An Agent-based Microeconomic Simulation of a local Market

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Abstract

We describe an agent-based microeconomic simulation of a local market. Consumers and Sellers are represented as agents in the Aglets framework. Consumers follow a Cobb-Douglas utility function, and they choose the seller that best matches their desired combination of goods and services. Different sellers provide different combinations of goods and services. The amount of money available to consumers for spending depends on an external parameter representing the state of the economy. Sellers make profit if revenues exceed costs. Although important aspects of a real economy, such as the total available money supply, the equilibrium between supply and demand, and the effect of the labour market, are not explicitly represented in this simple model, they can be incorporated in the future. The advantages of an agent-based simulation are the following: global macroeconomic behaviors arise naturally as a result of local agent interactions; individual consumer and seller agents can become as sophisticated as desired (for example, spatial locations of consumers and sellers may influence consumer choice of a seller, or consumers can follow an income and preference distribution that reflects a particular city), with no constraints imposed by tractability of any mathematical models; the mobile agents (Aglets) framework allows a distributed implementation of the economy over a network of workstations, thus allowing experiments on standard computing hardware with no requirement for access to a supercomputer. Future research will expand on these advantages, to demonstrate the usefulness of the proposed framework for business planning (as a tool to answer what-if questions to a prospective seller), as a teaching tool in economics and business, and as a framework for electronic commerce, whereby real stores and real consumers are represented by agents, who carry out business transactions on their owners' behalf.

1. Introduction

This paper describes an agent-based microeconomic simulation. Intelligent software agents play the roles of buyers and sellers in a virtual marketplace. These agents are imparted with realistic behaviors and goals. They are then introduced into an environment where they behave and interact in an autonomous fashion. The results of the simulation are the effects of their interaction.

The simulation is composed of four different agents. The primary agents in the simulation are the Buyer and Seller agents. The Buyer is allotted an income for each cycle. The Buyer is also imparted with preferences and a schedule of demand curves that enable her to select a Seller and purchase goods from that Seller. The Seller agent maintains a schedule of goods and prices. It presents a price index and value added index to the Buyer. The Buyer uses these indices to select a Seller to do business with. The third agent is the Controller agent. This agent permits the user to initialize the simulation. The Controller also maintains an economic state, which the other agents will use as input to make consumption decisions. There is only one Controller agent in the simulation at any given time. The fourth and final agent is the Finder agent. It permits the other agents to find the Sellers in the simulation. There is only one Finder agent in the simulation at any given time. A more detailed description of the agents will be included in a later section.

This report is organized in three sections with a conclusion. The background section will outline conventional techniques used in economic simulations and modeling. It will also include a more detailed description of agents and agent-based simulations and provide a historical backdrop for this methodology. The background section will conclude with an overview of related work in this area. The Simulation section will describe our model in greater detail. It will provide a detailed description of the agents as well as the Buyers' logic. The Future Work section will discuss the merits of the agent-based approach as well as areas of potential research.

2. Background

Conventional economic models can be divided into two paradigms, static and dynamic. The static model paradigm includes the graphical representations of supply and demand found in virtually every introductory microeconomic textbook. Also included are single equation and multiple equation models.

Dynamic models permit us to view the economy over time. This is the domain of economic simulation. This is currently accomplished using one of two methods, Dynamic multiple equation model and time series model. The following sections describe these modeling techniques in greater detail.

Dynamic Multiple Equation Model

In this context, a simulation is a mathematical solution to a set of simultaneous equations. These equations are known as difference equations. Pindyck and Rubinfeld define a difference equation as an equation that "…relates the current value of one variable to current and past values of other variables". A set of these difference equations that can be solved over time is known as a simulation model. The following is a classic macroeconomic example of such a model. (Pindyck, 1981)

$$C_t = a_1 + a_2 Y_{t-1}$$
$$I_t = b_1 + b_2(Y_{t-1} - Y_{t-2})$$
$$Y_t = C_t + I_t + G_t$$

Where
Y = gross national product
C = consumption
I = investment
G = government spending

Time Series Model

Time series models are used to forecast future actions of a variable by making predictions based on the past behavior of variables. As an example, an investor might predict the future performance of a stock by evaluating how it performed in the past. Time series models are useful when the use of a multi-equation model is no longer feasible. I.e. the variables required for a multi-equation model may not have been recorded or the relationships between the variables are unclear.

What is an agent?

The actual definition of a software agent is a matter of some debate. For our purposes we will use the following description. (Lange)

"An agent is a software object that

1. Is situated within an execution environment
2. Possesses the following mandatory properties
3. Reactive: senses changes in the environment and acts according to those changes
4. Autonomous: has control over its own actions
5. Goal-driven: is proactive
6. Temporarily continuous: is continuously executing
7. And may possess any of the following orthogonal properties:
8. Communicative: able to communicate with other agents
9. Mobile: can travel from one host to another
10. Learning: adapts in accordance with previous experience
11. Believable: appears believable to the end user"

Agent-based Microeconomic Simulation

In an agent-based simulation intelligent software agents are used to play the roles of participants in a complex economic system. In this case, agents act as buyers and sellers in a virtual marketplace. These agents meet and engage in economic activities. This system is able to simulate the “real world” by imparting the buyers and sellers with realistic behaviors and goals. In an agent-based simulation we do not control the simulation. We simply create the players and their environment and then allow them to interact. Our results are the effects of their interaction. This enables the researcher to create and observe a complex system while avoiding the difficulty of controlling it. Thus avoiding the inherent complexity of a more mathematical methodology.

Related Work

The most recent example of this methodology is ASPEN. ASPEN is an agent-based microeconomic simulation by Sandia National Laboratories. It makes use of intelligent software agents to play the role of economic agents within a model of the US economy. Microeconomic behaviors are combined to create macroeconomic results. ASPEN is composed of household agents, firms, government and financial agents (banks and the federal reserve).

Household consumption was not based on the maximization of a utility function, but rather used ad hoc rules of thumb. For example, the demand for food was based on the size of the household.

The model was used to test various federal monetary policies. The results were consistent with accepted economic theory and practice (Basu, 1996).

3. The Simulation

Unlike the ASPEN model, which relied on ad hoc rules, this simulation relies on the microeconomic theory of consumer choice. This theory models consumer-buying behavior as a choice between two goods. This theory can be extended to model consumer buying behavior as a choice between one good and all other goods (Varian, 1993). This simulation models the choice consumers make between the physical good and the service provided by the seller of the good. This simulation treats "service" as a good (not a bad) that Buyers pay for. All Buyers value service. However, some value it more than others. The Buyer makes a decision to spend X amount of his/her income on service and Y amount of his/her income on physical goods.

Service can also be referred to as "value added". Value added encompasses convenient location, pleasant surroundings, convenient hours, knowledgeable staff, good after sale service, etc… These are all costs that the Seller must incur and then recoup from the buyers by charging higher prices.

3.1 Agents

3.1.1 Controller

The Controller agent controls the simulation. It directs the activities of the agents involved in the marketplace. It also permits the user to initialize the marketplace. Initialization refers to the process by which the user creates agents (buyers and sellers) and provides them with behavioral attributes. The user is also permitted to alter the simulation as it progresses. Sellers can be added or removed, and their pricing strategies can be modified. There can be only one controller agent in the simulation.

The Controller enables user to initialize the agents in the simulation. Iτ controls the sequence of the simulation. (tells the Buyers to buy and the Sellers to report their status).

It also maintains an economic state that will be broadcast to the Buyers and Sellers in the simulation. The economic state will affect their behaviors, in that a change in the economic state will shift the Buyers' demand curve. The Controller agent interacts with the Buyers and the Sellers.

3.1.2 Buyer

The Buyer agents play the role of consumer within our virtual marketplace. The goal of the Buyers is to purchase the preferred bundle of goods given their income and preferences.

Each Buyer maintains a Cobb Douglas indifference curve as well as a demand curve for each good in the simulation. Each Buyer also maintains an income. How the Buyer gets this income is not part of our simulation (Although this increased sophistication could be added). We simply give each Buyer an allotment of money at the beginning of each cycle and the agent then spends the money according to her preferences. We assume that each Buyer either works or receives some sort of social assistance as income. The Buyers receive a message to shop from the controller agent and then communicate with then find their ideal store by communicating with the Finder. Once their ideal Seller has been found they purchase goods from this store. They may or may not spend all their money.

Buyer Choice

The Buyer chooses between services and goods. This choice between services and goods leads to an optimal bundle (X, Y). Where X is the quantity of goods and Y is the quantity of service.

Suppose the Buyer's income per cycle is $10. And the buyer prefers $3 worth of service and $7 worth of goods. We can treat this in percentage terms and say the Buyer prefers

30% of his/her income on service and 70% on durable goods. We can then treat these as price and service indexes of .3 and .7 respectively.

Once the Buyer has decided upon his/her optimal bundle of goods/value added, he/she must choose a Seller. The Seller presents the Buyers with two indices, a Price index and a service index (may also be called value-added index).

The following table shows the price and service indices for three different sellers.

Seller 1	Seller 2	Seller 3
PI = .8	PI = .7	PI = .9
SI = .2	SI = .3	SI = .1

The Buyer looks at the sellers and we see that she will get her optimum combination of price and service by buying from Seller 2.

Once the Buyer has chosen a Seller, he/she makes their purchases from that Seller given their demand curve for each good. They purchase goods until they can make no more purchases (may have money left over).

Different Buyers

Our simulation will involve the interaction of various types of Buyers. There will be three basic types. 1) The *frugal* Buyer, he values low price over value added. 2) The *average* Buyer, he values both price and value added. 3) The *prestige* Buyer, he is willing to pay a premium for value added. The type of buyer depends on the shape of their indifference curve (indifference curves will be discussed in a later section).

3.1.3 Seller

Sellers play the role of Vendors in the virtual economy. Their goal is to maximize profits.

Profit = Revenue – Cost

Where…

*Revenue = Price * QuantitySold*

*Cost = FixedCost + VariableCost * QuantitySold*

VariableCost = UnitCost + CostOfValueAdded.

*Price = UnitCost + UnitCost * Markup + UnitCost * ValueAddedIndex*

In our simulation, the per unit cost of the good is the same for every Seller. However, some Sellers have a higher variable cost due to the cost of delivering the Service (or value added). Therefore, they must charge higher prices to recoup this loss. They may also attempt to earn higher per unit profits.

All Sellers present a price and service index. If their service index is high their price index will be low (high prices). The Sellers can also present a high price index (meaning low prices) and a low service index (meaning little value added).

Each Seller maintains an inventory of goods. Just as the Seller's income is external to the simulation so is the production of good within the simulation. We assumed the Sellers would purchase their goods from the same supplier. This way, all Sellers in this economy have the same variable costs. The user is able to select what goods the Seller will carry as well as how much the Seller will charge. The user is free to add or drop goods from the Sellers product line at any time during the simulation. As well, the user is able to alter the Seller's pricing strategy. Altering the prices charged for the goods will affect the Sellers price and value-added indices. Each Seller maintains these indices and registers them with the Finder agent. This enables the Buyers to find the Seller with their ideal bundle of goods and services. At the end of the cycle each Seller receives a "report" message from the Controller. The Sellers then report their revenue, cost and profit to the

Controller. The Controller displays this information to the user. A Seller agent interacts with the Controller, Finder and Buyer agents.

Types of Sellers

In their book, "Principles of Marketing", Kotler, Armstrong and Cunningham (Kotler, 1999) identify three types of Sellers; self-service, limited-service and full-service. Our simulation will make use of these distinctions. The self-service Seller provides minimal value added but a low price. The limited-service Seller provides some value added at a somewhat higher price. The full-service Seller provides high value added at a high price. The self-service Seller accepts a lower margin than the full-service Seller does.

Under our model the self-service Seller will have a low value added index and a high price index (this indicates low prices). The full-service Seller will have a high value added index and a low price index (this indicates high prices).

3.1.4 Finder

The Finder agent allows the Buyer(s) and Seller(s) to meet in the virtual marketplace and perform transactions. The Finder makes it possible for the Buyer(s) to find the Seller(s). There can be only one Finder agent in the simulation. Once the Seller has been initialized it registers itself with the finder agent. The Finder maintains references to all the Sellers in the Economy. In this context Reference refers to the aglet id of each Seller agent. The Finder acts as a "middle man" in our simulation by interacting with both Buyers and Sellers.

3.2 Economic and Marketing Models

3.2.1 Buyer Behavior

The Buyers' behavior within this simulation is modeled upon the microeconomic theory of Consumer choice. The following is a brief description of this model.

3.2.2 The Budget Line.

The economic theory of consumer buying behavior assumes the buyer will attempt to purchase the best bundle of goods they can afford (Varian, 1993). The selection of this "best bundle" is dependent on the consumer's preferences and budget. With this theory we are able to reduce consumer behavior to a choice between two goods. The Consumer chooses between good X and Y and decides on quantities Xi and Yi. Xi and Yi make up the optimal bundle (Xi, Yi). This two good assumption may seem unrealistic at first. However, we can treat one of the goods as representing all other goods the consumer may want to consume. This good is known as a Composite good. This assumption greatly simplifies the graphical representation of this decision making process as well as future calculations regarding this choice.

In choosing between two goods, the Buyer must decide what he/she is able to afford. This requires the Budget Line. The Budget line can be represented in two-dimensional space. The quantity of good one in measured on the horizontal axis and the quantity of good two is measured on the vertical axis. The vertical intercept of this curve can be calculated by dividing the Buyer's income by the price of good 2. The Horizontal intercept can be calculated by dividing the Buyers income by the price of good 2. A budget line is shown in Fig 1.

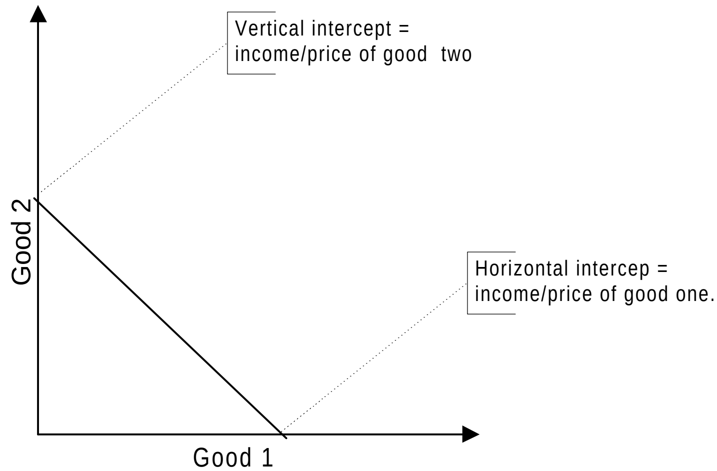

Fig 1.

3.2.3 Indifference Curve

The second part of the purchase decision involves what the Buyer wants, i.e. what combination of good 1 and good 2 is the most desirable. This is done by examining the Buyer's indifference curve. The indifference curve maps the rate at which the buyer is willing to substitute good 1 for good 2. The indifference curve is generally a downward sloping convex curve. The indifference curve shows all possible combinations of good 1 and good 2 that are equally satisfactory to the Buyer (Browning, 1992). The indifference Curve is shown in Fig 2.

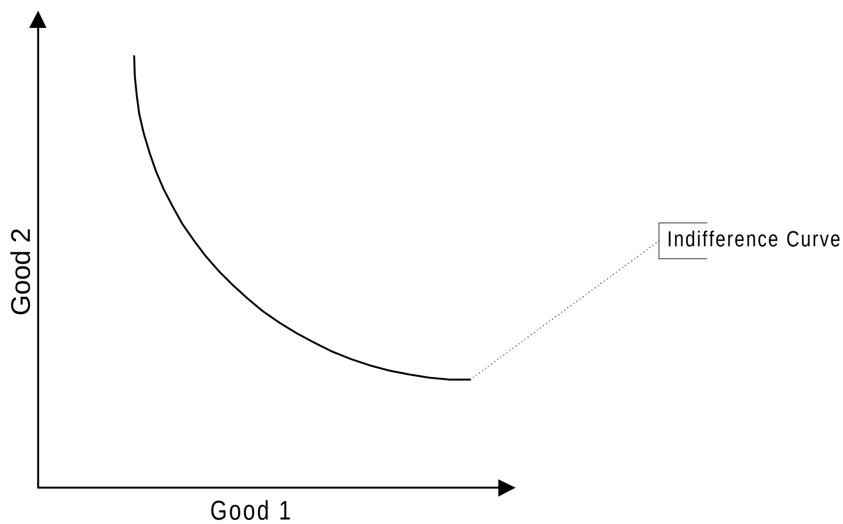

Fig 2.

The Buyer is equally satisfied with any distribution along the indifference curve. However, as the distribution moves down the indifference curve, the Buyer requires more and more of good 1 to compensate him for a small loss of good 2. As the distribution moves up the indifference curve the buyer requires more and more good 2 to compensate him for a small loss of good 1.

3.2.4 The optimal bundle

If the Buyer is equally satisfied with each bundle lying on the indifference in Fig 2, how does the buyer decide which is the "optimal" bundle? To answer this question we must combine the indifference curve from Fig 2 with the budget line from Fig 1. Fig 3 shows how the optimal bundle is determined.

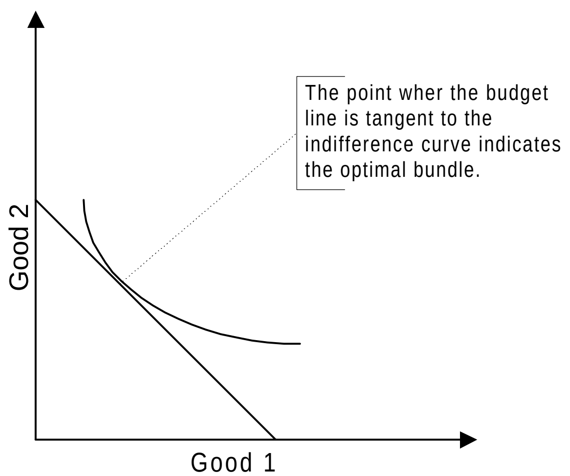

Fig 3.

Fig 3 shows the point where the budget line is tangent to the uppermost indifference curve. This point is the optimal bundle of Good 1 and Good 2. We can see from the diagram that this buyer prefers to have more of Good 2 and less of Good 1.

3.2.5 Seller Behavior

Seller Behavior is modeled according to economic and marketing theories. An integral part of the Seller's behavior is the economist's assumption of profit maximization. This assumption does have its limitations. In the case of a small firm where the owner may work in the firm profits may be traded off for increased leisure time. Or a firm may favor the goals of social responsibility or increased market share (Mansfield, 1997). For our purposes the goal of profit maximization will suffice. Another part of the Seller's behavior is the various business strategies the Seller can follow to achieve this goal. This strategy is displayed by what kind of seller they are; self-service, limited-service or full-service. Each Seller offers a different amount of value added to their good. The Buyer pays for this value added by paying a higher price. The value added can be in the form of convenient locations, good hours and increased customer service (Kotler, 1999).

The seller can take various forms. The discount seller is able to offer his goods at a low price because he applies a small amount of value added to his goods. The average seller offers his goods at a slightly higher price and offers a higher amount of value added. The prestige seller offers the highest amount of value added and offers his goods at the highest possible price.

4. Simulation Results

The simulation produced consistent results when initialized with a population of Buyers and Sellers. The Buyers chose Sellers that were consistent with their preferences. As the cost of providing value added changed (The price of value added increased or decreased) some buyers would choose to shop at a different seller. We also found the aglets framework to be extremely effective in modeling human behavior. Our Buyers use conventional microeconomic theories of consumer behavior. It would also be possible to take a more ad hoc approach and create a rules based system as proposed by researcher at the first Workshop on Artificial Intelligence in Economics and Management (Hoffman, 1986).

5. Future Work

Economists have long used the distinction between microeconomics and macroeconomics. Microeconomics focuses on the economic activities of the individuals within an economy, and Macroeconomics analyzes the economy as a whole. Clearly this is not an ideal starting point for the creation of a truly general economic theory. Present macroeconomic theory does not sufficiently account for the heterogeneity of Agents (van Ees, 1991) We feel that an agent-based framework can give macroeconomics in particular and microeconomics in particular an individualistic foundation.

“There is no other more difficult branch of economics than dynamic economic models” (Neal & Shone pg 124). The addition of time to an economic model greatly increases complexity. The researcher must decide what time interval(s) will be used. With multiple equation models each equation may require a different interval to achieve equilibrium. Also, an independent variable X at time t may require the calculation of a dependent variable Y at time t – 1. Of course at time t – 1 Y it is an independent variable. It in turn may require the calculation of variables at time t – 2, and so on. The researcher is then forced to make assumptions to deal with these complications. These assumptions may hinder the researcher's quest for realism. In an agent-based model or simulation the complexity of time is of no great concern. Each agent takes as much time as required to perform her task as is required (as is the case in the real world). In fact it is the agent's ability to mirror the real world that makes it such a compelling and (we think) useful tool for researchers.

In our local market simulation the Buyer is required to choose a Seller that offers the appropriate combination of goods and services. The next logical extension of this model would be the addition of spatial constraints. Each agent in the economy would be given an address and the location of the Seller would also be a part of the Buyers decision. Our simulation was designed so this could be a feasible extension. Conventional multiple equation models are ill equipped to deal with this added complication. There is the possibility of using a gravity model to deal with a spatial environment. However, an agent-based simulation could more easily reflect this reality. Agents could occupy a location within an environment just as real-life Buyers and Sellers occupy a location.

We used the aglets framework to implement our local market simulation. Aglets are Java objects that execute on a host. They are able to cease execution, store their state, transport themselves to another host and resume execution. This capability makes an aglet a Mobile Agent. Aglets also have the ability to send and receive messages. This makes the aglet framework a powerful tool in modeling and simulation research. Whereas other agent-based simulations might require powerful computational ability i.e. a super computer. Aglets can be deployed on a network and the processing load can be distributed over various hosts. The ASPEN project described in the Background section of this paper ran on Sandia's Paragon super computer. Our local market simulation is able to run on a PC. As more agents are added to the simulation more PCs can be added to the network to add processing capability. The processing capacity required is dependent on both the number and size of aglets within the simulation. Size referring to the complexity of each aglet. Greater sophistication will lead to larger processing requirements. This is somewhat of a subjective limitation. In that it is up to the researcher to decide what is an acceptable length of processing time for each cycle. The network paradigm could also be used to reflect the spatial reality of the marketplace being modeled. Each workstation in the network could house the Buyers and Sellers of a different neighborhood.

Macroeconomic fluctuations arise as a result of individual behaviors. Conventional economics are ill equipped to deal with this reality. Modeling complex human behavior within a mathematical framework is both conceptually and practically difficult (Hoffman et al. 1986) We believe that an agent based methodology would provide a more accurate and easier to implement model of the real world. Buyers are represented by buyer agents. Sellers are represented by seller agents. A central bank could be represented by a banking agent, and so on. Researchers would no longer be required to represent an economy (or part thereof) as a system of equations. This would also allow the researcher to avoid the inevitable mathematical errors associated with the conventional multi-equation approach.

Future research in this area is not limited to macroeconomic simulations. Our local market simulation might be the first step in the replacement of the conventional gravity model. The ability to model not only the spatial environment but the behaviors and preferences of Buyers and Seller could make it interesting from a marketing or business planning perspective. This local market simulation could also be extended to allow users to create a buyer or seller agent to represent them and act on their behalf in this virtual marketplace.

6. Conclusion

We conclude that software agents and the agent-based simulation methodology are valid and useful tools for economic modeling. Even in its present state, our local market simulation could prove interesting to those in the marketing and business community. It could serve to answer various “what if questions”, as well as assist decision-makers in selecting a product mix and pricing strategy.

Intuitively we know that macroeconomic phenomena arise as a result of individual behaviors and activities. However, the micro-foundations of macroeconomics have proven elusive with conventional mathematical modeling techniques. It is difficult for researchers to model complex human behaviors within a mathematical framework.

This has forced economists to adopt the familiar microeconomic vs. macroeconomic distinction. Software agents and agent-based simulations should permit economists to soften this distinction, and provide an individualistic foundation to macroeconomics.

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