilibrium, Walrasian Market, Pareto-allocation

1 Introduction

Managing the supply network of a manufacturing organization is a Herculean task because decision making usually involves more than one unit in the entire production system and cuts across organization boundaries (Stadtler 2005). This problem is even more severe in cases where a manufacturing system is meant to produce goods which share common capacities and materials, i.e. a multi-product manufacturing system. The decision making process can be divided into three levels based on the planning horizon under consideration – strategic, tactical and operational levels.

In this paper, we present a theoretical framework for characterizing the integration of a supply network based on the principles of Computable General Equilibrium (CGE) as used in a walrasian market system (Kaihara 2004). We propose a decision support model which will give a supply network planner a holistic view of the supply network at the strategic level. The walrasian market model used is a competitive market structure that conducts a pareto-optimal solution among a legion of trading agents provided the axioms of gross substitution of resources in the market and monotonicity of demand and supply are strictly adhered to (Wellman 1993).

The next section delineates the structure of the supply network being considered and mathematical formulations used to describe the trading agents in the competitive market. The following section explains procedures used in experimentation while the next section is devoted to discussing the experimental results. Lastly, we conclude the paper by suggesting ways this framework can be adapted for strategic decision making in a multi-product manufacturing environment.

2 Research Methodology

A typical supply network in a manufacturing environment is made up of layers as shown in figure 1 below:

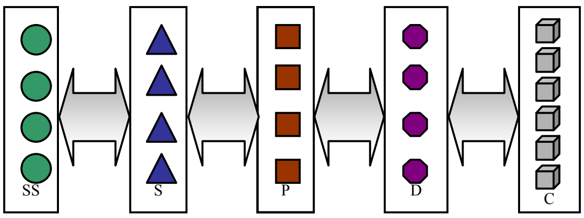

Figure 1: Manufacturing System Supply Network
*SS-Supplier's supplier, S-Supplier, P-Producer, D-Distributor, C-Consumer

Each of these layers is made up of trading agents that demand market resources for the manufacture of products with the consumers manufacturing a special product called utility and the D layer providing services. However, the main layer of interest is the P-layer which produces the final goods. The goal is to dissolve this layer into a competitive market made up of consumer and supplier agents. These agents are reactive agents that respond to changes in market prices to bid for specific quantities of resources offered in the market. The market mechanism computes an equilibrium price for the current market demand and supply and the agents continue to bid until no agent is willing to make a new bid at which point, a market clearing price is said to be reached and a pareto-optimal allocation is arrived at.

2.1 Consumer Agent

A consumer agent has a unique set of endowments $e_1, e_2 \ldots e_n \in \mathbf{E}$ of market resources $x_1, x_2, \ldots, x_n \in \mathbf{X}$ and preference indices $\alpha_1, \alpha_2, \ldots, \alpha_n \in \mathbf{A}$. This agent bids to maximize utility subject to its budget constraint. Using, a Cobb-Douglas function as the utility function with a constant returns-to-scale R_c, the constrained optimization problem is given as:

$$\max U = R_c \prod_{i=1}^{n} x_i^{\alpha_i} \quad for \sum_{i=1}^{n} \alpha_i = 1. \tag{1}$$

Subject to

$$Budget_c = \sum_{i=i}^{n} p_i e_i + \pi_c \text{ Where } p_i \in P \tag{2}$$

is price for resource i and π_c is profit share for consumer c.
An optimized bid for resource i by a consumer c is given as:

$$bid_i^c = \alpha_i^c .Budget(c) / p_i \tag{3}$$

Each consumer rents out all their endowments.

2.2 Supplier Agent

A supplier agent produces a unique resource $x_i \in \mathbf{X}$ by renting factors of production. Using its technology, it seeks to maximize profit. Again, using a Cobb-Douglas function with constant returns-to-scale R_s and technology indices for market resources represented by $\beta_1, \beta_2 \ldots \beta_n \in \mathbf{B}$, we define the constraint optimization problem for the supplier as:

$$\max profit_i^s = p_i x_i^s - \sum_{i=i}^{n} p_i x_i \tag{4}$$

Subject to

$$x_s = R_s \prod_{i=1}^{n} x_i^{\beta_i^s} \tag{5}$$

Supplier s bid for manufacturing resource x_i is:

$$x_s(p_j) = \left(\frac{p_i}{R_s \beta_j^s p_j} \right)^{\frac{\beta_j^s}{\beta_j^s - 1}} \tag{6}$$

3 Experimental Procedure

In the classical walrasian market arrangement, the supplier does not have endowments but rents endowments provided by consumers in the market. However, supplier members of the supply network are expected to have there own production budgets, which means they have endowments. In this work therefore, we model all suppliers (including producers and distributors) in the supply network as having both consumer as well as supplier sides as described using figure 2 below:

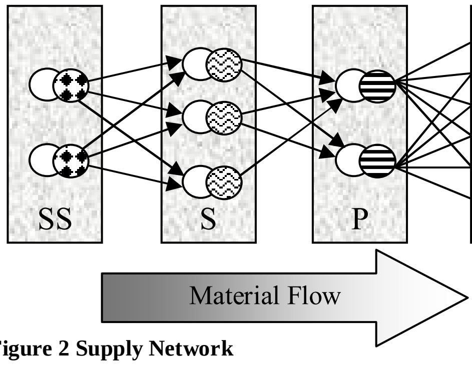

Figure 2 Supply Network

As depicted in figure 2, we used a four-layer network for conducting our experiment with |SS| =2, |S| =3, |P| =2 and |C| =5. This means there are 7 suppliers each having a consumer section and there are 5 pure consumers bringing the total number of consumers to 12 for the walrasian market. Figure 3 shows the structure of the walrasian market.

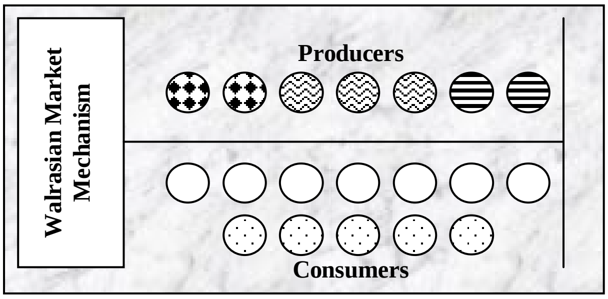

Figure 3: Remolding figure 3.1 into a Walrasian market

Tables 1-2 show examples of input data used in the experiment.

	Manufacturer(m1)			
	Investment		Technology	
	Preference	Endowment	Scale	Index
Good 1(ss1)	0	0	0	0
Good 2(ss2)	0	0	0	0
Good 3(s1)	0	0	35	0.15
Good 4(s2)	0	0	65	0.34
Good 5(s3)	0	0	40	0.26
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.75	250	63	0.2
Labour	0.25	30	51	0.05

Table 1 Input data for a producer in the supplier network

	Consumer 8	
	Preference	Endowment
Good1(ss1)	0	0
Good2(ss2)	0	0
Good3(s1)	0	0
Good4(s2)	0	0
Good5(s3)	0	0
Good6(m1)	0.27	0
Good7(m2)	0.73	0
Capital	0	110
Labour	0	300

Table 2 Input data for a pure consumer in the supplier network

The concept of Market-Oriented Programming (MOP) (Wellman 1993) was adopted in simulating the model.

4 Results and Discussion

Figures 4 – 5 show the price fluctuation and demand/supply fluctuation during 30 bidding iterations.

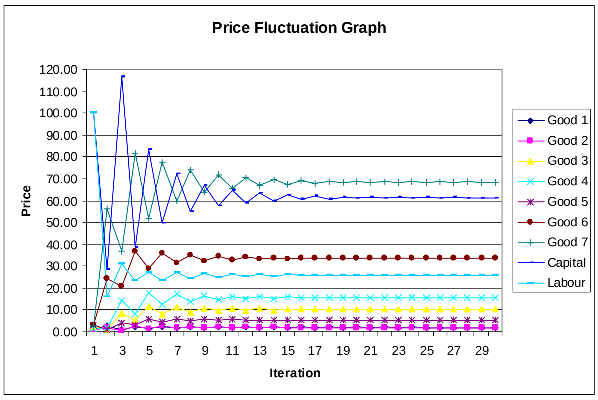

Figure 4: Price Fluctuation Graph

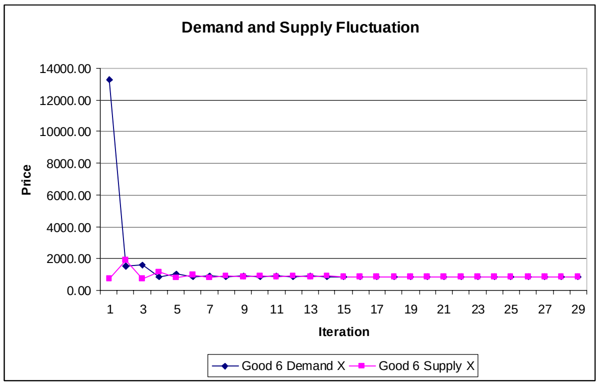

Figure 5: Demand/Supply Fluctuation Graph

As guaranteed by the walrasian market model under the axioms mentioned before, the simulation results showed convergence towards pareto-optimality after initial fluctuation in prices of the nine resources.

5 Conclusion

The framework presented above provides a multi-faceted outlook to strategic network planning because it provides information about consumer demand distribution and also capital and labour availability which are necessary in deciding the profitability of a network plan.

It is worthy of note however, that, in order to provide a useful characteristic of a network plan, it is necessary to have a good approximate of the input data described in tables 1– 2. Each element in the pure consumer layer can be viewed as a society and by using appropriate statistical tools; the consumer parameters can be aggregated to form an element in this layer. Also, the model affords us the opportunity of seeing at a coarse level the characteristic of our strategic production plan with respect to manufacturing capacities and material resources.

References

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