An Agent-based Computational Economic (ACE) extension to CMAP's Mesoscale Freight Model

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Background

In 2011, CMAP sponsored development of a mesoscale regional freight model to demonstrate how the Chicago region's goods movement system operates within the global logistics and supply chain network. CMAP's mesoscale freight model uses, as one of its primary inputs, data from the U.S. Census Commodity Flow Survey[2] organized by FHWA into the Freight Analysis Framework (FAF). In order to use the CMAP mesoscale model for regional planning, a method for establishing a "future FAF" is needed. Ideally this method would be somewhat prescriptive by permitting the user to specify macro-scale scenarios that affect freight-related decisions exogenous to the CMAP region. These decisions might be economic, social, political, environmental or a combination of all.

The typical method for generating a future economic scenario uses an **input/output framework** that is mathematically formulated, estimated and calibrated to predict aggregate quantities of production and consumption under equilibrium conditions. Using this approach, the current FAF would be factored up or down based on new predictions for the volume and value of various commodities[3] with flows then rebalanced using an iterative proportional fitting technique. An adventurous modeler in this aggregate paradigm might speculate about changing cost variables such as international tariffs, fuel availability or expanded infrastructure, but this type of experimentation is not typical and the method is not at all suitable for introducing new markets, political upheavals, technological innovation or unforeseen natural resource constraints. The historical appeal of this deterministic input/output framework is that it is mathematically simple and driven by existing data. It is also less likely to produce

confounding or unfamiliar outcomes; permitting analysts a higher degree of confidence when defending their results. But in truth, it has little capacity to actually explain how discrete transactions in the economy come about, how individuals react to evolutionary phenomena or the degree to which deliberate policy interventions might affect individual outcomes.

An intuitively appealing alternative, especially from the standpoint of understanding the effects of prescriptive policy interventions, is to employ an **agent-based framework** whereby the specific actions and reactions of individuals and elements can be prescribed and monitored. In the case of freight, a sample of representative responses from the Commodity Flow Survey (CFS) might be used to establish "pseudo-scripts[4]" for a typology of synthesized agents at work within a supply chain. The synthesized agents would use their assigned pseudo-script to "conduct business" within a "policy landscape" defined by various combinations of social, political and infrastructural arrangements. Outcomes, while not necessarily equilibrated, would leave a rich trail of cause-and-effect explanations of the outcome.

Analysis framework

To properly depict the outcome of planned policy interventions in an agent-based framework, we need to track the effects of real-world market phenomena such as asymmetric information, unbalanced competition, strategic alliances and social learning. The genesis for this notion (at least in this context) comes from a paper called "Agent-Based Computational Economics: A Constructive Approach to Economic Theory"[5]. This resource is an intuitive and easily understood primer for non-economic modelers to build an argument for extending traditional parametric forecasting frameworks beyond the artifice of enforced equilibrium outcomes.

Effective policy (i.e. law, regulation, or contract) instructs individuals how to behave in order to achieve a desired collective outcome. When using aggregate equilibrium models, however, the most elusive individual is the "coordinator[6]" charged with "clearing the market". This individual, it turns out, is essentially the fictional "the invisible hand" that possesses perfect information, imposes monotonic valuation and enforces the symmetrical trading assumed to prevail in free and open markets.

If we remove this fiction from our modeling construct, we must substitute a (much more painfully elaborate) means for tracking sequential production, pricing and trade decisions. The mechanism to accomplish this can be called "procurement[7]". As in any business enterprise, procurement consists of the rules and recordkeeping that govern bidding, buying, selling and delivering products. Once we've defined a procurement rule typology for use by the set of agents, the model can be designed to predict outcomes when different agents operating under diverse procurement rules come in contact with each other.

Procurement rules are carried by agents in "baggage[8]" formed from their habitual and cultural experiences while navigating a "constitutional maze[9]." The success of a complex logistic and supply-chain interaction is dependent to a significant degree on agent competence and robust communication. The "language of business" includes personal, as well as legal, technical and financial constructs[10] that serve as a shorthand for successfully arranging and completing a sequence of transactions.

While undertaking procurement, each agent brings his own baggage into the maze with each new transaction and exits having completed the procurement[11]. There are at least two main types of baggage to consider: habitual and cultural.

- **Habitual baggage** is manifest only when two agents discover mutually satisfying idiosyncrasies. The factors contributing to each agent's idiosyncrasies are deep-seated combinations of biological, emotional and experiential components that compose the unique person. A habitual harmony seen between two agents can rarely be any more understood in rational terms than those observed in an old married couple; they just "are" and, we must admit, are nearly indissoluble. In freight business transactions this inertia might be seen in the automatic renewal of longstanding contractual agreements between small firms, even when more cost-efficient alternatives could be found. While difficult to understand or explain, habitual baggage can be easily discovered by careful interpretation of longitudinal data or correctly inquiring of survey respondents.

- **Cultural baggage**, on the other hand, is built from the normative traditions respected by multiple agents intent on protecting their larger procurement chain. Culture, in this case, covers not only traditions associated with language, nationality and ethnicity, but also their industry cluster's[12] context in the evolution of the global market. The factors governing cultural rules are both additive and reductive. Several cultures may be present in a single procurement with the prevailing norm being the sum of several cultural norms involved. Respecting the totality of multiple norms fast becomes unwieldy, so each culture often offers a simplified or reduced share of norms that all agents can understand and adhere to. In short, agents in the procurement chain "learn their manners" with the result very likely being a significantly reduced number of possible outcomes[13].

Defining the agents

All agents behave as individuals, even if they represent a collective entity such as a firm or government corporation. Agents can be expected to navigate the procurement process according to a set of (essentially moral) precepts driven not only by traditional economic notions of self-interest and utility maximization, but also a certain predisposition toward altruism, cooperation and teamwork[14] that must accompany a complicated logistics-laden procurement chain. Economic climate, constraint on natural resources, technological innovation and infrastructure capacity are all exogenous scenario assumptions that will sway agent behavior, but are not, in themselves explicit to the outcome.

The precepts that guide each agent's choice are rooted both in the procurement baggage they carry and their experience with navigating the constitutional maze they find themselves in. But, as imperfect individuals, they may also waver in the moment a decision is to be made. Even if their choice is based on sound information and reason, it is essentially still an emotional reaction that causes a person to behave with selfishness or altruism, greed or generosity, independence or collaboration. Each choice is based almost entirely on information that is

current and immediately available[15] influenced by an overall gradient[16] that will establishes the velocity and general direction a sequence of independent choices will take.

Mapping the game

Two agent types were established in the mesoscale model as suggested by the organization of the FAF: Shippers and Receivers. It is important to consider that while a single firm in a particular supply chain might sequentially function as both a shipper and a receiver, the firms internal agent's handling of multiple transactions rarely requires them to have an exhaustive knowledge of each other's decisions. In fact, this becomes increasingly unlikely as firm size grows and certainly can't extend much outside the firm into previous and subsequent links in the supply chain[17] Rather, like in many organizations, procurement rules govern the range of acceptable actions and the agent merely monitors indicators related to his own organization's health, reacting based on whatever baggage he is currently carrying through today's maze. Particularly for significant macro-scale agents (e.g. nations, mercantile corporations, international shippers), an empirical supposition is that they pay closer attention to benchmark indices of corporate survival than auditing the utility-maximizing rationality of each transaction in minute detail.

A highly simplified example of two behavioral ingredients of a transaction between a shipper and receiver within the landscape of individual choices and procurement rules will help illustrate the architecture for an agent-based choice set array. In two opposing corners are the agents: S(hipper) and R(eceiver). Completing a rectangular space are two behavioral poles that can be imagined to "magnetically" influence the path of the procurement between S and R. The poles represent the attribute extremes possessed by each agent: Selfish and Altruistic. Selfish behavior represents the typical economic presumption of blind utility maximization. Altruistic behavior represents a disposition to act for the benefit of others, even if personal utility is not maximized. Altruism might be expected to be prevalent in the more rarified realms of large-scale freight logistics because of a cultural recognition that upstream or downstream disruptions will cause damage throughout the chain. Note that selfishness and altruism do

not imply a willingness to compete or cooperate with other agents, only an awareness that mutual effects can come from independent actions. Predicting an outcome requires that we specify environmental variables that define the scenario. These environmental variables control each agent's vulnerability to various degrees of economic or political conditions that affect his survival.

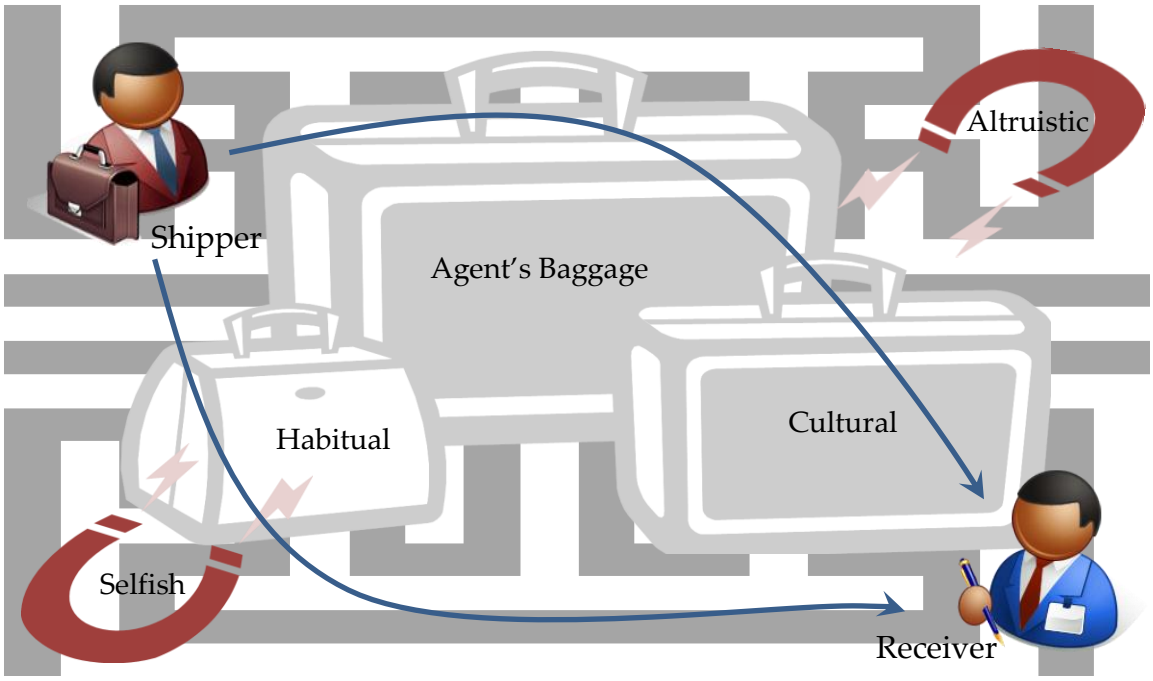

Figure 1: Agents navigating a procurement constitutional maze with their baggage.

Altruistic agents, with their habitual baggage, might choose to honor a long contractual history with known firms indicating a belief that they will survive a wider variety of exogenous threats. Cultural baggage may favor shared language, historical or political alliances. Constitutional maze paths may be prescribed by international compacts or extant corporate agreements[18].

Selfish agents, with their habitual baggage, might choose a large pool of alternative customers when there is little reason for loyalty or constancy. Cultural baggage might favor a product line or commodity that's value is universally understood and assessed (e.g. salt). Constitutional maze paths might include anti-trust laws, legal rulings or true open markets that employ effective price clearing information mechanisms[19].

The mesoscale model currently synthesizes agents from aggregate County Business Pattern data. This is simply a disaggregation of the total number of firms in each FAF zone into a single record for each firm according to industry type and size category (number of employees). The result is a long list of nearly 8.5 million synthetic agents about which we know three things: their location, their size and their industry type[20]. Each of these agents, acting as a buyer, asks the mesoscale model to identify a set of possible suppliers. The mesoscale model responds with information from Make and Use (a.k.a. input-output) tables that identifies the industries from which to draw the possible set of suppliers. The rest of the mesoscale model is devoted to matching shipper receiver pairs to match commodity flows observed in the FAF.

We now need to assign additional information about the habitual, cultural and constitutional influences on agent-based choices[21] and assign the correct mix of baggage to each agent. The currently known firm attributes (industry, size, location) need to be augmented with additional cultural information, perhaps synthesizing each firm's tenure, earnings, political contributions and corporate affiliations[22]. Next, each firm record need to be transformed into discrete records that follow their representative agents[23]. With this enriched profile of agents at the firm level, we could then extend our conjecture to the agents' idiosyncrasies. Census and workforce databases could be synthesized to assign gender, ethnicity, education, age and occupation[24]. Our goal is to establish a plausible profile of personal attributes for each agent that could be matched to an appropriate pseudo-script (i.e. assign them their baggage).

The current FAF database reports freight demand by commodity type, weight, value and mode of transport in origin-destination matrix form[25]. The mesoscale model, as outlined earlier, predicts shipper-receiver arrangements and also introduces logistics and touring logic for transactions[26]. This provides us with a very sketchy baseline maze upon which to frame a constitution governing procurement through the supply chain. Elaborating the procurement maze will certainly require a carefully designed enterprise-based survey; but rather than enquiring about volumes and value of shipments, the survey would enquire into the procurement rules followed by the firm's agents. Proprietary goods movement databases[27] also can be effectively mined to establish business regularities such correlating behavior at logistics

nodes with commodity weight, value, supply chain position and perishability. States and a sampling of local codes can be inventoried to establish the set of known policy constraints (i.e. the laws, regulations and taxes governing freight movement).

The constitution itself is simply an enumeration of "the articles of business" at the very highest level[28]. Constructing the future constitutional maze is a purely conjectural exercise that could be accomplished in a typical scenario-planning exercise.

A manageable direction

CMAP has been disappointed with the lack of explanatory power inherent in standard input-output economic applications[29]. As generic forecasting tools, these models have little sensitivity to evolutionary or policy driven change. When suggesting an agent-based macro model as an alternative in the past, we have been warned that constructing such a model at the global scale, much less estimating and calibrating it, is well beyond the capacity of any conceivable data or computing resources to implement. But do we really need a "regional model writ large"? CMAP's current mesoscale model already uses the input-output framework to synthesize the universe of commodity flows found in the FAF. What we want is a mechanism that will permit evolution of the FAF data in response to a set of understandable and intuitive cues from outside the data itself. While CMAP's professional background and that of our consulting support is typically drawn from the disciplines of urban planning, civil engineering, engineering, economics and geography. The architecture of many agent-based modeling concepts is more prevalent in anthropology, psychology, finance and telecommunications[30].

Our goal at the symposium is to identify some manageable first steps to implement an agent-based computational economic model of supply-chain and logistics business decisions as they relate to Chicago's position in the global goods movement economy.

Overall framework

- Is the agent-based computational economic approach an appropriate means for generating future macroscale policy and planning scenarios for input to the Chicago region mesoscale freight model?

Defining the agents

- How should we assign agent roles? Perhaps using a typology defining typical business roles assumed by individual decision makers[31]?

Mapping the game

- How can individual agents be assigned an initial set of baggage? This might be synthesized from larger control datasets that ascribe relative levels of asset wealth and earnings, industry maturity, political and union affiliation, corporate dominance, risk aversion. In addition each agent is an individual human who needs to be ascribed personal characteristics such as age, gender, ethnicity and educational attainment.

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[1] Disclaimer: This paper was written based the author's informal accumulation of observations over the course of planning and implementing advanced modeling practice at CMAP. The content was not exhaustively researched, vetted among peers or even meticulously edited. Its only purpose is to guide panel discussion at a one-day Symposium.

[2] Method: A sample of 100,000 establishments is selected based on geographic location and industry. Each establishment selected into the CFS sample is mailed a questionnaire for each of its four reporting weeks. Each sampled establishment is asked to report on a sample of individual shipments during a one week period in each calendar quarter.

[3] This is essentially the method used by FHWA in preparing a 2040 FAF database. http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports8/s2_forecastmeth.htm

[4] The term is borrowed from archaeology. "Marking systems such as masons' marks, property marks, pot marks, quarry marks and team marks .... The practical purposes of marks include claims to property and responsibilities, both individual and collective."

[5] Tesfatsion, Leigh, Economics Department, Iowa State University, Ames, IA, 18 December 2005.

[6] Referred to as the "Walrasian Auctioneer" who overcomes the need to place a value on the cost, time and network lags associated with the sharing and dissemination of information. Including this personage

eliminates the need to monitor, understand or explain discrete interactions between individuals. It encapsulates one of deepest conceptual problems in representing perfect competition.

[7] Procurement is the term adopted by Tesfatsion, ibid.

[8] This is (perhaps not the best) metaphor for the social learning agents bring to and take from their interactions with other agents.

[9] The **c**onstitutional maze represents the sequence of explicit agreements required to complete the procurement. The maze is a metaphor for the discrete set of path options through the supply chain. Like the labyrinthine counterpart, an agent knows that there must be one or more ways to pass through the maze, but does not have complete or perfect information of the path options in advance. Rather they must be discovered through a combination of intuition, strategy and learning.

[10] There are several on-line dictionaries devoted to explaining the terms used in freight logistics.

[11] Knowledge gained during the transaction may alter his baggage; the change being the product of his encounters while traversing the maze.

[12] An industry cluster is a group of interdependent firms and related institutions that draw a productive advantage from their concentration and interaction. A new CMAP "drill-down" report analyzes freight, one of the Chicago region's strongest industry clusters.

[13] An example is the uneven acceptance across different organizational cultures of text messaging as a substitute for e-mail in written communication. Which, in turn, was a substitute for fax, and before that, courier (mail).

[14] These are examples taken from an agent-based modeling application used for teaching. Wilensky, U. (1998). NetLogo Altruism model. http://ccl.northwestern.edu/netlogo/models/Altruism. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

[15] Such as rumor of a competitor's recent transaction or that day's final market closing prices

[16] A geometric metaphor for "trading volume". When trading volume is high, brokers tend to move faster and engage in riskier behavior than otherwise.

[17] We see this in survey responses when respondents "don't know" much about their product before or after their handling of it.

[18] When NuStats was acquired by PTV, NuStats staff were required to use MapQuest instead of the more popular GoogleMaps because of some apocryphal corporate agreement.

[19] An example would be a high volume but highly regulated commodity brokered at very high levels such as petroleum.

[20] FAF zone or County, number of employees and NAICS code respectively.

[21] A longitutional analysis of the FAF would be immensely valuable here if the successive CFS sample consisted of the same firms. This is unlikely. We can use two unconnected samples of commodity volumes and value to infer trends, but cannot explain agent choices themselves.

[22] Many business databases (D&B, InfoUSA) permit cross referencing firms by these types of headings.

[23] Medium and large sized firms will likely have multiple agents representing them in a succession of transactions. We should not assume that, just because these agents work for the same firm, they will act uniformly.

[24] This construct is no more immune to agent stereotyping than are current trip-based models' reliance on income, auto-ownership and geographic constants.

[25] The FAF also includes a network assignment result calibrated to reasonably match observed volumes on major freight facilities, but we are not interested in path choice at this point.

[26] At least for those movements within the Chicago region.

[27] e.g. HIS Global Insight TRANSEARCH

[28] For example, "In the United States, Highways are publicly owned, managed and maintained and Railroads are private." This may seem superfluous, but the lack of such a list results in great confusion and misinformation among those attempting to resolve freight-related arguments.

[29] CMAP's policy audience is already suspicious of black-box solutions. Agent-based modeling rhetoric is appealing because, even if it is computationally difficult, it promises to tell the story in plain language.

[30] Expressed mostly through application of mathematical game theory.

[31] For private firms; product user, budget manager, bid manager, contract officer, company owner. For corporations: stockholders, board of directors, executive management. For nations: residents, workforce, government and military.