Agent-Based Economic Extension to Mesoscale Freight Model

DRAFT Model Design

Table of Contents

Agent-Based Economic Extension to Mesoscale Freight Model

Model Design

DRAFT

1 Introduction

The Chicago Metropolitan Agency for Planning (CMAP) has in recent years developed a two-tiered modeling system to analyze regional freight traffic. The first tier is referred to as the "mesoscale model" or "national supply chain model" and represents freight flows between the CMAP region and the rest of the U.S. Commodity flows are derived from those found in the Freight Analysis Framework, Version 3 (FAF^3) data products, developed by the Federal Highway Administration (FHWA). The second tier model operates within the region, modeling local freight-hauling truck movements using a tour-based microsimulation and has been dubbed the "microscale model" or the "tour-based truck model." The purpose of this project is to develop a third major component to the modeling system, an extension of the mesoscale model that would enable CMAP to forecast future freight flows independent of FAF^3, based on macroeconomic indicators as well as a host of other stimuli. This document presents the conceptual design of this mesoscale extension, which features an agent-based computational economics modeling component.

2 Purpose and Need

The purpose of an agent-based economic extension to the mesoscale freight model is to provide scenario analysis capabilities that add behaviorally-based dynamics to the prediction of future freight-flows. In its current form, the mesoscale freight model simply apportions the FAF^3 prediction of future freight flows, which represent a continuation of current trends. The FAF^3 forecasts portray just one possible future. For policy and planning sensitivity analysis, CMAP would like a tool to systematically vary forecasts to reflect potential changes in macroeconomic conditions (e.g., foreign trade levels, price of crude oil); large-scale infrastructure changes (e.g., port expansions, new intermodal terminals); technological shifts in logistics and supply chain practices (e.g., near-sourcing, out-sourcing, productivity enhancements); and other assumptions and scenario inputs related to the economic competitiveness of the Chicago region and its infrastructure investments.

Endogenous Commodity Flow Prediction – Fundamentally, the extended model will need to create commodity flow levels endogenously, rather than relying upon exogenous inputs from FAF^3. Accordingly, it will be necessary to expand the consideration of input commodities beyond the "top-five" used in the current model to account for as much of the total flows as possible. In the current mesoscale model, buyer-supplier pairs are formed based on industries that produce and consume commodities of various types. For a firm that produces a particular commodity, the current model identifies the top-five dollar-value input commodities (from U.S. BEA input-output tables) and matches the producing firm with a supplier firm, based on firm size and distance. FAF^3 flows of commodities between pairs of FAF zones are then apportioned to corresponding pairs of matched firms that ship those same commodities between the same FAF zones. As described below, however, the top-five input commodities may not represent even a majority of flows for some commodities. Since the proposed model extension will forecast freight flows endogenously, rather than pinning forecasts on the FAF^3 predictions, it will be necessary to include a much larger number of producer-supplier pairs to achieve nearly full commodity flow coverage.

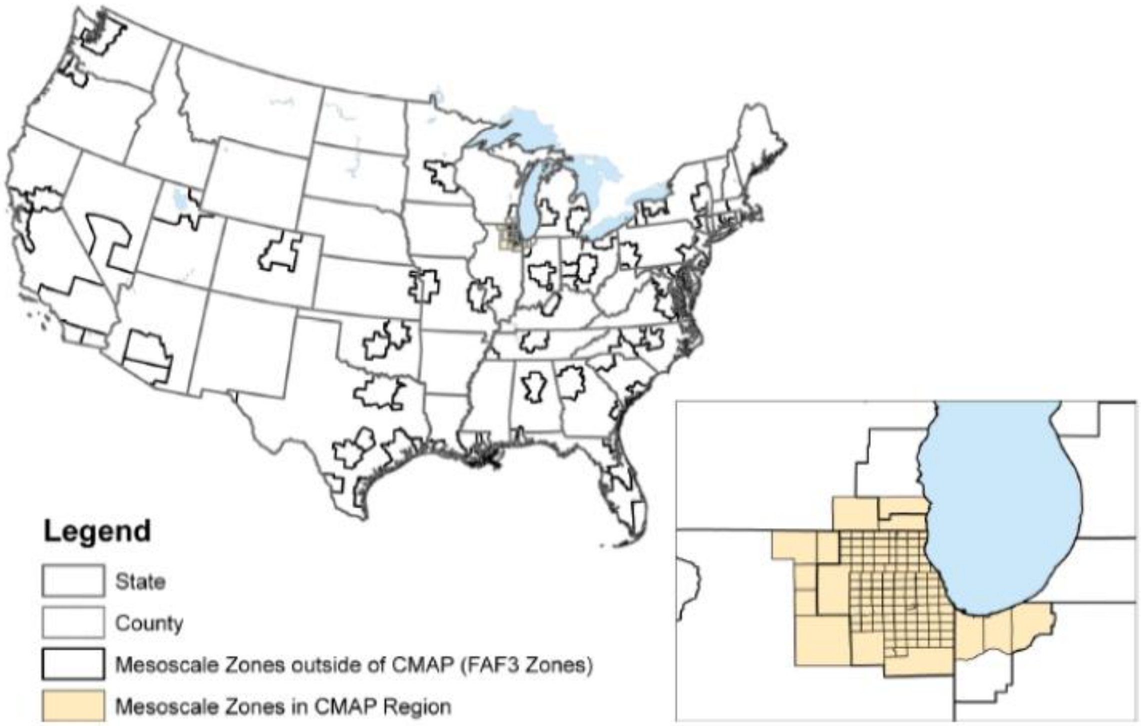
Foreign Trade – In addition, the current mesoscale model does not represent foreign trade with U.S., as it was originally designed to pivot off of the FAF^3 flows, focusing only the portion of travel within the continental U.S. To represent foreign trade interests from various countries, it will be necessary to create simulation agents that represent these countries and the commodities that they trade with the U.S.

Response to Price Signals – Importantly, the desired policy sensitivity requires demand patterns to be responsive to price signals. In the current mesoscale model, transportation travel impedances enter the model in a mode selection phase, which is run downstream of the supplier selection module. To achieve the level of policy sensitivity expressed above, it will be necessary to create a new supplier selection module that is sensitive to supplier costs and related level-of-service attributes, which may also necessitate re-specification of model components that determine shipment size and mode.

3 Summary of Prototype Mesoscale Model

The current CMAP mesoscale model provides several key features that lend themselves to agent-based modeling, namely a simulation architecture consisting of synthesized firms that represent shippers and receivers of freight flows. As discussed above, the current model utilizes commodity flows from the FAF^3 data product to set both the level and spatial distribution of modeled flows. Commodities are classified by the 43 2-digit Standard Classification of Transported Goods (SCTG) classes used by the 2007 U.S. Commodity Flow Survey (CFS).

Spatially, this includes flows between the CMAP zone system and the rest of the world, which is represented in the model by FAF zones. FAF Zones represent primary trading areas, such as metropolitan regions and states within the U.S.; two foreign countries, Mexico and Canada; and six other world regions: Africa, Latin America and the Caribbean, North America, Europe, Asia, and Oceania. Within the CMAP modeling region, the freight modeling zone system is comprised of townships nearer to Chicago, and by counties in the distant suburbs, Southeast Wisconsin and Northwest Indiana, as shown below in Figure 1.



Source: Federal Highway Administration for FAF zones and Cambridge Systematics for Mesoscale zones

Figure 1. Mesoscale zone system for the CMAP prototype freight model.

The existing mesoscale model has seven major component steps. As shown below in Figure 2, blue boxes represent sources of data inputs, green boxes represent processes, and the red boxes represent the outputs of those processes. The following seven paragraphs describe the way these processes currently function.

1. ***Firm Synthesis*** - The initial element of the framework synthesizes all firms in the study area, which is defined as the U.S., for purposes of capturing long-haul freight movements. The geographic detail within the region of interest is based on jurisdictional boundaries such as cities (although the allocation down from counties to individual cities takes place in Step 4, business location), and the geographic detail outside of the region of interest is defined by FAF zones. This model synthesizes firms by industry category and by size category to capture the primary drivers of commercial vehicle travel. Firm synthesis can be controlled by regional, county and state control totals obtained from State, MPO, or national sources.
2. ***Supply Chain*** **-** The next element of the framework predicts the demand in tonnage for shipments of each commodity type between each firm in the synthetic population. The demand represents the goods produced by each firm and the goods consumed by each firm in the U.S. The model is applied in two steps. In the first step, buyers who have a demand for goods are paired with suppliers who sell those goods using a probabilistic

model. The connections between industry types for each commodity are based on input-output tables.

Figure 1: National Supply Chain Section of the Freight Forecasting Frameworks

3. ***Goods Demand*** - Once the buyer-supplier relationships are established, the amount of commodity shipped on an annual basis between each pair of firms is apportioned based on the number of employees at the buyer and their industry so that observed commodity flows are matched nationwide.
4. ***Business Location***.- The subsequent steps of the model framework use additional spatial detail in the region of interest. To support that spatial detail, this model component allocated businesses to a smaller zone system from the counties used in the firm synthesis model. The allocation is based on employment by industry category.
5. ***Distribution Channels*** - Using a multinomial logit model, each shipment between each buyer-supplier pair is assigned a probability of choosing a specific distribution channel to represent the supply chain it follows from the supplier to the consumer. The model

predicts the level of complexity of the supply chain, for example whether it is shipped directly, or whether it passes through one or more warehouses, intermodal centers, distribution centers, or consolidation centers. Since this model is prior to mode choice, the distribution channels are multi-modal rather than mode specific.

6. ***Shipment Size*** - Shipment size is estimated using a discrete choice model based on a variety of firm, commodity and travel characteristics. It is as this point in the model that the units of analysis change from annual commodity flows between pairs of firms to discrete shipments that are individually accounted for and delivered from the supplier to the buyer.
7. ***Modes and Intermodal Transfers*** - There are four primary modes (road, rail, air, and water) that are modeled. Detailed networks of road and rail for the U.S. are used, with simpler functions of distance and the value of goods being transported to represent the air and water modes. The modes and transfer locations on the shipment paths are determined based on the travel time, cost, characteristics of the shipment (perishable, expedited, containerized) and characteristics of the distribution channel (whether the shipment is routes via a warehouse, consolidation or distribution center, and whether the shipment includes an intermodal transfers, e.g. truck-rail-truck). Once the modes and intermodal transfers have been assigned, the shipment list is converted from all annual shipments to a daily sample to represent the day being modeled. This process can be calibrated to allow for seasonal variations in commodity flows where that information is available. This step also assigns shipments to specific warehouse, distribution, and consolidation centers if the shipment passes through one of those locations.

4 Design Objectives and General Approach

The design of the agent-based economic extension should be a flexible, scenario simulation tool. It should extend the mesoscale freight model by adding modeled variation in the prediction of future freight flows as a function of economic actors, such as in an agent-based modeling system. These agents should be responsive to price signals inherent in the production of commodities, including both transport and non-transport factors of production.

4.1 Enhanced Supply Chain Network

The proposed approach is to enhance the components of the prototype mesoscale model by replacing the current static method of matching shippers and receivers in independent pairs with a set of new structures and algorithms that would simulate the formation of a supply chain network for each producing agent in the simulation. The new process would incorporate transport and non-transport costs into a supplier selection mechanism, which the current model does not. For each commodity produced by a firm, the model would consider the inputs to the production process and find at least one suitable source for each input, and multiple sources may be considered. The suppliers may be local, national, international, or even from within the same firm, but matching would be based on well-recognized typologies for the industry and commodity as well as for the Chicago region. Since the current mesoscale model is limited to selecting suppliers for only the top-five input commodities (by dollar value), to create future freight flow endogenously, each producer's supply chain network will need to cover a broader scope of inputs in order to capture as much of the total commodity flows as possible. In addition, producers and suppliers in foreign countries will need to be represented.

4.2 Agent-based Computational Economics

Agent-based computational economics (ACE), described in more detail below, would play a role in agents' assessing the utility of potential producer-supplier relationships to determine whether to establish and maintain trading ties. Rooted in game theory, ACE approaches to modeling procurement markets may include bi-lateral trades, bargaining, multi-agent bidding and more complex behaviors related to cooperation between agents under uncertainty. The inherent appeal of the ACE approach is the ability to simultaneously represent the interests of multiple decision-making agents, using relatively simple assumptions of agent information, attributes and payoffs, and to allow a market mechanism to emerge. In essence, this project will be creating a "procurement market game" which will be used to simulate sourcing markets for each of the 43 commodity types used in the model.

For each firm's level of commodity output, the procurement of sufficient quantities of various input commodities from suppliers would be modeled. The procurement market game is where ties are formed between agents representing buyers and sellers. The outcome of a specific tie results in the procurement of a dollar-valued quantity of an input commodity. Initially, it is anticipated that commodity flow units would be expressed in the same format as the FAF^3 flows, as annual tonnage and dollar-valued freight flows.

4.3 Firm and Agent Typologies

The synthetic firms in the mesoscale model shall be redesigned and augmented with attributes related to the production of specific commodity types, such as an assumed output level and a "recipe" of inputs need to produce a unit of output. In addition, firms will be classified as to whether they are more likely to practice vertical integration for key input commodities and by the importance of supplier prices relative to other attributes such as responsiveness or perceived quality. As described in more detail below, it should be possible to endow seller agents with attributes representing variations in service characteristics, such as shipment mode and frequency, creating a joint choice of supplier, mode and shipment size and frequency. As buying and selling firms are assumed to be located spatially, this results in commodity shipments that can be assigned to modes of transport and converted into vehicle trips in the next stage of the mesoscale model.

4.4 Supply Chain Dynamics

An important concept in the model design is the dual role of firms as both producers and suppliers of commodities. For example, a producer of machinery will use steel as one of many inputs to production, and steel producers will themselves have multiple inputs to steel production, such as iron ore. If the cost of shipping iron ore for steel production were to change significantly, this should in turn affect the producer price of steel and these cost changes would be reflected in the production costs for the machinery manufacturer. This dual role of the synthetic firms in the model as both producer and consumer, with the possibility of modeling the effect of costs propagating throughout the supply chain, is a desirable behavior for the model system. This level of behavioral realism is complex, however, so a phased approach is recommended and described in more detail below.

4.5 Software Functionality

The design of the software tool itself should permit the analyst to perform sensitivity tests by varying key inputs, including but not limited to:

- Assumptions on global, national and regional demand for commodities;
- Input-output tables relating factors of commodity production to output quantities;
- Assumptions on multi-factor productivity changes (unit output per unit input);
- Assumptions on regional commodity production costs;
- Parameters described in transport network files for each of the primary modes (truck, rail, water and air), such as unit transport costs, frequency of service, vehicle capacities, and travel speed assumptions;
- Multi-modal port and land-based freight transfer facilities, including throughput capacities and storage costs;
- Assigning operating-style typologies to firms and their buying/selling agents, based on their attributes and commodities;
- Utility expression parameters that map buyer typologies onto preference weights for costs, frequency, transport time, and potentially other attributes;
- Parameters used in algorithms used to simulate agent interactions through a market mechanism, such as assumptions on agent information and payoff values; and
- Run-time parameters and stopping criteria.

5 Design Principals

There are several key assumptions that should be incorporated into the design, some of which inspired the very formation of this project.

5.1 Variation in Agent Value Systems

One assumption is that supply chain decisions are made by individuals on behalf of the companies for whom they work. That is, we are not modeling the firm as the decision maker, but rather an individual. These decisions are made without perfect information and may be influenced to some degree by the cultural baggage of a particular industry, commodity or regional market, or by the affinity for particular business partners. For reasons such as these, while it is desirable to assume that purchasing agents who act on behalf their firms have cost savings in mind, it may not be realistic to assume that agents will make mathematically optimal decisions. For similar reasons, sales agents acting on behalf of their firms will assuredly have revenue growth as an objective, but will often make choices that do not maximize long-run revenue. An important aspect of this project will be to develop typologies of agents based on decision making behavior or value systems. The underlying objective will be to develop a manageable set of typologies and to correlate those with firm and commodity attributes.

5.2 Variation in Market Mechanisms

With such a description of “imperfect” buying and selling agents in mind, it is assumed that agent interactions can be modeled through an iterative simulation that mimics, at a high level, the strategies that decision-makers use when forming buyer-seller relationships—what price to offer and which offer to accept. In addition, other attributes of a commodity should come into play, such as perceived quality and timeliness, offsetting price to some degree, depending on buyer priorities. For example, producers may emphasize cost savings for bulk commodities with low storage costs, but may emphasize frequency of shipments for perishable commodities, or practice vertical integration (in-house sourcing) for complex commodities, such as components of high-precision medical equipment.

Real-life sourcing markets are diverse. Sourcing strategies may involve limited search efforts, such as looking to nearby sources for a reasonable offer, or they may involve more competitive bidding scenarios. For some commodity markets, competing suppliers may cooperate, possibly leading to collusion, side-agreements, and the formation of coalitions. Some market mechanisms may include a single buyer and multiple sellers, while others may be more accurately represented by multiple buyers, competing with one another, as well as multiple sellers. In other representations, the procurement decision could involve a combinatorial bundle of production inputs, not just a single commodity. It is not realistic to expect to model the multiplicity and complexity of potential procurement markets for various commodities; therefore, the model design should be based on simpler, more generalizable market mechanisms, as described below.

5.3 Theoretical and Empirical Underpinnings

This research will endeavor to develop a baseline model with agent properties and market mechanisms that resemble those found in the real world. The selection of strategies and algorithms should include only those that are consistent with reasonability tests. For example, agents should not seek to lose money for their firms. Moreover, the sets of strategies and algorithms adopted should produce end states from which emerge a pattern of behavior that resembles a real-life procurement market. As another example, the model should not produce monopolies or even duopolies where they are known not to exist. Subject to further refinement, a sufficient baseline condition may be to have the right level of competition (number of viable firms) as well as commodity prices and flows that are of the right order of magnitude, compared with empirical data.

5.4 Market Coverage

The future freight forecasting tool should cover all of the relevant flows within the current mesoscale model. Therefore, the model must represent the flow of commodities:

- From CMAP region suppliers to producers within the region and outside of the region, including foreign countries;

- To CMAP region producers from suppliers within the region and outside of the region, including foreign countries; and
- Transshipments of commodities that are neither produced nor consumed within the CMAP region, but which utilize CMAP regional transshipment facilities on their path between shippers and receivers in other regions.

5.5 Why Agent Based Computational Economics?

5.5.1 Background

Agent-based computational economics (ACE) (e.g., Tesfatsion and Judd 2006) is a growing sub-discipline within applied economics that has emerged as an approach to studying markets, offering an alternative to more traditional, general computational equilibrium methods. General equilibrium methods, based on the "invisible hand of the market," predict outcomes based on the achievement of a market clearing price, which may be described as a "top-down" approach. In contrast, ACE is a "bottom up" approach in which individual agents are simulated in a virtual world in which they make decisions, interact and react to each other, and patterns emerge from the collective actions of many agents. ACE has been used to study such diverse phenomena as racial segregation in housing markets (e.g. Sander et al 2000) and electric power trading among public utilities (e.g., Aliprantis et al 2010). ACE is also closely aligned with the more general field of dynamic complex systems, which includes agent-based studies of biological systems such as honeybee swarms (e.g., List et al 2009) and habitat destruction (e.g., Perez et al 2010), as well as human social choices and voting (e.g., Kollman and Page 2006).

Typically, agents are endowed with little more than payoff values (i.e., utilities) for specific outcomes of the market/decision context under study. Assumptions are made about what information agents have about each other, the initial state of the system, and the rules of interaction. Many interaction contexts are based on spatial adjacency or proximity, making ACE systems useful for studying network formation and evolution, including supply chain formation. Through simply binary choices about whether to cooperate or not with another agent, agents receive payoffs that may be positive or negative depending on what the other agent decides.

Agent interactions are often structured as "games" and methods tend to draw on the rich literature of game theory in economics and other social sciences. Analysts strive to solve game theory problems by finding a set of best-response strategies that agents would follow using common logic for expected payoffs under repeated interactions. This is not to say that agents are maximizing their utility in a global sense; rather, they are reacting myopically to a narrow decision problem and seeking to maximize gain or minimize loss based on expectations of what other agents will do. For many games, a stable strategy emerges in which agents simply mimic what other successful agents have done, or what their nearest neighbor has done in spatial games. In the aggregate, however, the collective actions of individual agents tend to form patterns which, in an economic system, may represent markets.

5.5.2 Advantages

A primary objective of ACE study is to develop methods for the rigorous study of economic systems through computational experiments. ACE approaches to analyzing economics systems can lead to better understanding and insights in answering at least three types of research questions (Tesfatsion 2005):

- *Why have certain global regularities emerged and persisted despite the absence of centralized planning and control, while other global outcomes have not been observed?*

  There are impactful and well-known trends in supply-chain and logistics practices, such as insourcing, outsourcing, and near-sourcing that are theorized to partially relate to privately held values and beliefs regarding various forms of uncertainty (demand, competition, technology, supplier performance), asset specificity, and commodity attributes. While operational efficiency might suggest that increasing supply chain surplus (value added) should drive these decisions, these other factors clearly play a role.

- *What types of micro-level dynamics of individual traders lead to the collective patterns market behavior that we observe?*

  In supply-chain networks, decisions made regarding the allocation of resources to produce a commodity will affect the prices and general utility of using that commodity in the production of other commodities. Discovering which agents in the supply chain network have the greatest influence on other agents (commodities, industries) and identifying the strengths of ties between agents may be important to assessing regional competitiveness and the likely trends in future freight flows.

- *How can good economic (infrastructure) policies be designed to achieve their intended effect?*

  For CMAP and other public agencies, economic policies under consideration may include road pricing as well as various infrastructure investments and traffic flow management strategies aimed at more efficient system-wide effects. The policies and investments made by other regions, such as tariffs and port expansions, also play a role.

6 Model Design Overview and Integration

A flow diagram showing the primary extension model components and where they plug into the current mesoscale modeling system is shown below in Figure 3. The eight green boxes contained within the dotted-line represent new or modified model components, or steps. The purple boxes represent both quantitative and qualitative input data elements, most of which need to be integrated through this research. The final output of the extension, a multi-dimensional matrix of commodity flows, is shown in the orange box at the bottom of the diagram.

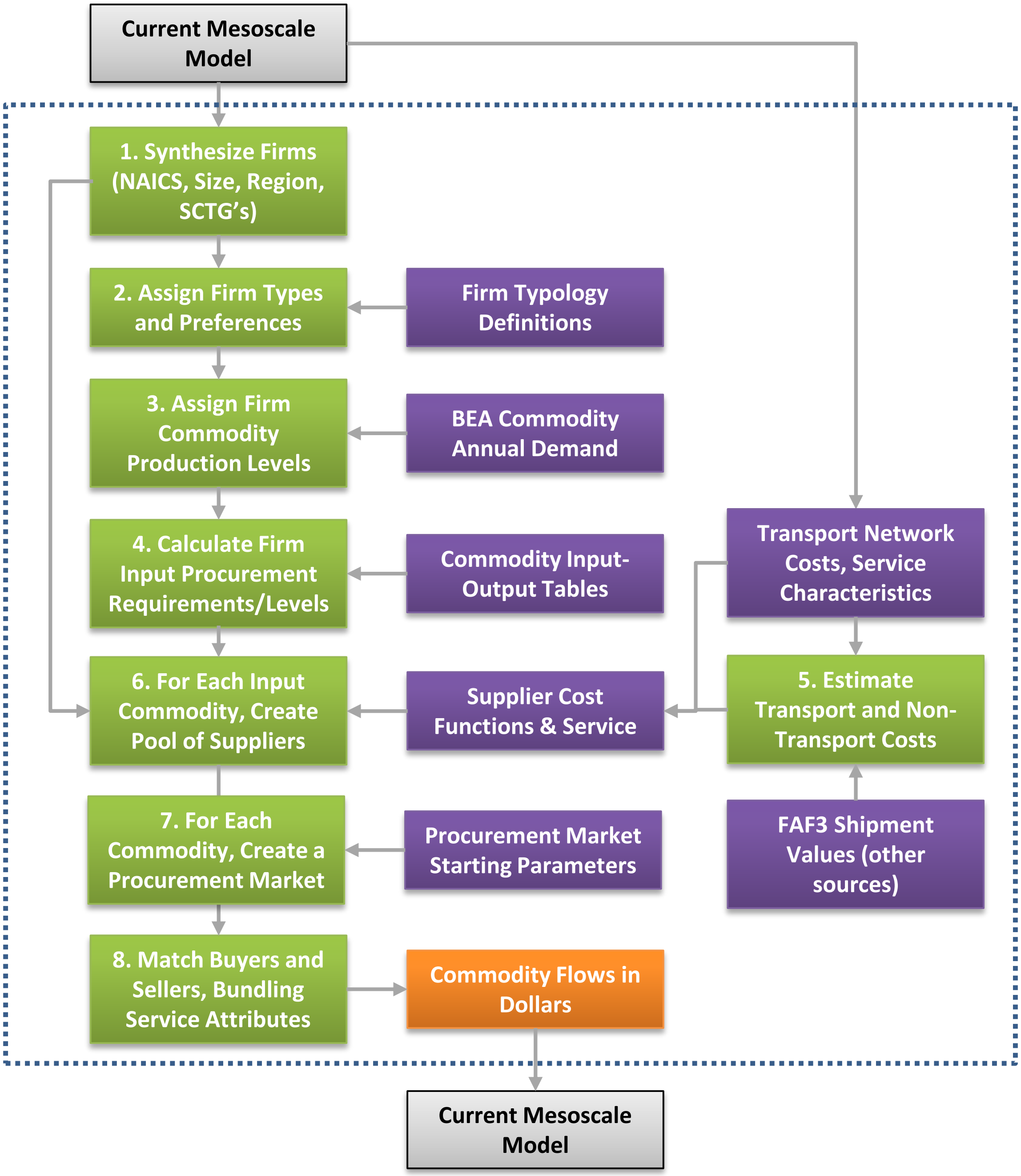


Figure 3. High-level flow of model components and integration within Mesoscale model

In terms of integration into the mesoscale model, the extension illustrated in Figure 3 would:

- Pick up at the point where firms have been synthesized by the current model;
- Modify and augment the attributes of each firm and create purchasing and selling agents;
- Replace the current mesoscale model's static matching of buyers and sellers with the agent-based procurement markets approach;

- Integrate the choice of supplier firms with the choice of shipment modes and sizes and choose distribution channels, using the same method found in the current mesoscale model; and
- Return a set of annual commodity shipments by mode-path and average shipment size.

Each of the model steps shown in Figure 3 are described in detail below.

6.1 Synthesize Firms

This step accepts as inputs the synthetic firms created through the mesoscale model. As this research proceeds, we may find it necessary to define firms somewhat differently; however, the current model should be a good starting point. For discussion purposes, it is assumed that the extension tool will be programmed using object-oriented methods, where there will be a “firm” class, and instance of this class will be firm objects. At this step, each firm must be endowed with the attributes necessary for the modeling exercise. A preliminary list of these attributes would include:

- Industry Code (NAICS)
- CPB Zone (County Business Patterns zone used during supplier selection)
- FAF Zone (country/region)
- CMAP modeling zone
- Commodity Type(s) Produced (SCTG)
- Size (number of employees)
- Production capacity (commodity units produced per year)

6.2 Assign Firm Types and Preferences

The purpose of assigning firm types is to create an expectation for supply chain formation behavior that is not captured by the firm’s initial set of attributes, as describe in 6.1 above. Of specific interest are attributes related to firm and agent *preferences* for various combinations of source attributes, such as:

- Unit cost / total cost
- Average shipment time
- Frequency of shipments / Average shipment size
- Proximity of supplier
- Perceived quality of the supplier’s commodity
- Perceived reliability of the supplier

It is assumed that purchasing agent consider these “bundle” of attributes when making their sourcing decisions. While monetary costs are relatively straightforward to assign and evaluate, preferences for other elements in the bundle are less so. Firms will differ in what they are willing to pay for better services, reliability and quality. These preferences vary by industry and firm size, but also by the nature of the commodity that they produce and the nature of the commodities that they use in the production process. For example, smaller firms may be more cost sensitive and therefore more willing to compromise on other aspects of the sourcing bundle. Bulk non-perishable commodities (e.g., mining, lumber) may be purchased in large, less frequent shipments and stored for longer periods of time and, which typically induces firms to save as much money as possible. In contrast, perishable items and other items that have high storage costs or highly variable demand may require more frequent shipments and faster delivery, so firms will be willing to pay more in order to obtain more frequent service to avoid either loss of stock or running out of inventory. As another example, firms the produce highly specialized goods, such as computers and electronics, require specific or strategic input commodities that they may prefer to manufacture themselves for reasons of wanting to have direct control over the commodity quality or because the need to frequently make design modifications that require customized inputs.

To capture these operational styles, a set of preference weights will be developed for use in the downstream procurement market process in which producers select suppliers for input commodities. Attributes of the firm, as listed above in 6.1, will be used to create a mapping of firm type. Based on a review of the literature (*to be added as a future appendix*) a firm typology will be developed and used to assign firms to various behavioral preference categories. Initially, three behavioral dimensions have been identified:

- Degree of Vertical Integration – the extent to which a firm supplies its own production inputs as intermediate goods on the way to the producing the final commodity. For example, some commodities are so specialized (e.g., luxury glassware and home furnishings) that a manufacturer may make nearly every component in-house, other than raw materials. Other commodities (e.g., eating and drinking establishments) may look to external suppliers for nearly all of their inputs. Others may be more of a mix and more flexible, which is the case with automobile manufacturers who sometimes outsource sub-assemblies or parts to other companies and sometimes make these inputs within the same firm, although often at a different location.
- Degree of Centralization – more relevant for large firms with a retail commodity, the extent to which a central office dictates procurement of inputs and makes available local distribution facilities for branch locations. For example, companies like Home Depot and McDonald's and national retail store chains typically have a central purchasing office that buys inputs from multiple suppliers and distributes them through national distribution system, using both company-owned and for-hire trucks at various stages. Smaller firms within the retail sector are likely to be more locally owned and operated.
- Efficiency vs. Responsiveness – the extent to which companies weight the cost of an input relative to its quality and timeliness of delivery. This should be a commodity-driven parameter and will reflect attributes such as a commodity's perishability and substitutability, or whether the commodity is considered to be "innovative" or simply "functional." As an example, a high-end ice cream manufacturer will put a premium on quality and timeliness of dairy farm suppliers, and may show a preference for "near sourcing." At the other end of the spectrum, clothing retailers will tend to emphasize cost

minimization and are known for buying from manufacturers in distant countries with low wages.

These firm type attributes would be used to group firms to identify how they are likely to approach input procurements and the formation and management of supply chains. From a modeling perspective, we would use these parameters to formulate firms' response sets and preference structures. Actual numerical values for preferences weights will be developed as part of the experimentation in the Task 2 model development phase of the project.

6.3 Assign Firm Commodity Production Levels

The U. S. Bureau of Economic Analysis (BEA) data will be used to estimate the total dollar-value of commodities produced by each synthesized firm in the model. Based on assumptions that firm production levels of a specific commodity are proportional to firm size, this step should be fairly straight forward. This should, however, take into account regional differences and other potential sources of variation, particularly where firms from non-U.S. countries are concerned. In other countries the technologies of production are likely to differ for some commodities, with varying levels of automation relative to manual labor. For imports, BEA report producer prices based on U.S. dollars at the domestic port of entry.

6.4 Calculate Firm Input Procurement Requirements

For a given commodity type, each firm's procurement inputs can be estimated by using the BEA Input-Output (I-O) tables. For each dollar unit of output, the BEA tables specify what fraction of that dollar came from each relevant input commodity. Thus it is a simple matter of multiplying these fractions by the total output commodity determined in 6.3.

Given the imperative to model demand levels endogenously, it is important to capture as much of the total commodity flow value derived from the transport of inputs to production as possible. How many input commodities need to be considered? If we model only a limited set of inputs (e.g. top five), will this lead to under-representation of the market and commodity flows? What threshold should be used to determine how many input commodities is enough?

6.4.1 Type of I-O Tables

It is important to understand the different type of I-O tables available from BEA, which are often referred to as Make and Use tables. The Use tables show the dollar valued of commodities used by intermediate and final users in the production of a particular output commodity and are what will be used in this modeling step. For example, for the electronic computer products industry, the use table shows the amount (in dollars) of semiconductors, computer terminals, ornamental metals, and other electronic component inputs that are necessary to produce electronic computer products and the secondary products of the industry.

Annual I-O accounts have more recent but more aggregated level data (3 digits NAICS codes), while the Benchmark I-O accounts have older (the benchmark 2007 planned to be released at the end of 2013) but more detailed data (6 digit NAICS codes). The annual and benchmark use and make tables are available as two sets of data by BEA. The "standard" or "before redefinitions"

Make and Use tables are based NAICS industries and are more consistent with other economic accounts and industry statistics. The "supplementary" or "after redefinitions" make and use tables are derived from the standard tables by reassigning, or "redefining" some secondary products to the industry in which they are the primary products. The estimates in these tables are used to calculate the requirements tables and the requirement tables are created as after redefinitions tables. The Direct requirements table shows the amount of a commodity that is required by an industry to produce a dollar of that industry's output. Total requirements tables show the relationship between final uses and gross output. In addition, BEA makes available Import tables that are useful in determining what portion of the input commodities come from foreign rather than domestic sources.

6.4.2 Capturing Maximum Freight Flows by Value

If we were to model only a limited set of inputs (e.g. top 5 or top 10), this may lead to under-representation of the market and commodity flows between establishments. To investigate this research question empirically, the Use and Direct Requirements tables were used to find how many inputs account for more than 95 percent of value of intermediate inputs of an industry. **Error! Reference source not found.**1 shows the results of calculating top inputs for industries by value.

Table 1. Comparison of Different I-O Data based on the Percentage of Industries that captures more than 95% of Inputs by Value

Number of Input Commodities	**2002 Benchmark** *4 digits NAICS All Codes*	**2002 Benchmark** *4 digits NAICS Only up to 5111**	**2002 Direct Req.** *6 digits NAICS All Codes*	**2002 Direct Req.** *6 digits NAICS Only up to 511*
Top 5	0%	1%	0%	0%
Top 10	1%	7%	1%	6%
Top 20	7%	52%	3%	16%
Top 25	14%	85%	5%	36%
Top 30	24%	98%	-	-
Top 50	94%	100%	56%	97%

**This is what currently used in the current mesoscale freight model*

Source: BEA, Industry Economic Accounts

The numbers shown in the table are the percentage of industries for which the number of "top" inputs shown in first column capture more than 95 percent of total inputs by value. For example there are 7 industries out of 100 industries for which the Top 20 inputs capture more than 95 percent of total input value in 2002 benchmark 4 digits code data. When total value is limited to industries that produce freight flows, NAICS codes 5111 and below, the Top 20 captures 95 percent of flows in 52 out of 100 industries.

In order to compare the percentage of input values by different industries, Error! Reference source not found.2 shows the results of calculating the top inputs for two-digit codes industries by value using the 2002 Direct Requirements table (6 digits NAICS only up to 5111). The numbers in the table are the percentage of industries that capture more than 95% of inputs by value for different numbers of top inputs. As the table clearly shows, a 95 percent coverage of flow values is rarely achieved by consideration of only the Top 5 inputs (Commodity 11 is Agriculture, Forestry and Fishing; Commodity 23 is Construction). Many industries do not cover 95 percent of commodity flow values even with the Top 25 inputs accounted.

Table 2. Comparison of Different 2-digit Industries based on the Percentage of Industries that Capture at least 95% of Inputs by Value

Commodity	Top 5	Top 10	Top 20	Top 25	Top 50
11	5%	11%	32%	95%	100%
21	0%	9%	9%	45%	100%
22	0%	67%	100%	100%	100%
23	0%	0%	0%	0%	29%
31	0%	11%	46%	70%	100%
32	0%	7%	15%	36%	99%
33	0%	1%	3%	14%	98%
42	0%	0%	0%	0%	100%
48	0%	29%	43%	57%	100%
49	0%	0%	33%	67%	100%
51	0%	0%	0%	60%	100%

Source: BEA, Industry Economic Accounts. http://www.bea.gov/industry/ (Accessed August 2013)

Provisionally, the assumption is that each commodity produced by the synthetic firms in the simulation will be treated differently, and the total inputs required to achieve 95 percent coverage of commodity flows will vary by the commodity being produced, as determined by the Direct Requirements tables.

6.5 Estimate Transport and Non-Transport Costs

It is assumed that the multi-modal network model created as part of the current mesoscale model will be sufficient for generating travel time and cost skims for each of the principal freight-hauling modes under consideration: truck, rail, air and water. In order to estimate non-transport costs of commodity production, the initial planned approach is to use the FAF^3 estimates of shipment values between FAF zones to provide a total cost figure. Unit transportation costs will be assumed, consistent with the most recent estimates used in the mesoscale model, but may need to be adjusted, based on the outcome of the current work. By then applying the transport costs derived from the skims to these very same FAF^3 flow estimates, we can calculate the difference between the shipment values and the estimated transport costs. This difference would represent non-transport costs of the commodity. It is anticipated that this approach may have some as yet undiscovered flaws, or be more accurate for some commodities and regional flows than others, in which case non-transport costs for production will be derived from independent sources. In particular, it would be beneficial to ascribe differences in the non-transport costs of production by region to differences in underlying technologies, wage rates, tariffs, etc.

The outcome of this module is expected to be a non-linear production cost function that estimates non-transport and transport costs separately as a function of the quantity to be procured. This function will vary by commodity type, firm size and region, as well as other factors to be determined.

6.6 Create Supplier Pools

For each of the 43 SCTG commodity groups, synthetic firms in the simulation will be identified as producers of that commodity. Rather than represent a supplier firm by a single agent, depending on the commodity type and the firm's location, there may be additional agents created to represent alternative bundles of service offerings. Supplier agents will be created to represent a firm and its bundle of source offerings, as dimensioned by unit costs, shipment sizes/frequency, shipment times and freight mode-paths. The geographic locations of each firm will in large part determine mode availability and shipping times and costs, as described above in 6.5. Additional information on shipment sizes will be derived from tables used in the current mesoscale model. These multi-dimensional agents will be "compete" with one another for supplier contracts through an agent-based computational simulation of a procurement market, as described below.

6.7 Create a Procurement Market Scenario

There are many different scenario assumptions embedded in the extension model design; however, they can be generally grouped under the following categories:

- Transport system cost parameters;
- Regional, national economic growth assumptions by industry/commodity sector;
- Technical coefficients representing the factors of production that transform inputs into outputs, as represented in the I-O tables; and
- Commodity-market-specific parameters representing assumptions about the typologies of buying and selling agents and their behavior.

The baseline model to be developed under this project will include a set of baseline assumptions and parameters for the base year of the model. For future scenarios, it will be important to develop methods for "growing" the regional economy under "business-as-usual" assumptions as well as alternative views of the future. Forecasting considerations are discussed in more detail in Section 10, below. In addition, the multi-modal freight network will need to be updated to reflect existing and committed facilities and projects along with their assumed costs and service rates.

6.8 Match Buyers and Sellers, Bundling Service Attributes

The heart of the mesoscale model extension is an agent-based computational economics approach to modeling the formation of supply chains. For each of the 43 commodity types under consideration, a procurement market model will be run, using the procurement market scenario inputs described above. The objective of this step is to find suppliers for every commodity input required by buyers. As described above, supplier agents will be created to represent a firm and its bundle of source offerings, as dimensioned by unit costs, shipment sizes/frequency, shipment times and freight mode-paths. Producers will be represented by buying agents, who will represent firm interests with respect to the particular commodity, based on firm typology definitions, and will express preferences for different elements of the supplier bundle. The outcome of this module will be a set of commodity shipments between suppliers and buyers that will be spatially distributed, dimensioned by shipment size/frequency, and a primary mode path. The procurement market model is described in detail in Section 8, below.

7 Game Theoretic Approaches to Procurement Markets

The literature on game theoretic approaches to procurement of suppliers focuses on reverse auctions (sometimes called procurement auctions). These games portray a market condition in which one or more procurement agents solicit bids from potential suppliers, and the lowest bidder wins the contract. The number of buying and selling agents and the complexity of the commodity (single or multiple types, and single or multiple attribute) determine the complexity of the game and the likelihood of it resolving to a unique equilibrium, as opposed to multiple equilibria or none at all. An auction mechanism may be appropriate for some commodity markets, but certainly not all.

For many producers, particularly those producing relatively functional products as well as smaller firms, procurement is more about negotiation and bargaining with known and relatively limited set of alternative suppliers. In light of this diversity of procurement market contexts and decision-making agents, a more general and flexible approach to agent-based modeling of procurement markets will be pursued.

8 Procurement Market Game

An ACE approach to matching producers with suppliers will be implemented in what is provisionally called a “procurement market game.” This approach is intended to be sufficiently general and flexible such that it can be applied to all of the commodity markets that need to be modeled to support the forecast of future freight flows without modifying the basic structure of the game. A general, flexible framework avoids the complicated, time-intensive and potentially error-prone task of studying and trying to represent what actually goes on in 43 different commodity markets. Instead, commodity markets would be differentiated from each other by the inputs to the game—the number and attributes of agents assumed to be competing in the market, their preferences and cost structures.

The approach to the procurement market game was inspired by the “trade network game laboratory” (TNG Lab), a more general tool developed by an ACE research group at Iowa State University (McFadzean et al 2001). The TNG Lab game allows users to test various gaming assumptions for simple bi-lateral trading scenarios. Agents in the TNG game are referred to as “buyers,” “sellers,” and “dealers,” which are agents that can both buy and sell. Agents are generic, possessing no other attributes. The user specifies the number of buyers, sellers and dealers in the game, and specifies scalar values in a 2 x 2 payoff matrix, which uses common cooperate-defect labeling as found in games such as the Prisoners Dilemma. The payoff matrix is symmetric, so the same payoff values pertain to buyers, sellers and dealers. The TNG is designed to play multiple rounds of games during which agents play pairwise games with each other, deciding whether to cooperate or defect. The results of each round (called “trade cycle”) of pairwise trades are evaluated, maintained in agent “memories” for the next round, and used to update expected utilities for subsequent trade cycles. Expected utilities are updated using a genetic algorithm approach. The user specifies “mutation rates” for the genetic algorithm, how many generations to maintain, and how many trade cycles to play. At the end of the game, it is revealed which agents established strong ties, weak ties, or were left without a tie, and the average utilities of each of the three agent types.

The proposed procurement market game (PMG) will use this general approach to modeling multiple rounds of pairwise trades between buying and selling agents and updating agent expectations about the outcomes of subsequent interactions. To be useful for mesoscale model extension, the PMG design will need to incorporate domain-specific information about firms, including their attributes related to their typology and preferences, and data-driven commodity costs and supplier service characteristics. Payoffs will need to be asymmetric and have domain-specific meaning.

8.1 Proposed PMG Rules

The proposed rules of the PMG are as follows.

- For each of the 43 SCTG commodity types, a PMG will be played to determine producer and supplier relationships for the commodity.
- The producer (buyer) pool will consist of all firms that use the particular commodity as a production input, and an annual purchasing amount will be determined by multiplying the direct requirements percentage of this input commodity by the firm’s total output level for their primary output commodity.
- The supplier (seller) pool will consist of all firms that are primary producers of the particular commodity, and the amount that they are able to supply (capacity) will be determined by their total output level for that commodity.
- Firms will be represented by buying and selling agents who possess attributes representing typologies describe above in Section 7.
- For buyers, typologies will be used to assign preference weights for various sourcing bundle attributes, such as:
  - Total unit cost
  - Expected delivery time (travel time)
  - Expected shipment frequency or size
  - Geographic proximity
- Selling agents will be defined by offering a particular bundle of these same attributes. Unit costs will be determined as described in Section 6 and will reflect both non-transport costs and transport-costs. Transport costs will be derived from the multi-modal skim tables, based on the geographic locations (FAF zones) of each buying and selling agent. Each selling agent will be represented by a single representative transport mode path, e.g., truck, rail-truck, water-truck, or air-truck. For any potential buyer-seller pair, this

mode-path combination will also determine the expected delivery time and expected shipment size, based on modal capacity.

- The PMG will be initialized by creating payoff matrices for each potential buyer-seller pair. Payoffs to buyers will be expressed in terms of the utility to be derived from the relationship with the seller, which will be a function of the preference weights applied to the attribute bundle offered by the seller, weighted by the extent to which the seller has the capacity to fill its procurement needs.
- Payoffs to sellers will be expressed in terms of the expected annual revenue to be derived from the relationship, which will be a function of unit costs multiplied by the buyer's expected annual purchasing amount.
- For each game, the payoff matrix will be defined as follows.

Buyer		**Seller**	
Decision	Payoffs	Decision	Payoffs
Yes	Utility of Transaction	***Yes***	Revenue of Transaction
No	Expected Utility if another supplier must be chosen	***No***	Expected Revenue of holding out for other (more lucrative) buyers

- The PMG will be an iterative simulation, played out over several rounds, with agent "beliefs" updated after each round. Within each round, the PMG will proceed by playing bi-lateral trading games between all feasible pairs of buyers and sellers.
- For the buyer, initially the expected utility if another supplier must be chosen will be based on the average utility to the buyer of all of the other sellers in the game, assuming uniform odds of any one of them being willing to trade and accounting for the presence of other buyers in the market.
- For the seller, the initial expected revenue of holding out for other (more lucrative buyers will be based on the average revenue of the potential orders of the other buyers in the market, weighted by the expected probability of a successful alliance with these buyers, which would be influenced by the presence of competing sellers.
- To force trading, buyers will be assessed a disutility penalty if they fail to secure a procurement partner during the round. This opportunity cost should be proportional to amount of the unfulfilled input commodity requirements.
- Preliminary trades are made if both buyer and seller say "Yes" to a procurement agreement. If either or both say "No," then there is no trading between the pair during the round.
- Payoffs to buyers and sellers for a trading outcome are recorded as the amount they would receive during the round. The payoff that they would actually receive will not be determined until the end of the round, because it will be calculated based on outcomes of all pairwise trades.

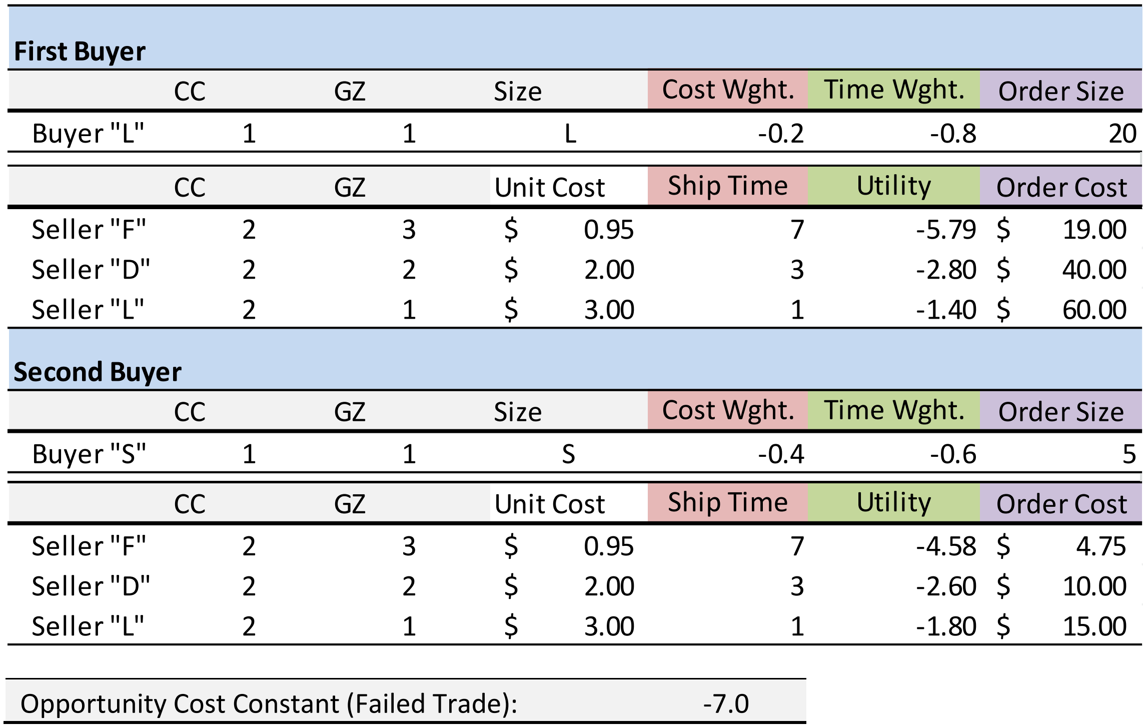
- At the beginning of the second round, the expected utilities/revenues of no-trade decisions are updated for each pairwise game, based on the outcomes of the previous round. Successful trade alliances will raise the expectation of a trade with the same partner, whereas spurned trade offers will lower the expected probability of a trade with that partner. Pairwise games are played out once again, and the outcomes recorded to update agent beliefs for the subsequent round.
- At a minimum, the PMG will continue for as many rounds as required to ensure that every buyer has at least one seller that meets its commodity input needs. Subject to testing, additional rounds may be required to improve the match between buyer purchasing requirements and seller fulfillment capacity.
- To meet the overarching goal of predicting total commodity flows for the Chicago region, it will be necessary to find sources for every input commodity for every producer. This does not mean, however, that every selling agent will be matched with a buying agent. The structure of the PMG will reveal some agents to be uncompetitive within the regional market.

8.2 Example of PMG

A simplified example will serve to illustrate how the PMG might work. As shown below in Table 4, consider a scenario in which we have a large buyer “L” and a small buyer “S” who are both in the packaged foods industry, commodity code, CC=1. Each buyer needs to purchase a quantity of an input commodity, seafood, commodity code, CC=2. Both buyers are in the local geographic zone, GZ=1.

For the commodity market for seafood, there are three potential suppliers. Seller “F” is located in a foreign country, GZ=3, and offers a very low unit cost, but shipping time is lengthy at 7 days. Seller “D” is domestic, located in another U.S. state, GZ=2, and offers a mid-range unit cost and 3-day shipping. Seller “L” is local, GZ=1, offers a specialty farm-raised product of high quality with 1-day shipping, but the unit cost is the highest of the three sellers.

Table 4. Example Trade Scenario “A”



First Buyer

	CC	GZ	Size	Cost Wght.	Time Wght.	Order Size
Buyer "L"	1	1	L	-0.2	-0.8	20

	CC	GZ	Unit Cost	Ship Time	Utility	Order Cost
Seller "F"	2	3	$ 0.95	7	-5.79	$ 19.00
Seller "D"	2	2	$ 2.00	3	-2.80	$ 40.00
Seller "L"	2	1	$ 3.00	1	-1.40	$ 60.00

Second Buyer

	CC	GZ	Size	Cost Wght.	Time Wght.	Order Size
Buyer "S"	1	1	S	-0.4	-0.6	5

	CC	GZ	Unit Cost	Ship Time	Utility	Order Cost
Seller "F"	2	3	$ 0.95	7	-4.58	$ 4.75
Seller "D"	2	2	$ 2.00	3	-2.60	$ 10.00
Seller "L"	2	1	$ 3.00	1	-1.80	$ 15.00

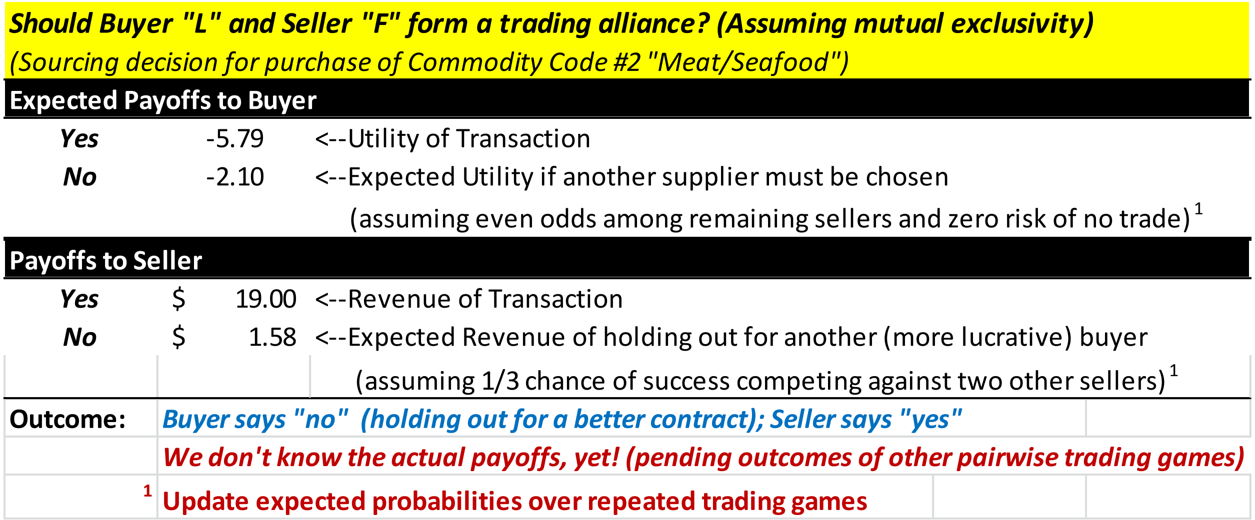
Opportunity Cost Constant (Failed Trade):	-7.0

Buyer “L” represents a large manufacturer who is of the type that values timely delivery and is willing to pay a little more for it. Buyer “L” being smaller needs to be more cognizant of costs, even though timeliness is important for obvious reasons of freshness. The weights that each buyer places on the (dis)utility of cost and shipping time are shown in Table 4.1. In this example, an opportunity cost of -7.0 is the payoff at the end of a trading round if a buyer fails to secure a seller. Also, in this game it is assumed that there can only be one seller for each buyer, so at least one seller will be left out of the market.

Scenario A

Table 5 below illustrates how a pairwise game between the large buyer and foreign seller would play out. Buyer “L” would reject the trade based on the expectation of getting a better deal (more positive utility) from one of the other two sellers. Seller “F” would say yes to the deal based on the expected revenue being greater than what could be expected from the other buyer, taking into account the competition with two other sellers.

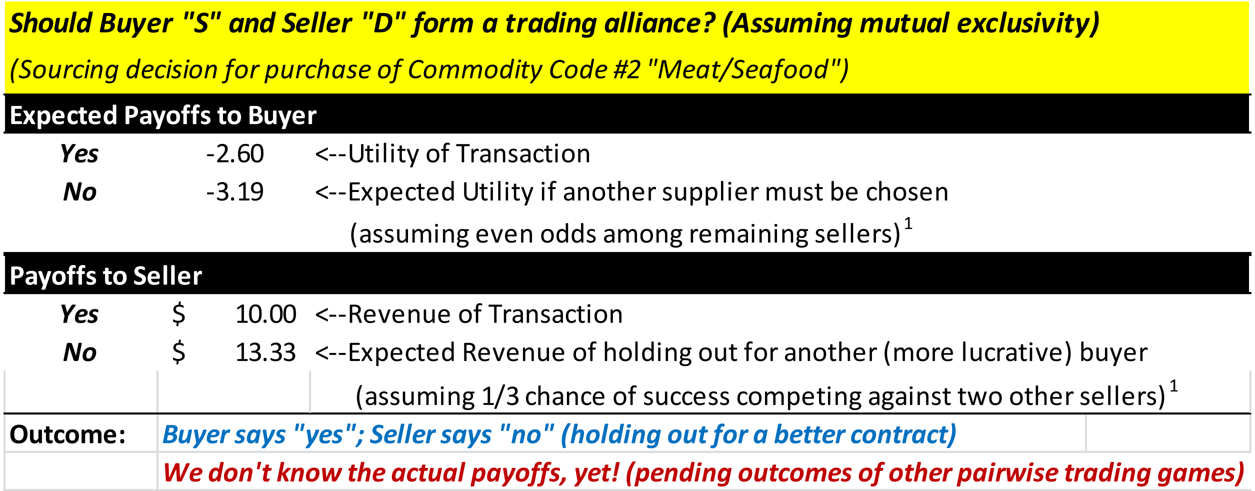
Table 5. Pairwise Trade L-S



Should Buyer "L" and Seller "F" form a trading alliance? (Assuming mutual exclusivity)		
(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")		
Expected Payoffs to Buyer		
Yes	-5.79	<--Utility of Transaction
No	-2.10	<--Expected Utility if another supplier must be chosen
		(assuming even odds among remaining sellers and zero risk of no trade) [1]
Payoffs to Seller		
Yes	$ 19.00	<--Revenue of Transaction
No	$ 1.58	<--Expected Revenue of holding out for another (more lucrative) buyer
		(assuming 1/3 chance of success competing against two other sellers) [1]
Outcome:	***Buyer says "no" (holding out for a better contract); Seller says "yes"***	
	We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)	
[1]	**Update expected probabilities over repeated trading games**	

It is important to note here that it is assumed that pairwise trades take place in no particular order. Within a round, the agents in each pairwise game have no knowledge of any other pairwise game. Table 6below shows the outcomes of a pairwise game between the small buyer and the domestic seller. In this case, the buyer says “yes” to the deal, but the seller say declines, holding out for a higher expected revenue from the large buyer.

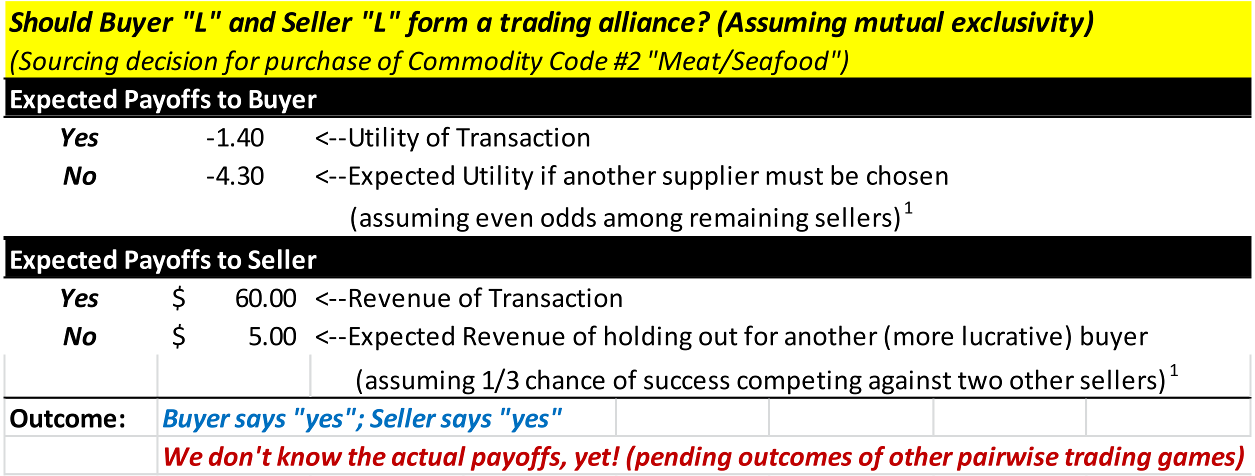
Table 6. Pairwise Trade S-D



Should Buyer "S" and Seller "D" form a trading alliance? (Assuming mutual exclusivity)		
(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")		
Expected Payoffs to Buyer		
Yes	-2.60	<--Utility of Transaction
No	-3.19	<--Expected Utility if another supplier must be chosen
		(assuming even odds among remaining sellers) [1]
Payoffs to Seller		
Yes	$ 10.00	<--Revenue of Transaction
No	$ 13.33	<--Expected Revenue of holding out for another (more lucrative) buyer
		(assuming 1/3 chance of success competing against two other sellers) [1]
Outcome:	***Buyer says "yes"; Seller says "no" (holding out for a better contract)***	
	We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)	

Table 7 below depicts a pairwise game between the large buyer and the local seller. In this game, both parties agree to trade and receiving the commensurate utilities/revenues from the trade.

Table 7. Pairwise Trade S-D



Should Buyer "L" and Seller "L" form a trading alliance? (Assuming mutual exclusivity)
(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")

Expected Payoffs to Buyer		
Yes	-1.40	<--Utility of Transaction
No	-4.30	<--Expected Utility if another supplier must be chosen (assuming even odds among remaining sellers)[1]

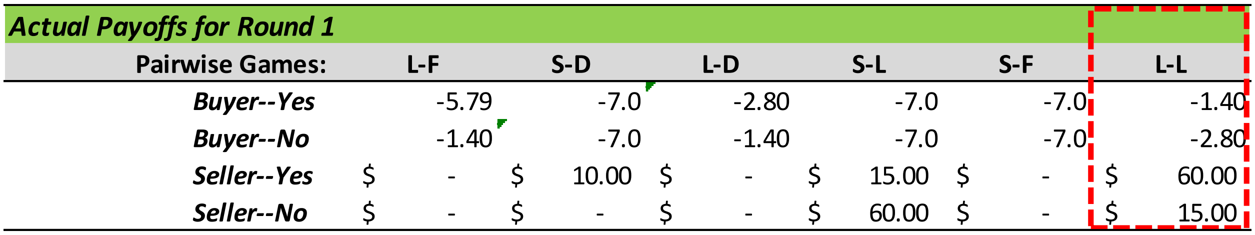
Expected Payoffs to Seller		
Yes	$ 60.00	<--Revenue of Transaction
No	$ 5.00	<--Expected Revenue of holding out for another (more lucrative) buyer (assuming 1/3 chance of success competing against two other sellers)[1]

Outcome:	***Buyer says "yes"; Seller says "yes"***
	We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)

And so on…

All of the other pairwise combinations (2 x 3 = 6) are calculated and expected payoffs for each game are updated based on these pairwise outcomes. Table 8 below summarizes the actual payoffs for Round 1.

Table 8. Summary of Round 1 Pairwise Trades



Actual Payoffs for Round 1

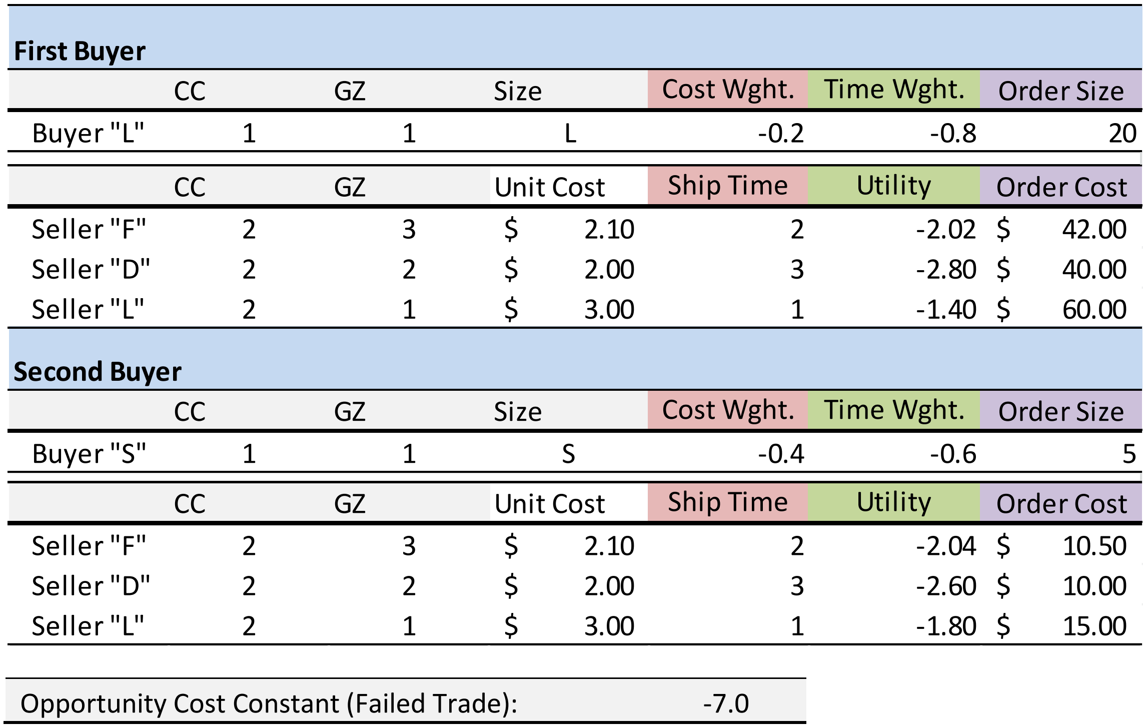
Pairwise Games:	**L-F**	**S-D**	**L-D**	**S-L**	**S-F**	**L-L**
Buyer--Yes	-5.79	-7.0	-2.80	-7.0	-7.0	-1.40
Buyer--No	-1.40	-7.0	-1.40	-7.0	-7.0	-2.80
Seller--Yes	$ -	$ 10.00	$ -	$ 15.00	$ -	$ 60.00
Seller--No	$ -	$ -	$ -	$ 60.00	$ -	$ 15.00

- Only partnership formed was between Buyer L ("large") and Seller L ("local").
- Under an assumption of mutual exclusivity, an initially favorable L-D match was superseded by L-L (slightly better for the buyer)
- Buyer S ("small") was outbid after holding out for the preferred provider ("local").
- Buyer S was rejected by all of the sellers, who were holding out for Seller L ("large").
- During the second round, buyers and sellers would update their beliefs about the probability of a successful trade, which should result in a second alliance forming between Buyer S and Seller D ("domestic").
- Seller F ("foreign") is priced out of this market for meat/fish, but could become competitive in a different scenario if cost structures or preferences were to change.
- This example is simple enough that only two rounds are required!

Scenario B

In this scenario, the Foreign Seller "F" invests in an air freight service to Chicago that allows shipments to arrive in 2 days, which more than doubles unit costs, although they were already quite low. This changes the utilities that both buyers with respect to Seller “F”.

Table 9. Example Trade Scenario “B”

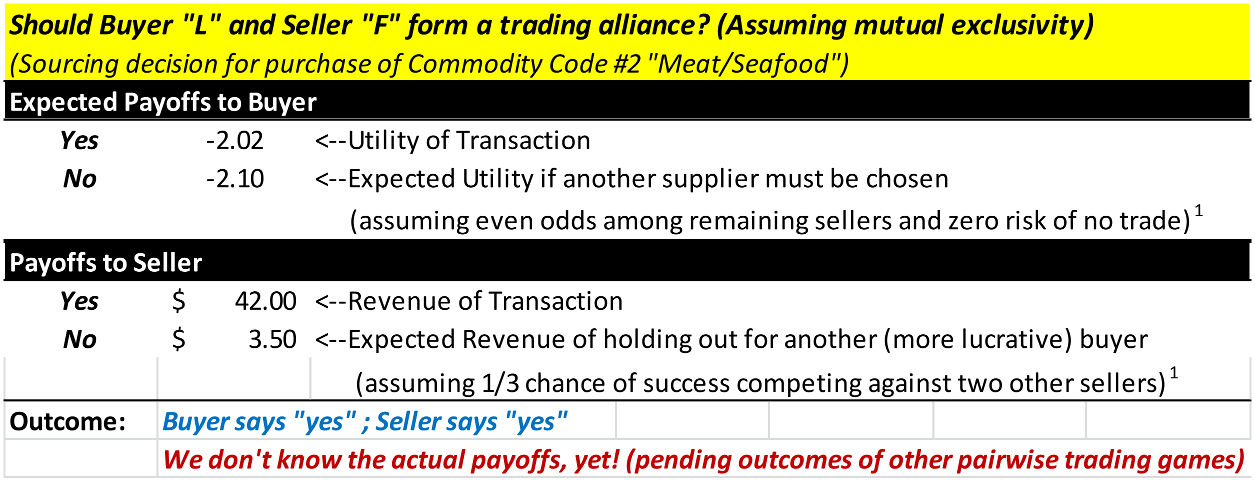


First Buyer						
	CC	GZ	Size	Cost Wght.	Time Wght.	Order Size
Buyer "L"	1	1	L	-0.2	-0.8	20
	CC	GZ	Unit Cost	Ship Time	Utility	Order Cost
Seller "F"	2	3	$ 2.10	2	-2.02	$ 42.00
Seller "D"	2	2	$ 2.00	3	-2.80	$ 40.00
Seller "L"	2	1	$ 3.00	1	-1.40	$ 60.00
Second Buyer						
	CC	GZ	Size	Cost Wght.	Time Wght.	Order Size
Buyer "S"	1	1	S	-0.4	-0.6	5
	CC	GZ	Unit Cost	Ship Time	Utility	Order Cost
Seller "F"	2	3	$ 2.10	2	-2.04	$ 10.50
Seller "D"	2	2	$ 2.00	3	-2.60	$ 10.00
Seller "L"	2	1	$ 3.00	1	-1.80	$ 15.00

Opportunity Cost Constant (Failed Trade):	-7.0

As shown below in Table 9, despite the higher unit cost, the large buyer’s preference for fast delivery makes the foreign seller’s bundle more appealing than other sellers, while the foreign seller will gladly accept business from the large buyer. A trade alliance is formed.

Table 9. Pairwise Trade L-F



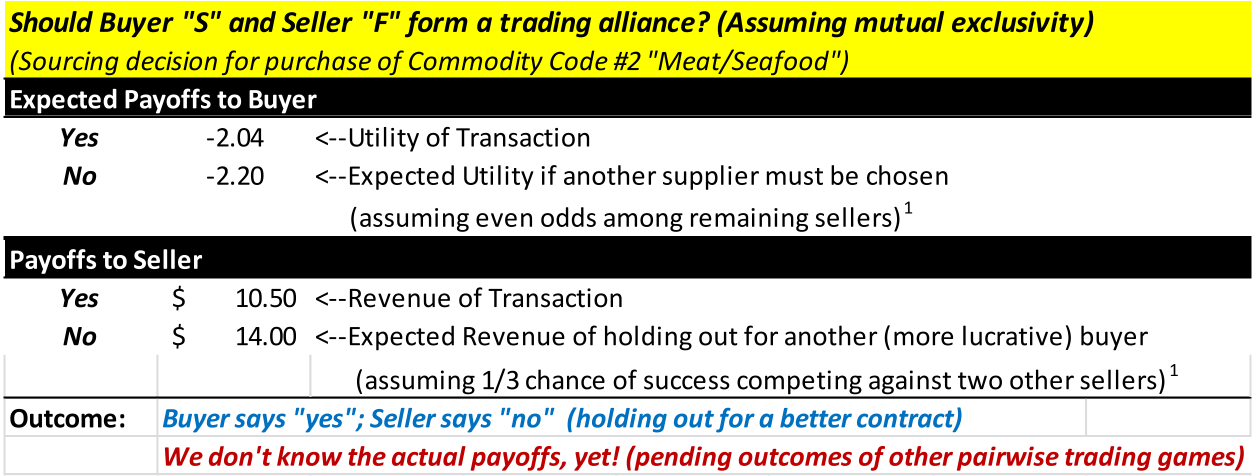
Should Buyer "L" and Seller "F" form a trading alliance? (Assuming mutual exclusivity)

(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")

Expected Payoffs to Buyer		
Yes	-2.02	<--Utility of Transaction
No	-2.10	<--Expected Utility if another supplier must be chosen (assuming even odds among remaining sellers and zero risk of no trade) ^{1}
Payoffs to Seller		
Yes	$ 42.00	<--Revenue of Transaction
No	$ 3.50	<--Expected Revenue of holding out for another (more lucrative) buyer (assuming 1/3 chance of success competing against two other sellers) ^{1}
Outcome:		*Buyer says "yes" ; Seller says "yes"*
		We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)

Table 10 below shows the results of a game between the small buyer and the foreign seller. Here the small buyer agrees to trade with the foreign seller, but the foreign seller declines, preferring to hold out for the large buyer based on better expected revenue.

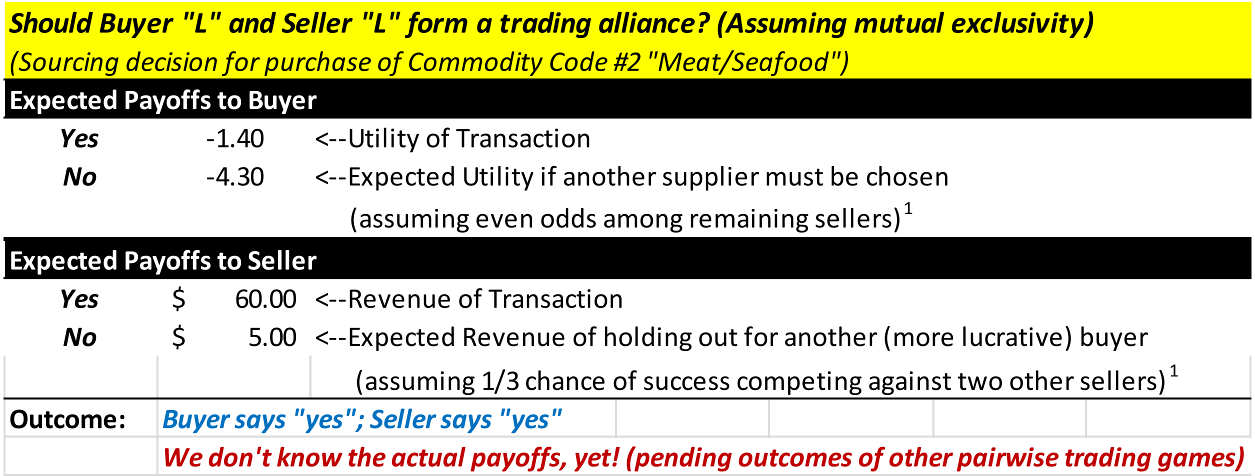
Table 10. Pairwise Trade S-F



Should Buyer "S" and Seller "F" form a trading alliance? (Assuming mutual exclusivity)		
(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")		
Expected Payoffs to Buyer		
Yes	-2.04	<--Utility of Transaction
No	-2.20	<--Expected Utility if another supplier must be chosen
		(assuming even odds among remaining sellers)[1]
Payoffs to Seller		
Yes	$ 10.50	<--Revenue of Transaction
No	$ 14.00	<--Expected Revenue of holding out for another (more lucrative) buyer
		(assuming 1/3 chance of success competing against two other sellers)[1]
Outcome:	***Buyer says "yes"; Seller says "no" (holding out for a better contract)***	
	We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)	

As shown in Table 11, the results of the pairwise trade between the local seller and the large buyer once again indicate mutual agreement to trade. Because this trade results in a higher utility to the large seller than the alliance with the foreign seller, the foreign seller will lose out on this round.

Table 11. Pairwise Trade L-L



Should Buyer "L" and Seller "L" form a trading alliance? (Assuming mutual exclusivity)		
(Sourcing decision for purchase of Commodity Code #2 "Meat/Seafood")		
Expected Payoffs to Buyer		
Yes	-1.40	<--Utility of Transaction
No	-4.30	<--Expected Utility if another supplier must be chosen
		(assuming even odds among remaining sellers)[1]
Expected Payoffs to Seller		
Yes	$ 60.00	<--Revenue of Transaction
No	$ 5.00	<--Expected Revenue of holding out for another (more lucrative) buyer
		(assuming 1/3 chance of success competing against two other sellers)[1]
Outcome:	***Buyer says "yes"; Seller says "yes"***	
	We don't know the actual payoffs, yet! (pending outcomes of other pairwise trading games)	

All of the other pairwise trades are completed. Table 12 below shows the final payoff matrix for Round 1 of Scenario B.

Table 12. Summary of Round 1 Pairwise Trades

Actual Payoffs for Round 1						
Pairwise Games:	**L-F**	**S-D**	**L-D**	**S-L**	**S-F**	**L-L**
Buyer--Yes	-5.79	-7.0	-2.80	-7.0	-7.0	-1.40
Buyer--No	-1.40	-7.0	-1.40	-7.0	-7.0	-2.80
Seller--Yes	$ -	$ 10.00	$ -	$ 15.00	$ -	$ 60.00
Seller--No	$ -	$ -	$ -	$ 60.00	$ -	$ 15.00

- Only partnership formed was between Buyer L ("large") and Seller L ("local"), who outbid Seller F (foreign).
- Buyer S (“small”) was rejected by all of the sellers, who were holding out for Seller L ("large").
- Whereas in the first scenario, the foreign seller was priced out of the market, in this scenario, the presence of the foreign seller is enough to induce both buyers to reject the notion of trading with the domestic seller because of higher expected value for waiting.
- During the next round, buyers and sellers would update their beliefs about the probability of a successful trade, which should result in a second alliance forming between Buyer S and Seller F ("foreign").
- Seller D (“domestic”) will be priced out of the market by the now competitive foreign Seller F, whose investment in air freight is starting to pay off.

8.3 Additional Assumptions to Test

Provisionally, it is assumed that there may be more than one selling agent representing a particular firm for the same commodity, where it is desirable to represent different bundles of service attributes related to mode-paths and shipment size or frequency combinations. For example, this would allow the seller to choose between a less expensive but less frequent and potentially riskier shipment alternative, and a more expensive but more frequent and reliable shipment schedule. This would allow also allow the simultaneous consideration of supplier, shipment size/frequency and mode within a single decision.

It is also assumed that seller capacities (firm output levels) will be used to limit the amount that they can be expected to supply, but that they can develop procurement contracts with one or multiple buyers. By the same token, buyers may establish procurement contracts with one or multiple sellers in order to fulfill their needs for the particular input commodity. For example, a buyer requiring 100 units of a particular input commodity could meet that need through a contract for 100 units with a single supplier, or through two contracts—one for 25 units with a small local supplier and another for 75 units with a large national supplier. As another example, a large national supplier of a particular commodity may have procurement agreements with 10 separate buying agents. Strict capacity limitations may be relaxed to some degree, however, if needed to fulfill total buyer requirements. Additional simplifications may also be needed for the sake of computational tractability, such as limiting buyers to only one seller.

In the current mesoscale model, FAF^3 flows are used to reduce the consideration set to only those pairs where there are existing commodity flows between FAF zones. It is assumed that this project will not use FAF^3 to restrict commodity flows; however, it may be necessary to impose some availability constrains to eliminate illogical pairings, or to reduce combinatorial computation time. Subject to investigation and testing, heuristic rules will be applied to eliminate illogical buyer-seller pairs from consideration, based on geography, firm size and potentially other attributes.

It may be possible to utilize the "dealer" class of agents in the original TNG Lab to represent third-party logistics firms as agents who both buy and sell commodities. Given the complexity of the buying and selling agents described above for the PMG, it is recommended that this be saved for future considerations.

8.4 PMG Simulation Test Bed

A simulation test bed will be necessary for the development and testing of alternative game theory algorithms prior to implementation of PMG in the forecasting tools. The general idea is to experiment with plausible agent typologies, behavioral assumptions and parameter spaces, evaluating the resulting solutions spaces and run-time behavior. The test bed should permit testing any number or permutation of agents and make it relatively easy for the designer-analyst to insert and modify assumptions regarding agent information, payoff matrices, and stopping criteria. For repeated games, such as described above, the test bed should have the ability to produce outputs that save the results from each round for analysis and debugging.

The TNG Lab (McFadzean et al 2001), mentioned above, made available open-source code for the "trade network game" (TNG), which is built upon a layer of simulation classes called SimBioSys that is written in C++.[1] In order to adapt the TNG source code for the PMG, several major modifications will need to be made:

- Modifying the generic buyer and seller agent classes to include attributes as described above;
- Allowing games to have asymmetric payoff matrices;
- Allowing payoff values to be calculated as parameterized functions of agent attributes;
- Expanding the dimensionality of the genetic algorithm fitness function calculations to handle multiple agent types and calculate agent-specific expected values; and
- Various input and output data modifications, including a customized user interface.

Specification and calculations related to agent types, utility preference weights, and cost functions will be done outside of the core PMG and fed as static inputs to initialize the game.

---

[1] http://www2.econ.iastate.edu/tesfatsi/tnghome.htm

The anticipated format of the inputs will be lists of buyer and seller agents, along with their attributes, as well as lookup tables for agent-pair costs.

9 Supply Chain Activity Network Concept

One of the great appeals of the supply chain activity-network approach is the ability to track both direct and indirect inputs to a production process. As the price of a fundamental input, such as fuel prices or raw materials are factored into the production of more refined commodities, one would expect these input production costs to increase as well. Price changes are a legitimate and common response to changes in production costs. In addition, allowing propagation of producer prices throughout the supply chain would enable CMAP to better assess the direct and indirect impacts of supply chain disruption.

To facilitate the study of supply chain network propagation, the project proposes to explore the “supply chain activity network” as an analytical device. An activity-network describes a set of relationships, much like a social network, but representing activity flows directed towards a central goal. Activity networks have been used in various applications to describe specialized types of social interaction networks, such as the study of disease transmission in the field of epidemiology (e.g., Klohvdahl 1985; Kretzchmar and Morris 1996; McKenzie et al., 2006). In the field of criminology, activity networks have been used to study drug- and arms trafficking (Milward and Raab 2002), border security (Marshall et al. 2004), youth gangs (Fleisher 2005), and terrorist networks (Clark 2005). The term activity network has also been used for many years to describe workflow-process relationships in the practice of management science (e.g., Dodin 1985; Buss 1995; Bowers 2000).

Nodes in the network represent agents, usually human but some nodes may be institutions or automated systems. Links in the network represent connections between agents, and the flows on the network are proportional to the strength of ties between agents. These flows can represent flows of information, flows of goods, flows of money, or flows of work performed. The order in which nodes are visited when traversing the network is usually important, e.g., the steps in a production process; however, that may not be a necessary aspect of this modeling effort.

The original mesoscale freight model simulates the freight flows between individual firms, and this extension would aim to position each firm at the center of its own supply chain network. The firm-centric supply chain network would be oriented to a production output goal for a specific commodity type. The nodes in the network would represent suppliers for each production input, and the links would represent input commodity flows, in this case expressed in dollars. The central modeling activity is the formation of the network through the simulation of tie formation between the firm at the center of the network and potential suppliers, i.e., the creation of a link between a buyer and a seller.

An example for “hospitals” is shown below in Figure 4, with the top-five (by flow value) commodity inputs shown. For each of these five input commodity types, we would select a synthetic firm as a supplier. For some commodity inputs, such as animal processing, there will likely be several local suppliers from which to choose. For others, such as surgical appliance and supplies, a more distant supplier may be required. In addition, the sourcing of pharmaceuticals will likely involve multiple suppliers. This “Level 1” of the supply chain activity network model.

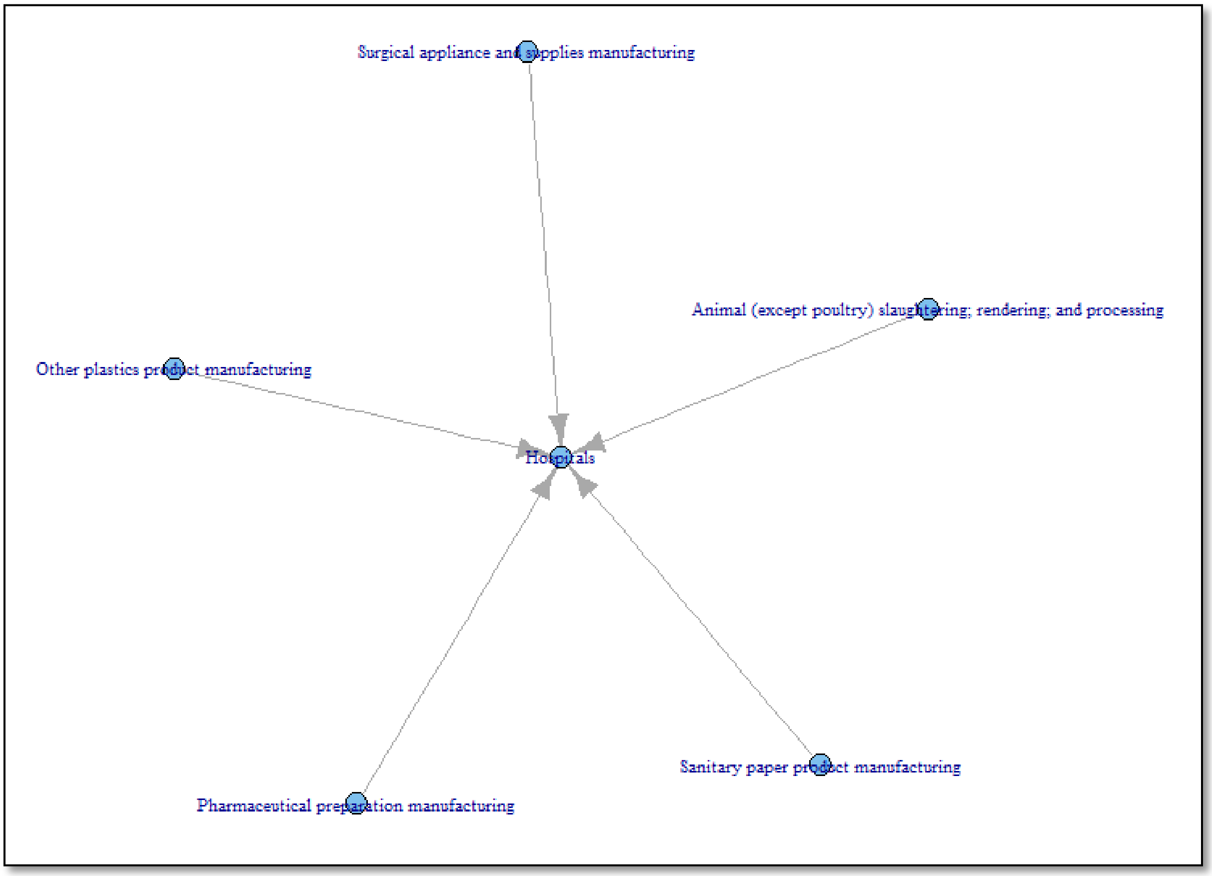


Figure 4. Hospital suppliers at Level 1

“Level Two” recognizes that the some of the same firms that supply commodities as inputs are themselves at the center of its own supply chain network with its own set of input relationships. Thus, for a given commodity type we can model the inputs to that commodity’s production as well as the inputs to the inputs. The linkages between one firm’s supply chain and another firm’s supply chain constitutes the supply chain activity network.

Figure 5, below, shows these second-order relationships for hospitals, which include links to the top-five supplier for each of the original top-five suppliers. As can be seen, for some commodities there is a recursive relationship within the same industry. This does not necessarily imply that a firm would be manufacturing its own production inputs; however, this will be true for some industries and firms.

This could be extended to several more levels by showing the inputs to the inputs at each level until we reach a raw material end point (e.g., resource extraction or farming), or a recursive relationship becomes evident.

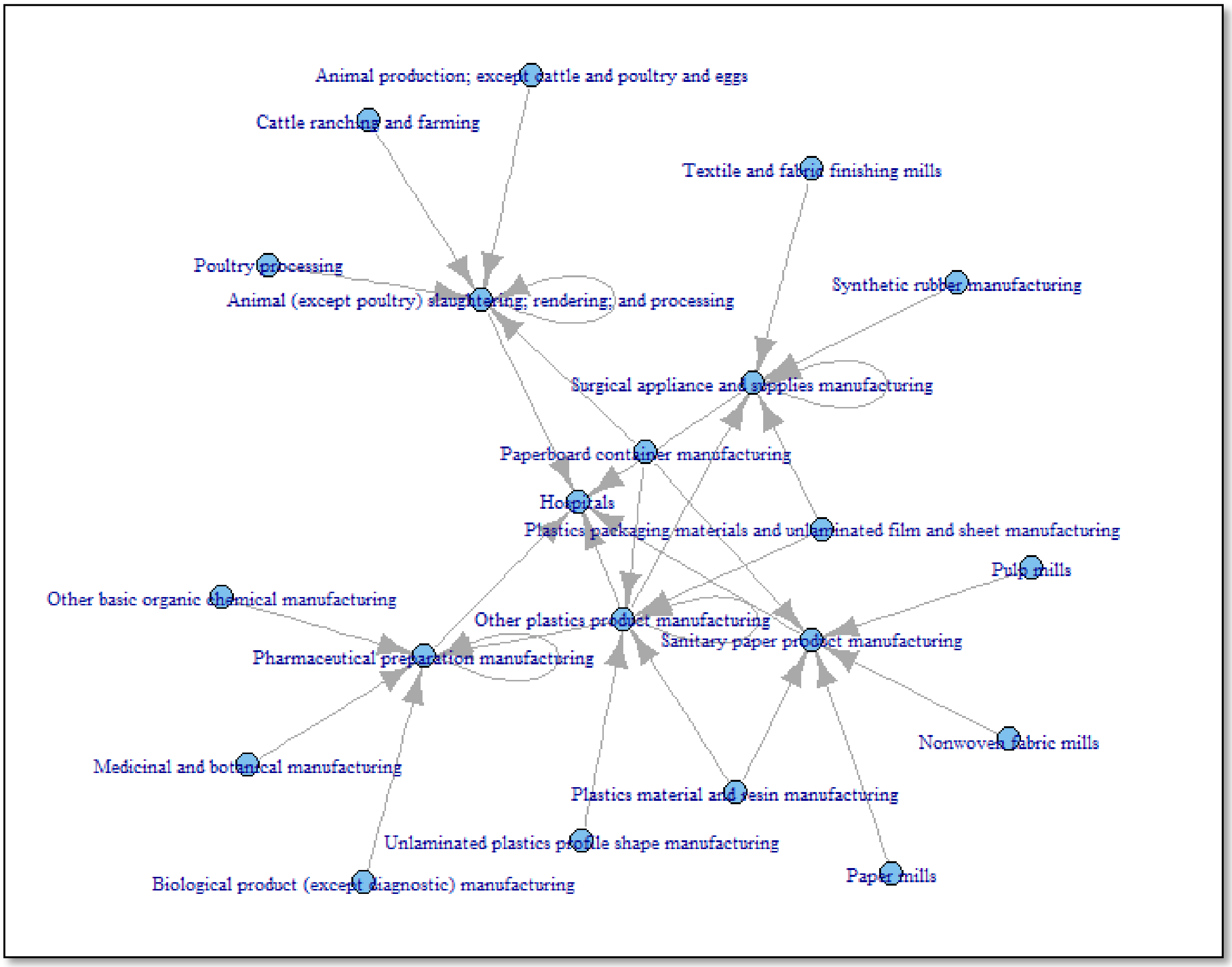


Figure 5. Hospital suppliers at Level 2

By representing the multidimensional relationships between industries, firms and agents, it is possible to derive potentially interesting network-level statistics, similar to those used in other activity network studies. Examples include:

- Measures of centrality (prestige) for particular industries/firms/agents;
- Clustering, cohesion among groups of nodes (interdependency);
- Weak links and gaps in the network;

Potential applications using activity network analysis include identifying policies and infrastructure investments that exploit the centrality of certain actors in the network, that focus specific sub-groups of industries, or that identify places where the regional supply chain activity network could benefit most by strategic investments.

10 Response Sensitivity and Forecasting

The extent to which the proposed model design is realized will in large part determine the level of sensitivity and range of scenarios that can be analyzed. As with most models of dynamic complex systems, the fundamental tradeoff is one of desired realism versus complexity. Often this complexity is difficult to model because of lack of data or understanding of the true behavioral mechanisms. Moreover, it may be unclear whether the improvement in model resolution will be enough to warrant the additional effort to produce it.

For the proposed agent-based economic extension, there are fairly clear tradeoffs in the types of analyses that may be feasibly undertaken with the tool under alternative model development scenarios. Given a stimulus for change, say a change in commodity costs, there are multiple levels of response that a firm might take and different ways in which the market as a whole may be expected to react. For forecasting to more distant future years, it will be necessary to take into account trends in industrial productivity and consumer demand that affect both commodity inputs and outputs, and to make assertions where necessary.

10.1 First-Order Response: Direct Commodity Impacts

As defined here, a first-order, or direct response to a change in commodity cost might be to choose a different supplier for that commodity. If the change is regional, say a less expensive shipment mode or better level of service, then one possible response by a firm would be to choose a supplier-mode combination that provides this improved utility. Similarly, if commodities sourced in a foreign country become more expensive due to rising wages or political unrest, a Chicago-area firm may abandon its foreign supplier and choose a domestic source.

This response to modifying a supply chain by selecting a new supplier-mode source is fundamental to the proposed design and is an outcome of the new supplier selection model. This level of response is good for answering question of regional competitiveness, such as infrastructure capacity changes or a change in trade tariffs with a particular country. It may not provide good answers when the question is one of a global change in the price of a commodity, such as fuel prices, that might affect all suppliers and lead to global price increases. Nor would it help if the input commodity in question is of such special nature (asset specificity) that switching suppliers due to a change in cost would not be the purchasing firm's preferred option.

<u>*Recommendations*</u>: This is a fundamental element of the model design and is captured in the basic design of the procurement market game.

10.2 Second-Order Response: Cross Commodity Impacts

A second-order, or cross-sourcing response to a change in commodity cost might be to choose a different supplier for a different commodity. For example, if a manufacturer of specialty food products is affected by a change in the prices that farmers are charging due to a bad growing season, there may not be time or better sourcing alternatives for the primary input commodity. Instead, the firm may attempt to reduce costs elsewhere in their supply chain by choosing different supplier-mode combinations for less critical inputs, such as product packaging.

The type of response in which a firm modifies their supply chain by selecting a different supplier-mode combination for one or more input commodities other than the one that was directly affected by the cost change is a bit trickier because it requires a modeled “awareness” of total production costs for a firm and, realistically, may be more of a firm-wide response than one made by a purchasing agent. Although budget-based planning is central to business decision-making, this would require additional algorithmic steps to tabulate the total cost implied by each supplier selection decision. Moreover, by necessity there would need to be a prioritized approach to supplier selection whereby the most important input commodities are sourced first, after which the preference weights of purchasing agents for low-cost versus other attributes would be adjusted. This would require building the supply chain separately for each producer firm, rather than having multiple producers and supplier competing in the sourcing market. Alternatively, the simulation could loop through multiple rounds of sourcing in which purchasing agents’ preference weights are updated based on the total costs incurred in previous rounds.

This indirect response to a change in the cost of one commodity by switching supplier-model combinations for a different production input is useful for addressing issues related to asset specificity and various forms of uncertainty, as well as for firms that are highly vertically integrated where a key input cannot be outsourced. It may not, however, provide a complete response, particularly when costs and producer price changes are unavoidable.

Recommendations: Due to the complexity of needing to account for firm-wide production budgets across multiple input commodities and to adjust preference weights dynamically, it is recommended that the initial model design and structure not incorporate cross-commodity effects. Rather, it is recommended that this be considered as a future model enhancement, subject to further study once the initial model design has been implemented and thoroughly tested.

10.3 Third-Order Response: Propagation through Supply Chain Network

One of the great appeals of the supply chain activity-network approach is the ability to track both direct and indirect inputs to a production process. As the price of a fundamental input, such as fuel prices or raw materials are factored into the production of more refined commodities, one would expect these input production costs to increase as well. As discussed above, price changes are a legitimate and common response to changes in production costs. In addition, allowing propagation of producer prices throughout the supply chain would enable CMAP to better assess the direct and indirect impacts of supply chain disruption.

To implement this dynamic sensitivity in the model system it would be necessary to allow the supplier selection outcomes for an intermediate producer to influence the cost of that producer’s commodity and its bid to potential consumers of that commodity. For example, the cost of the iron ore purchased by a steel maker, as determined through the supplier selection model, would affect the steel maker's total production cost for steel. That total production cost would then be reflected in the price bid by the steel maker to a machinery manufacturer who is attempting to select a supplier from among competing steel makers. This would imply that the supplier selection step should follow a prescribed order of commodities, starting from raw materials, and progressing to increasingly refined commodities. This may result in ambiguous ordering for some combinations of commodities, although there may be heuristic methods of dealing with such ambiguities. As with the cross-commodity response, this would require additional algorithmic steps to tabulate the total cost implied by each supplier selection decision in order to update producer prices.

The alternative is to disallow price updating using the results of supplier selection and thereby limit the supply chain network model to only a static, single-level representation of commodity prices without propagation.

Recommendations: Due to the inherent appeal of allowing sourcing decisions and the propagation of prices and sourcing decisions throughout the supply chain activity network, it is recommended that the initial model design and structure include this network propagation feature. This would require a data structure, mimicking the BEA Use tables, that updates the cost of each input commodity as the source is selected and updates the producer price of the output commodity accordingly. The assumption would be that the Direct Requirements table will remain unchanged and that the target level of output produced will remain unchanged from the initialization step. As described above, a simple ordering scheme would be developed whereby raw material sourcing markets would be simulated first, followed by slightly higher-level commodities that serve as intermediate inputs, progressing to the most refined commodities that serve as final demands. A heuristic approach to settling "tie breakers" will be developed as needed, based on a consideration of prevailing I-O directionality found in the Make and Use tables.

For purpose of phasing model features and testing, it is recommended that network propagation be implemented and test after the initial implementation of the procurement market game. With the network propagation feature "switched off," producer prices would remain at their initialization values. Once the procurement market game without network propagation has been thoroughly tested, network propagation could be enabled and tested. As it would only provide inputs to the procurement market game, network propagation would not affect the performance of the game itself, but would affect the outcomes, potentially resulting in very different spatial patterns for commodity flows.

10.4 Capturing Global Trends in Forecasts

Although much of the work that CMAP undertakes will involve studying the potential impacts of infrastructure investments on the spatial distribution of freight flows passing through the region, there is also the desire to consider "what if" scenarios on a global scale. The above three sub-sections each described scenarios in which some price change resulted in a change in the cost-competitiveness of a particular supplier agent or a particular region, where the market response is to select suppliers based on the new information. These may be described as local or regional impacts. When prices changes are more global in nature, however, such as a world-wide change in energy prices or the proliferation of new microchip manufacturing technology, it is appropriate to consider changes in the basic factors of production.

The prototype mesoscale model utilized 2002 Benchmark I-O tables, which were the most recent year available that provided 6-digit NAICS level of resolution. The 2007 Benchmark tables are expected to be released in late 2013; however, Annual I-O accounts at the 3-digit levels are available for each year up to 2011. A summary glance at the changes in inputs and outputs between 2002 and 2011 reveals some interesting trends.

Table 13, below, compares the changes for “Computer and Electronic Products” (NAICS code 334), showing significant changes between 2002 and 2011 in this industry’s value of inputs. The total input used to produce an output in the computer and electronic product industry decreased by about $100 million from 2002 to 2011, while gross operating surplus increased enormously and the total industry output remained relatively unchanged. In other words, this industry became much more productive using less input value to produce the same level of total output, with significant profits being made. In addition, the structure of top ten input commodities did not change significantly, with the same top ten commodities accounting for more than 90 percent of the total input values. From a freight perspective, this means that U.S. producers in this industry were shipping about the same amount of product in 2011 as in 2002, but were receiving about half the 2002 level of inputs. Thus as the U.S. Computer and Electronics Products industry was becoming more efficient and profitable, it was not growing, perhaps due to competition from foreign manufacturers.

Table 13. Changes in “Computer and Electronic Products” Industry Top Inputs

Rank	Commodity	2002 (M$)	2011 (M$)	Change (M$)	% Change	% of total inputs	% of total inputs
1	Computer and electronic products	78,107	39,881	-38,226	-49%	49%	48%
2	Wholesale trade	25,737	13,846	-11,891	-46%	16%	17%
3	Fabricated metal products	9,783	5,020	-4,763	-49%	6%	6%
4	Publishing industries (includes software)	9,219	5,509	-3,710	-40%	6%	7%
5	Chemical products	6,681	3,720	-2,961	-44%	4%	4%
6	Primary metals	5,836	5,587	-249	-4%	4%	7%
7	Plastics and rubber products	5,442	1,590	-3,852	-71%	3%	2%
8	Electrical eq., appl., & components	4,357	2,832	-1,525	-35%	3%	3%
9	Utilities	2,928	1,012	-1,916	-65%	2%	1%
10	Truck transportation	1,864	1,045	-819	-44%	1%	1%
Sum of Top 10		**140,954**	**80,042**			**94%**	**96%**
Total Intermediate Inputs		218,835	121,089	-97,746	-45%		
Compensation of employees		112,861	121,311	8,450	7%		
Taxes on prod. and imports, less subsidies		4,695	5,496	801	17%		
Gross operating surplus		5,972	86,731	80,759	1352%		
Total value added		123,528	213,538	90,010	73%		
Total industry output		342,364	334,628	-7,736	-2%		

Note 1: Commodity names are shortened to fit the tables

Note 2: Percent of total inputs is based on freight generating industries (before 511 NAICS code: in the current model)

Note 3: Chain dollar levels are referenced to 2005

Source; BEA I-O “Use”Tables, 2002, 2011 (after redefinition, producers’ price, 2002 top inputs)

A somewhat different story emerges when comparing the value of inputs in 2002 and 2011 for the “Food and Beverage and Tobacco Products” (NAICS code 311FT) industry. As shown below in Table 14, the total inputs used to produce an output in this industry grew by 68 percent, increasing from 2002 to 2011, while total industry output increased by 53 percent. Gross operating surplus increases were fairly small, and the structure of top ten input commodities did not changed significantly, having almost the same commodities accounting for more than 90% of the total input values. In other words, this industry produced more by using more input value, making it somewhat less efficient. From a freight perspective, this means that U.S. Food, Beverage and Tobacco producers where shipping more products, and receiving even more shipments based on dollar value. For reference, during this same time period (2002-2011) the U.S. population grew by 8.3 percent. Although additional consideration of exports from this industry should also be considered, it would seem that levels of per capita consumption of Food, Beverage and Tobacco products in the U.S. increased during this period.

This quick analysis underscores the need to consider changes in both productivity as well as output levels that result from changes in production technologies as well as global competition and demand levels.

Table 14. Changes in “Food and Beverage and Tobacco Products” Industry Top Inputs

Rank	Commodity	2002 (M$)	2011 (M$)	Change (M$)	% Change	% of total inputs	% of total inputs
1	Farms	113,575	227,393	113,818	100%	34%	39%
2	Fabricated metal products	97,240	159,125	61,885	64%	29%	27%
3	Wholesale trade	27,834	55,044	27,210	98%	8%	9%
4	Electrical eq., appl., & components	20,742	23,858	3,116	15%	6%	4%
5	Truck transportation	12,527	19,361	6,834	55%	4%	3%
6	Miscellaneous manufacturing	12,350	18,052	5,702	46%	4%	3%
7	Utilities	10,868	13,808	2,940	27%	3%	2%
8	Wood products	9,702	12,807	3,105	32%	3%	2%
9	Furniture and related products	4,749	8,282	3,533	74%	1%	1%
10	Textile mills and textile product mills	4,273	4,957	684	16%	1%	1%
	Sum of Top 10	**313,860**	**542,687**			**93%**	**91%**
Total Intermediate Inputs		393,262	659,631	266,369	68%		
Compensation of employees		76,495	90,107	13,612	18%		
Taxes on prod. and imports, less subsidies		19,291	33,674	14,383	75%		
Gross operating surplus		80,329	89,281	8,952	11%		
Total value added		176,115	213,062	36,947	21%		
Total industry output		569,377	872,693	303,316	53%		

Note 1: Commodity names are shortened to fit the tables

Note 2: Percent of total inputs is based on freight generating industries (before 511 NAICS code: in the current model)

Note 3: Chain dollar levels are referenced to 2005

Source; BEA I-O “Use”Tables, 2002, 2011 (after redefinition, producers’ price, 2002 top inputs)

10.4.1 Multi-Factor Productivity Changes

The Multi-Factor Productivity (MFP) is measured annually by the U.S. Bureau of Labor Statistics (BLS). The MFP Index attempts to measure changes in the productivity of U.S. manufacturing output relative to inputs and is intended to capture productivity improvements due to changes in technology and management practices. Inputs are broken down by three broad categories: capital, labor, and intermediate purchases. The MFP Index considers the simultaneous contribution of all three inputs to industry output. BLS publishes tables with annual productivity indexes for all 4-digit NAICS manufacturing industries. Currently, tables are available for years 1987-2010.

Figure 6, below, shows the multifactor productivity index (2002 base year) for the Computer and Peripheral Equipment industry (NAICS 3341) over this 13-year span. This is one of the most dynamic industries to look at because it shows tremendous growth in productivity. In contrast, Figure 7, below, shows the productivity changes in the Seafood industry, a relatively flat overall trajectory where labor and capital productivity seem to have switched places in their importance, which may be indicative of changes in the worldwide shortage of live-caught seafood and the compensating emergence of aquaculture.

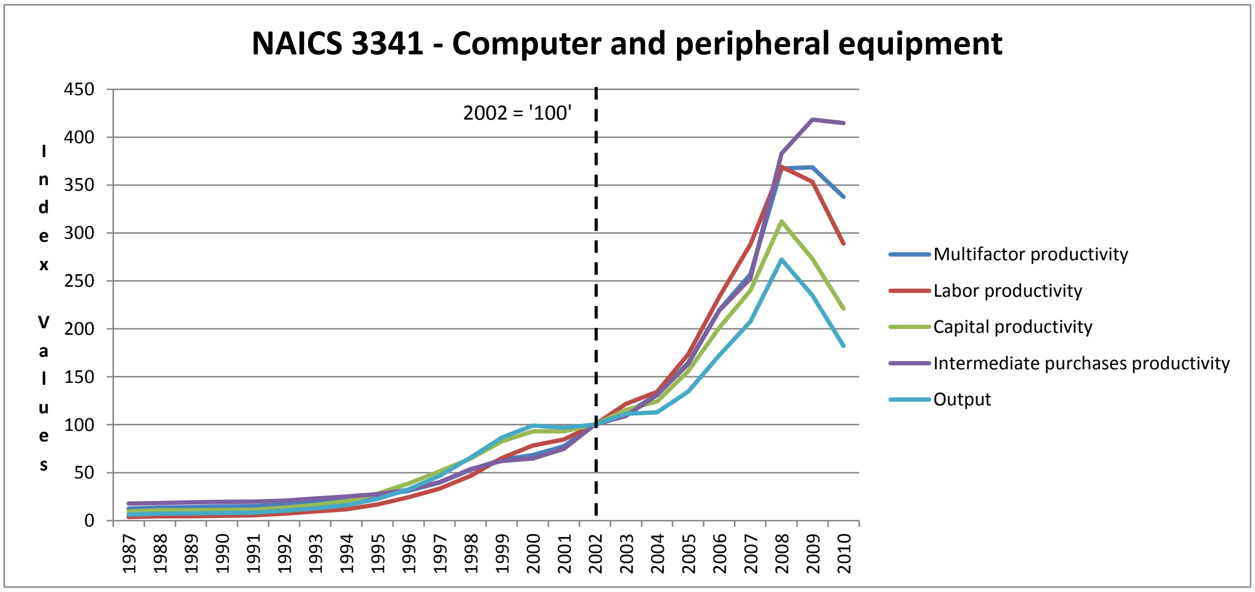


Figure 6 Multifactor productivity index and constituent factors for computer and peripheral equipment manufacturers,1987-2010.

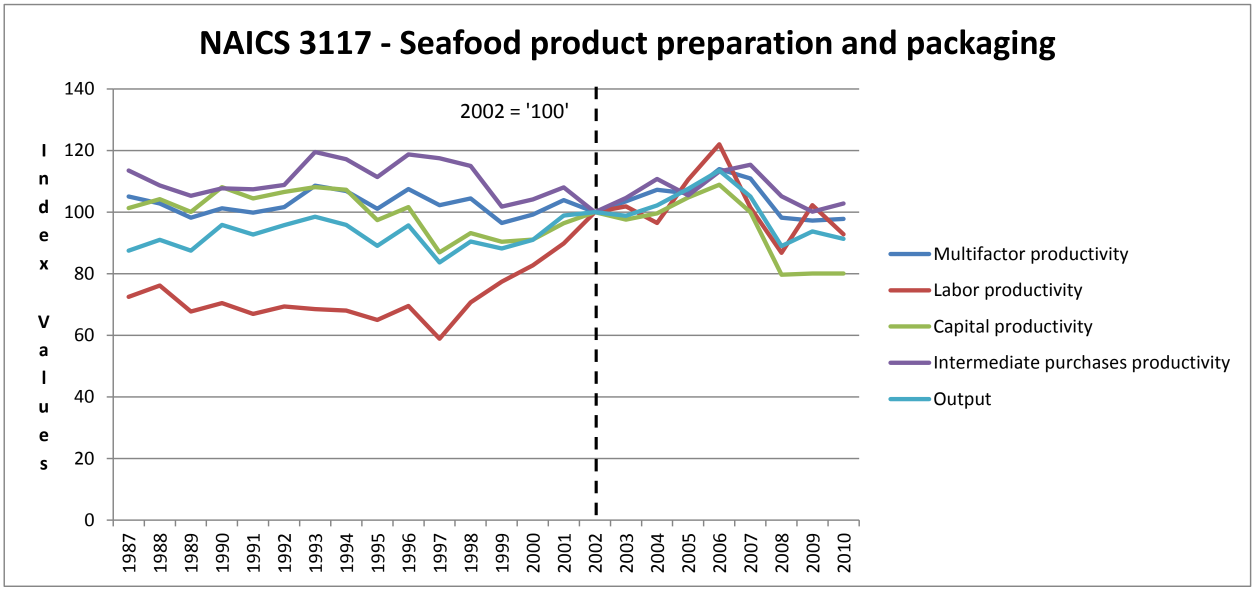


Figure 7. Multifactor productivity index and constituent factors for seafood product preparation and packaging,1987-2010.

The potential value of the MFP tables to the mesoscale model extension is provide an historical basis for assumptions in changes to the technical coefficients found in the BEA I-O tables. One change would be the total output per unit input, which would affect the quantities of commodities purchases as inputs to production for future-year forecasts. All else being equal, application of MFP trends by industry should provide a fairly straightforward, data-driven basis for projecting trends.

MFP should probably not be used to assess changes in the mix of inputs, which it does not provide, although BEA Annual Accounts could provide these data at the 2- and 3-digit NAICS level. Since MFP focuses on U.S. industries, it provides no information on productivity of industries based in other countries.

10.4.2 Other Future-year Assumptions

The technical coefficients of the Make and Use tables, or the Direct Requirements version thereof, reflect U.S. producer prices for the year that these tables represent. Foreign supplier prices are converted to their U.S. port-of-entry equivalents. As mentioned in the project objectives, however, it may be desirable to make changes to assumption that differ from the current trends. If the commodity in question were more global, such as oil prices, should the change in technical coefficients reflect the fact that the input costs of petroleum products has become a larger part of total production costs? If so, should these changes be passed on to the total cost of production but assume that the demand for the final products remains at the same level, which would be attributed to inflation, or should there be a drop in demand for these products?

These are big questions that reach well beyond the scope of this model, yet they may be central to some of the policies that CMAP would like to consider. To incorporate such considerations, it is certainly easy to assert changes to either the technical coefficients in the Direct Requirements table or to the predicted commodity output levels. In that way, the assumptions are clear and there is no implication that the model itself is predicting such macro-level changes.

Recommendations: The need to predict future freight flows as a function of global changes in commodity costs, technologies of production, and market demand is an essential attribute of the future freight forecasting tool. As a baseline assumption, it is recommended that trends in input-output productivity be derived from the Multifactor productivity index tables when making projections for more distant future years. Additionally, it is recommended that other assumptions regarding future conditions be asserted as conditional statements in the future forecast input parameters. These asserted statements would include assumptions regarding deviations from the technical coefficients that describe the mix of input commodities used to produce a particular output commodity, as well as any assumptions regarding the total demand for a particular commodity.