Simulating Inflation: Is the Economy a Big Balloon?

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Abstract

Inflation is a common problem in modern economics, and it seems to persist, requiring government financial policy intervention on a regular basis in order to properly manage. The mechanics of inflation are difficult to understand, since the best metric modern society has for inflation involves taking samples of prices across the country. A simulation can give deeper insight into more than the mere fact that prices rise over time: a simulation can help to answer the "why" question. The problem with this statement is that developing a simulation is not as simple as writing some code. A simulation is developed according to a paradigm, and paradigms are not created equal. Research reveals that traditional paradigms that impose order from the outside do not mimic reality and thus do not give a good degree of accuracy. By contrast, Agent Based Modelling models reality very closely and is consequently able to simulate economic systems much more accurately.

Simulating Inflation: Is the Economy a Big Balloon?

It is often said that life's two inevitabilities are death and taxes. It seems that inflation could easily be added to this list. In most countries in the world, the average prices of goods and services slowly rise over time. Generally, this trend is so gradual as to be of minor impact to the people of the country. However, there have been countries where inflation has turned into hyperinflation, with devastating effect. Sowell (2011) describes money being used as toilet paper and wallpaper by Russians, or life's savings being worth less than a pack of cigarettes in 1920s Germany. Some governments have instituted price controls to stem the tide of hyperinflation, but this has generally only led to shortages of goods, rather than end to the crisis. The only real end to the runaway inflation (at least in practical experience) is to use a different currency for trade. Part of the trouble with solving inflation is that while historical data analysis can be performed, this historical data is limited in scope and not truly repeatable. Since one cannot simply run repeatable experiments on the economy, historical data is all that is available. This is where the software simulation enters the picture by enabling experimentation with a model economy in order to test hypotheses regarding inflation. While it is obvious that a simulation is not the same thing as real-world experimentation, a well-constructed simulation can provide a useful approximation that can validate or call to question theories about the real-world economy. The simulation paradigm defines how the simulation is constructed, thus a good paradigm is necessary to construct a simulation well. The agent based simulation paradigm is the most effective for simulating inflation in an economic system because it structures simulations in a way that mirrors a real economic system, whereas the alternative paradigms follow structures alien to the real world, as backed up by the concepts of economics on which inflation relies.

Economics Concepts

In order to simulate something, one needs to understand what it is and how it works—that is, the nature and mechanics of that thing. Since the paradigm forms the basis for the entire simulation, choosing the right paradigm is a necessary first step in development. The paradigm needs to fit the real-world domain one is simulating. Thus choosing a paradigm for an economics simulation requires getting a good picture of what goes into an economics simulation. To this end, a number of economics concepts will be explored, with the concept of inflation being a bounding goal to limit the number of concepts described.

Economics

Lionel Robbins provides a good definition of economics: “Economics is the study of the use of scarce resources which have alternative uses.” (as cited in Sowell, 2011, p. 3). In order for economics to study the use of resources, there needs to be a user of resources. This user could be a computer or an animal; however, the most impactful study of economics is that of the use of resources by humans. Humans are presented with the problem of scarcity and must choose between different uses of a limited resource. Humans make this choice based on some idea of value—an idea of which use of the resource is more meaningful or more important than the other uses of that resource. Thus in order for an economics simulation to function it needs to have resources, these resources need to have alternative uses, and the resources need to have users. Most paradigms can model resources in multiple ways, but the chosen paradigm must also effectively model users of a resource.

The Economy

An economy is simply a collection of individuals who produce, own, consume and trade resources. As such, it is a container that enables high-level analysis of trends in individual interactions that cannot be measured at the individual level, but can still have an impact on the individual level. For example, if there are job losses in an entire industry while unemployment is low and decreasing dramatically in the broader economy, the chance of one of those laid off finding another job is high. Resources are simply being reallocated. However, the chances of finding another job would be far lower if the overall unemployment rate were high, as that would indicate that average demand for employees was lower than if unemployment were low. The key here is that while the concept of an economy enables the measurement of high-level trends, it is important to remember the grounding of these trends in individual interactions when computing and analyzing these trends, even though the high-level trend and specific individual interactions may appear very different. Thus the paradigm chosen needs to function such that its high-level trends are the result of interactions between individuals.

Person

A person is an entity in an economy that produces, owns, consumes and trades resources in order to gain value. At various points in time a person chooses from the available activities the one that gains him the most value. Each activity generates value in a different way, and these aspects need to be understood as part of understanding what a person is.

Production is how resources enter the system. The specific means of resource entry can be an activity such as mining, agriculture or manufacturing. Whatever the specific means, production yields resources to the producer, and may or may not require other resources to cause the production to occur. Thus production provides value by bringing a certain amount of one or more resources into the ownership of the person, which can then be consumed to satisfy a desire, or traded for something the person desires. The cost of production is the time taken (which could have been used for trade or consumption), the space now occupied by the produced resources (which could be used for other resources) and any resources required by the production process (which could have been used for other purposes).

Ownership is not an activity, but the possession of resources that results from activities. This is modeled by variables that keep track of the amount of each resource that a person possesses, which are incremented when the person acquires resources, and decremented when he trades or consumes them. The amount of space available to a person is computed, and if a person acquires resources that do not fit in the space, he must choose which resources to discard. Owning resources has value in that those resources can be immediately consumed or traded (they do not have to first be produced or obtained through trade), and owning resources has the cost of using space that could be used for other resources.

Consumption involves destroying a resource to satisfy a desire. For example, the hunger desire described above for modeling hunger would be satisfied by the consumption of food, which would then be destroyed. Consumption is necessary as a component of causing agents to need to trade. More complicated models could include manufacturing, which would produce resources in part as a result of consuming resources. Consumption is in essence the termination of the value process, and has value in satisfying the desires of the person. However, there is a cost to consumption, and that is the destruction of the resource, which could have been traded or kept on hand for later.

Trade involves the exchange of resources between two persons, and will be discussed further in its own section. Relative to the person, the value of a trade is the potential to obtain more valuable resources in exchange for less valuable resources, as well as gaining information regarding the market value of a resource. The cost of trade is the time taken to exchange messages and the risk stemming from uncertainty regarding what the other person deems valuable, and consequently uncertainty as to whether or not the person will accept a trade after one has invested time in proposing it.

A person is an entity in an economy that produces, owns, consumes and trades resources in order to gain value. For these activities to be meaningfully modeled, a person needs to be modeled as an autonomous entity. Further, a person needs to be able to decide between these activities by determining which one will bring about the greatest gain in value. The chosen paradigm will need to model the independent choice of activity by the person, and a value structure that enables that choice.

Value

The most important concept in all of economics is value, as it is the concept on which all of economics depends, in that uses of a resource offer differing degrees of value. Value is defined in the *Oxford English Dictionary* as: “Worth based on esteem; quality viewed in terms of importance, usefulness, desirability, etc.” (“Value,” 2012, para. 16). At some level this definition is somewhat circular, but that is part of dealing with a fundamental topic.

The salient point of the definition, and an important concept in economics, is that value is subjective. In the given definition value is esteem-driven and something that is viewed—in other words, value depends on the one who esteems or views an item, and is thus valid only for the person who is so esteeming or viewing the item. One could argue that value is objective and there are merely different perceptions of the inherent value of an object. However, decisions in economics depend on who most values a resource. Something that has very little inherent value may still have much value economically thanks to one person's subjective perception of that item as having high value to him. Trade is motivated by differences in subjective value (regardless of inherent value), in that each person trading values the thing he has less than the other person. As a result, for economics purposes it is sufficient to view value as subjective, not inherent.

Since value is subjective, it is an internal measure of the degree to which a person esteems an item. To say that value is internal is to say that it is not manifested outwardly as an independent number. Rather, internal value can only be seen through the trades a person makes, which express the relative value of the two resources involved in the trade to each person. In other words, not only is value subjective, it is also only expressed relatively and not absolutely. Consequently, the internal value each person has for an item can never be truly known, rather it is only known in relation to the other things around the person. There is a limit on the information that a person can have about the value of a resource in an economic system, because economic value is subjective and internal.

In order to model internal, subjective value, one needs to model the reasons why humans value things—desires. In general desires are broken down into needs and wants—needs being those things a person requires for survival, wants being everything else the person desires. Value can then be viewed as the degree to which a person believes that an item will satisfy one or more of those desires. However, because resources could be traded for more than the person values them, or other resources cannot be obtained without trade, all resources have not only value to a person in their perceived ability to satisfy his needs and wants, but also in what that person perceives to be the market value of the resource. Market value of an item is perceived by each person based on his interactions with others—the prices they offer and the prices they will accept. Consequently the value of a specific resource can be computed as a function of its ability to satisfy a person's needs and wants and the perceived market value of that item.

Ultimately it is important to understand that value is internal and subjective and stems from survival needs and desires. Even the concept of a market value is derived from the aggregation of expressions of value by many persons, and thus rooted in internal, subjective value. The chosen paradigm will need to accurately reflect the internal, subjective nature of value and the limitation that value is only expressed relatively.

Trade

Trade is the voluntary exchange of resources between two individuals. For trade to be meaningful, ownership, a transfer mechanism, multiple scarce resources, subjective value, interaction capabilities and negotiation capabilities are all necessary. Ownership is necessary, for it is meaningless to give someone something one does not own and that the receiver cannot own. A mechanism that enables ownership of resources to be transferred from one person to another is also necessary. Without multiple resources there is no reason to trade either—that would be equivalent to giving someone else a twenty dollar bill in exchange for a twenty dollar bill. Scarcity of resources is necessary to motivate trade in that if one can obtain a resource easily without giving up something in exchange for it, there is no reason to obtain it by giving something up. Trade could still exist without subjective value, but it would have less power, as each person would desire the same things to the same degree, and it would therefore be less common to find terms where both parties saw a trade as an increase in value. These concepts are relatively simple to understand.

Interaction capabilities and negotiation capabilities are necessary for obvious reasons. If two people cannot interact in any way, they will be completely unable to trade. In order for individuals to interact, there needs to be a structural interaction mechanism—some way in which messages are passed from one agent to another—and an internal cognitive capability, an ability within the agent to generate and respond to messages. Since the messages between agents will concern trade and prices, these messages will either concern: (a) proposing new or amended trade terms, and (b) accepting or rejecting trade terms. Both types of message depend on computations of value: in the case of (a), the agent needs to be able to compute his subjective relative value and produce a price at which to propose trading. In (b), the agent simply determines whether or not the trade is in his interest. The computation of value will likely take into account to some degree what the agent perceives to be the market value of an item, which will be impacted by the terms of trade proposed and accepted by others. For example, if agent B proposes to give agent A 5 items of food in exchange for 10 pieces of wood, even if agent A has no wood and rejects the trade, agent A now perceives that agent B wants wood, and agent A may be more willing to accept wood because he perceives that he may be able to trade that wood for something he can use. Thus an interaction structure and cognitive capabilities based on value computations are necessary to enable the interaction that is necessary for trade.

Trade requires the concepts of ownership, multiple scarce resources and subjective value. Further, a structure for persons to interact and individual cognitive interaction and negotiation capabilities will be necessary. The individual cognitive capabilities will depend on computations of value that will take into account the person's desires as well as that person's perception of market value, influenced by his interactions with other persons. The chosen paradigm needs to enable modelling ownership, interaction and decision-making internal to a person based on value.

Prices

Generically speaking, a price is the amount of resource given up in exchange for another resource. Following this definition, a price could be in terms of any resource, not just a currency. Indeed, a currency is used primarily for efficiency, because it would be incredibly economically inefficient to price goods in barter terms, or to compare barter prices. That prices can be in terms of anything is illustrated by this quote from an interview with the author of a book on counterfeit trading: "in 1986, in a town in Kenya called Kolowa, you could get an AK-47 for fifteen cows. This year you can get it for four" (Myers & Naím, 2005, para. 22). Prices can be in terms of anything, currency just makes it easier to measure and compare prices.

Since a price is the amount of resource given up, it implies that the resource given up has less value to the person giving it up than the resource received. This difference in value applies to both parties in a trade—each person perceives the resource received to have more value than the resource given up. Both persons need to feel this way, or the trade will not occur. Consequently prices express the relative value of objects. If one aggregates this price data across an economy, one can get an idea of the degree to which resources are valued relative to one another in general by members of the economy.

Sowell (2011) says, “Prices are not just ways of transferring money. Their primary role is to provide incentives to affect behavior in the use of resources and their resulting products” (p. 15). As an expression of relative value, a price forms an incentive to transfer resources to their highest valued uses. If person A has the highest value for resource X, he will in theory be willing to give up more for X than any other person—enough that any person holding X will accept what A offers as more valuable than resource X. If person A was not willing to give up enough to obtain resource X from person B, it would indicate that A valued that which he did not want to give up more than resource X. If A acquires X, X has moved to its highest valued use. If A does not do so, X has remained in its highest valued use. Thus a price is a powerful incentive that will move resources to their highest valued uses.

On the whole, prices in a market will tend to be driven by supply and demand. If an item is in great supply and less demand, its price will be low, whereas if it is in greater demand and less supply, its price will be high. In light of the discussion of resources moving to their highest valued uses, it follows that if many people desire a resource, the aggregate value in the market for that resource will be greater. Such an in-demand item will require more to be given up for it to draw it to the highest-value use, since more people are willing to give something up for the resource, and less are willing to give it up. On the other hand, when many want to give up the resource (high supply), they will have to accept less in return for it if they want to pass it on, because there are many people competing to get rid of the same resource, and the person desiring it can choose the supplier that will accept the lowest price. In this way, overall supply and demand drive overall prices in a market.

Ultimately, prices can be measured in terms of any resource. The primary purpose of prices is to communicate relative value and thereby incentivize the allocation of resources to their highest valued uses. As a result, the chosen paradigm needs to enable prices that are determined by trading entities, not by the system, since the price should incentivize resource allocation, thus is dependent upon the ever-changing distribution of resources and desires for them.

Currency

Currency is simply a resource that is accepted as a medium of exchange. It derives value more or less circularly from the fact that it is accepted as a medium of exchange—in other words, people accept currency in exchange for resources if they know someone else will accept that currency in exchange for resources. As Sowell (2011) put it in referring to examples of currency throughout history, “What made all these different things money was that people would accept them in payment for the goods and services which actually constituted real wealth” (p. 388). This circular nature of the value of currency is in part what makes it susceptible to inflation. While any resource can experience price increases based on supply and demand shifts, most resources have some reason for existence that motivates someone to purchase them at some price. Currency, on the other hand, often has little reason for use outside of trade. Thus, when it is no longer accepted for trade its value declines to that of whatever it is made from (paper money becomes useful only for purposes for which scrap paper is useful). This loss of value through declining acceptance is a component of the inflationary dynamic. Thus the paradigm needs to model individuals in such a way that they can perceive value in something they have no use for if they perceive that others will accept it in trade.

The reason that currency becomes accepted for trade is efficiency. Sowell (2011) explains that using currency is much more efficient than barter, because the currency can be easily traded, and it is divisible, implying that the value of currency given up or accepted can be adjusted to the value of the other resource in the trade more effectively than a normal resource. Thus divisibility and ease of use contribute to the value of a currency because these attributes make currency more efficient for trade than barter.

Currency is an emergent trait in an economy. It arises from the decisions of a large number of individuals to accept a certain resource in exchange for other resources. Consequently the chosen paradigm will need to have sufficient conditions for a currency to emerge from the interactions of individuals.

Inflation

Inflation is defined as “A general rise in prices” (Sowell, 2011, p. 389). Inflation is a general rise in that it applies to the average of all prices in an economy—in other words, it is not a rise in prices in one part of an economy with a corresponding decrease in prices in another area of the economy. As such, inflation is a general, or emergent, trend in an economy. The above discussed concepts are tied together by the concept of inflation.

Inflation is a good example of the difference between the real-world and a simulation in terms of both levels of information and measurement techniques. The generally accepted measure of inflation is the Consumer Price Index (CPI), which is published by the Bureau of Labor Statistics (BLS). In order to compute CPI, employees of the BLS seek out and record the prices of a number of predetermined goods and services at a wide variety of retail locations throughout the country. Thereafter a group of product experts accounts for changes in quality of the goods to ensure as consistent a comparison between periods of time as possible (U.S. Bureau of Labor Statistics, 2011). Since this measure of inflation is based completely on sample data, it seems obvious that there are potential flaws, including the possibility for the goods and services that are sampled to increase in price while those that are not decrease in price. In the context of potential flaws, it is interesting to note that, as Sowell (2011) points out, many economists believe the CPI is upward biased by approximately one percent each year. By contrast, a simulation that involved persons interacting in trade would be able to track every trade interaction and the prices at which those transactions took place, and would be able to compute an exact value for inflation based on complete knowledge of the simulated world. This demonstrates that a simulation has a far higher level of information available to the person running it, and affords simulation developers the ability to develop far more exact measurement instruments than the real-world can develop. While these aspects of simulations are greatly beneficial for analysis purposes, the fundamental methodological differences they produce will need to be taken into account when comparing data obtained from running the simulation with real-world based expectations.

Inflation depends on at the very least the existence of trade with prices, and is more relevant when a currency is the general pricing instrument. Further, inflation must emerge within a simulation rather than being contrived. Thus the paradigm will need to enable not only currency, but also (given appropriate conditions) inflation, to emerge.

Paradigm Criteria

In light of the above examination of economics concepts, a set of criteria for a paradigm can be developed. The paradigm needs to enable modeling users of resources. These users need to make independent choices between various uses of resources based on a value structure that is internal to the users of resources. These users need to be able to own resources and interact with other resource users. Prices need to be determined by the users as they interact, not by the system. Finally, the paradigm should focus on developing sufficient conditions for emergence, as currency and inflation are emergent properties of an economic system.

The Simulation Paradigm

In developing software, one follows a process. In developing a simulation specifically, one additionally develops according to a simulation paradigm. The simulation paradigm forms a framework for relating the real world to the simulation. In other words, the framework defines how the objects and concepts in the real world are to be understood both in terms of their relationships to one another and in terms of their relationships to external forces such as time. In light of the above developed requirements for a paradigm for a good economics simulation, a few paradigms need to be examined to see if they measure up to the standard.

There are three primary paradigms for simulation software development that should be examined to determine which one most effectively models inflation in an economic system: System Dynamics (SD), Discrete-Event Simulation (DES), and Agent-Based Modeling (ABM). Each paradigm will be evaluated against the above developed criteria for the appropriate simulation paradigm.

System Dynamics

SD models reality as a set of stocks and flows or feedback loops between the various stocks. The stocks are aggregate, system-level variables quantifying various aspects of the system being modeled. As a result of the stock-flow mindset, the entire system can be constructed into a system of differential equations in terms of the aggregate variables that vary with respect to time. One significant advantage of this method over others is that its equation-based nature makes it fast to run (Heath, Brailsford, Buss & Macal, 2011; Bagni, Berchi & Cariello, 2002; Borschev & Filippov, 2004).

In addition to its speed, the SD paradigm is useful for getting quick, high-level views of a system that demonstrate the key components and relationships. This high-level effectiveness derives from the fact that SD does not delve into individual or low-level system interactions, but stays at the aggregate level, thus avoiding detail that is unnecessary for getting an overall system view (Heath, et al., 2011; Bagni, et al., 2002).

In contrast with its speed, one of the most significant issues with the SD paradigm is identified in the Lucas Critique, as described by Tesfatsion (2012). The Lucas Critique explained that government policy decisions were being made according to models of the economy that did not take into account the impact of government policy on individual behaviors in the economy. As a result, these models were invalid when they attempted to predict the effects of changes in government policy, because the model by which they predicted the effects depended on the current model of individual behavior, which in turn depended on the current government policy rather than the expected policy being analyzed. The Lucas Critique also mentions that government decisions are not the only causes of change in individual behavior, but that individuals change their behavior based on what policy changes they expect the government to make in the future. Ultimately, for a paradigm to reliably predict the effects of government policy on individual behaviors (and consequently the entire economy), that paradigm must somehow model what expectations individuals have regarding government policy. The Lucas Critique implies that since an SD model is unable to model the fundamental interactions that cause a certain aggregate variable to behave in a certain way, it is unable to predict the behavior of that aggregate variable when changes in policy change the fundamental interactions underlying that variable. Thus SD models are only truly valid for situations where people do not change in their patterns of behavior. While this may hold for much of society, it is not truly reflective of the real-world. A paradigm is needed that enables fundamental interactions in an economy to be modeled.

SD does not satisfy the criteria established for the paradigm. While it does model the use of resources, it does not enable modeling interactions between individual users who choose independently how to use the resources they own. Instead, users are lumped together into aggregate stocks, and resource usage is lumped into flows. While this may be effective for high-level analysis, the Lucas Critique brings into question any significant economic conclusions regarding causal relationships based on an SD model. Finally, because the system is modeled in terms of the aggregate variables that would be used to measure global regularities, it is not possible to demonstrate true emergence of global regularities in an SD model.

Discrete Event Simulation

The Discrete Event Simulation paradigm models the real world as a set of stateful entities that use resources and change states in accordance with system-level rules in reaction to events. In order to have a state, the entities have certain variables that describe their state and can be modified. The transition between states proceeds according to system-level rules, as opposed to being driven by algorithms encapsulated in the entity. When events occur, they cause the system to change the state of an entity, and may also cause the scheduling of new events (such as the end of an activity that is beginning in the current change of state). The occurrence of or time between events can be determined randomly in order to make the simulation more realistic. However, the use of randomness implies that the simulation must be performed multiple times in order to produce statistically valid results (Borschev & Fillipov, 2004; Heath, et al., 2011; Copstein, Pereira & Wagner, 1996).

The benefit of using DES over SD is the ability to capture individual (rather than purely aggregate) interactions thanks to its entity focus. Thus the factors underlying the trends in aggregate variables can be captured, although the paradigm is generally more computationally complex than a corresponding SD model. DES is more capable of capturing low-level details of a system than SD.

While DES captures individual interactions and details of the system, it has a fundamental flaw that does not quite correspond to a true economic system. DES models apply behavior at the system level—in other words, entity behavior is determined by the system, rather than by the entity. While this may not seem significant, it is an important modeling concern, in that human entities in an economy make decisions for themselves—their decisions are not made by an external controlling entity. The patterns that occur in an economy are emergent, and the DES structure of system-level rules prevents true emergence from being demonstrated in the simulation.

DES matches many more of the paradigm criteria than SD. DES can enable modeling users of resources, the making of choices between how to use those resources, and even a value structure. However, DES applies behavior to entities as system-level rules, limiting the autonomy of resource users. Thus the choices between uses of resources are not truly independent, value structures are not entirely internal, and interaction is not truly directed by individual persons. Consequently, the system-level rules prevent the demonstration of truly emergent traits such as currency and inflation. DES is close to being the right paradigm, but philosophically not quite what is needed.

Agent-Based Modeling

Agent Based Modeling (ABM) models the real world domain as a set of autonomous agents who interact with one another within an environment. ABM is similar to DES in that it models with individual entities; however, the way in which ABM does so is significantly different to DES.

Emergence, that is, the formation of system-level attributes that form purely as a result of agent interactions, is the characteristic that most distinguishes ABM from other paradigms. Heath, et al. (2011) explain that in ABM, agents interact with one another according to internal rules (behaviors), rather than according to system-level rules that are external to the agent (as in DES). Tubaro (2009) and Tesfatsion (2005) both point out that ABM does not enforce the traditional assumptions and equilibriums of traditional economic models, rather the modeler constructs agents and observes their interactions for global regularities. In this way ABM is more true to real economic systems, in which the behaviors of individuals are not governed by system-level behaviors, but by individual decisions made according to each person's available information and way of thinking, and the regularities that are observed at the aggregate level of an economy are purely emergent from the individual interactions.

Since ABM is focused on emergence, agents are the most important element of the paradigm, as they are the fundamental component whose interactions bring about emergent traits of an economic system. Tesfatsion (2005) explains that in discarding the equilibriums and gross assumptions of traditional models, an ABM economic model must develop greater complexity into the agent. She describes an agent as a self-directed, encapsulated entity with data and behaviors. Behaviors are algorithms that describe how the agent acts on its data (information and resources). Due to encapsulation, the behaviors are restricted to use only what information and resources the entity would have available to it. The use of the term "behavior" corresponds to the idea of an agent being driven by internal rather than external rules. Encapsulation and internally defined behavior are characteristics of an agent in ABM that correspond well with agents in economic systems.

In addition to encapsulated behavior, Tubaro (2009) and Tesfatsion (2005) both emphasize the role of agent learning in ABM. A significant consequence of encapsulation is that agents have limited information. As a result, the agent must learn, that is, change future decisions in light of the results of past decisions. Tesfatsion (2005) mentions that learning can be extended to meta-learning: that an agent “learns to learn over time” (p. 12). This emphasis on learning distinguishes ABM from other paradigms and enables it to more accurately reflect the real-world, where individuals change their behavior based on the results of both their own and others past actions.

An interesting aspect of ABM is the ability to incorporate the economics of information into the model, thanks to the concept of limited information. In the real world, economics applies to information because information is a scarce resource. As Tubaro (2009) and Tesfatsion (2005) both mention, traditional economic models make assumptions that essentially make information unlimited and of no concern. However, in ABM, one must now deal with “the acquisition, accumulation and use of information at the individual level, and the circulation of information at system level” (Tubaro, 2009, p. 6). Tesfatsion (2005) talks of a trade-off between exploiting and exploring information. The idea of a trade-off alludes to the idea that economics applies to information. Thus ABM is able to more accurately incorporate the economics of information into its models through the concept of limited information.

ABM fully satisfies the criteria specified for the paradigm. Agents are the users of resources. Agents are autonomous, thus able to make independent choices. The data available to the agent is exclusive to the agent, thus enabling a truly internal value structure and ownership of resources. ABM focuses on interactive agents, who can be made capable of determining prices independently. Finally, because ABM focuses on agents who interact, any system-level regularities must emerge from the interaction of individuals who are sufficiently constructed to enable the regularities to develop, not imposed system limitations. Thus ABM is the best paradigm for simulating economics, since its structure most closely resembles a real-world economic system.

Conclusion

An economics simulation needs to be built according to a good paradigm. A good paradigm for economics must use the same structure as a real-world economy in its simulation. Through examining economics concepts, it has been established that the structure of a real-world economy consists of users of resources who interact with one another in trade. High-level trends are a result of the aggregation of interactions between individuals, and can include a currency and price inflation. The users of resources are independent decision-making entities who choose among available activities according to internal, subjective value structures and who express their internal values relative to others through trade.

Three paradigms have been analyzed that differ in their satisfaction of the criteria. The System Dynamics paradigm has been found to be too high-level, aggregating users of resources into collective groups, rather than examining their interactions as individuals. This abstraction away from individual interaction causes the paradigm to lose the grounding for the high-level trends it models and the ability to demonstrate emergence. Thus System Dynamics is found wanting.

Discrete Event Simulation is more appropriate, in that it enables modeling users of resources at the individual level who can interact and make choices. However, the application of system-level rules to individual behavior is a problem for independently directed decisions and trade interactions, and prevents emergence from being truly demonstrated. Consequently Discrete Event Simulation is not quite what economics needs.

Agent Based Modeling focuses on independent, autonomous agents who have limited data available exclusively to themselves. These agents also interact in self-directed ways. Due to its focus on individuals and their interactions, any system-level regularities can be considered truly emergent, as they have not been specified in the system as a whole. Consequently Agent Based Modeling is fulfills the criteria, and is the best paradigm for simulating economics, since its structure most closely resembles a real-world economic system. Also, the paradigm's focus on emergence makes it very well suited to simulating the emergent trait of inflation in an economy.

References

Alogoskoufis, G. S., & Smith, R. (1991, December). The Phillips curve, the persistence of inflation, and the Lucas critique: Evidence from exchange-rate regimes. *The American Economic Review, 81*(5), 1254-1275. Retrieved from: http://www.jstor.org/stable/2006916

Bagni, R., Berchi, R. & Cariello, P. (2002). A comparison of simulation models applied to epidemics. *Journal of Artificial Societies and Social Simulation*, *5*(3), n.p. Retrieved from: http://jasss.soc.surrey.ac.uk/5/3/5.html

Borshchev, A., & Filippov, A. (2004, July). From System Dynamics and Discrete Event to Practical Agent-Based Modeling: Reasons, Techniques, and Tools. *Proceedings, 22nd International Conference of the System Dynamics Society, Oxford, England*. Retrieved from: http://www2.econ.iastate.edu/tesfatsi/SystemDynDiscreteEventABMCompared.BorshchevFilippov04.pdf

Copstein, B., Pereira, C. E., & Wagner, F. R. (1996). The Object-Oriented Approach and the Event Discrete Simulation Paradigms. *European Simulation Multiconference*. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.39.1231&rep=rep1&type=pdf

Friedman, M. (1977, June). Nobel lecture: Inflation and unemployment. *Journal of Political Economy, 85*(3), 451-472 Retrieved from: http://www.jstor.org/stable/1830192

Friedman, M., & Friedman, R. D. (1990). *Free to choose: A personal statement*. San Diego: Harcourt Brace Jovanovich.

Heath, S. K., Brailsford, S. C., Buss, A., & Macal, C. M. (2011). Cross-Paradigm Simulation Modeling: Challenges and Successes. *Proceedings of the 2011 Winter Simulation Conference.* Retrieved from: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6147983

Kau, P. & Hill, L. (1972, August). A threshold model of purchasing decisions. *Journal of Marketing Research, 9*(3), 264-270. Retrieved from: http://www.jstor.org/stable/3149536

Lucas, R. (1976). Econometric policy evaluation: A critique. In Brunner, K., & Meltzer, A. (Eds.) *The Phillips curve and labor markets*, Carnegie-Rochester Conference Series on Public Policy, (Vol. 1), (pp. 19–46). New York: American Elsevier. Retrieved from: http://pareto.uab.es/mcreel/reading_course_2006_2007/lucas1976.pdf

Myers, J. (Interviewer) & Naím, M. (Interviewee). (2005, November 9). *ILLICIT: How smugglers, traffickers, and copycats are hijacking the global economy* [Interview transcript]. Retrieved from The Carnegie Council for Ethics in International Affairs website: http://www.carnegiecouncil.org/studio/multimedia/20051109/index.html

Reierson, R. L. (1957, May). Is inflation avoidable? *The American Economic Review, 47*(2), 145-160. Retrieved from: http://www.jstor.org/stable/1831587

Smith, A. (1843). *An inquiry into the nature and causes of the wealth of nations.* Edinburgh: Thomas Nelson. Retrieved from: http://books.google.com/books?id=8k_K8rf2fnUC

Sowell, T. (2011). *Basic economics: A common sense guide to the economy (4th ed.).* New York: Basic Books.

Tesfatsion, L. (2005, December 18). Agent-based computational economics: A constructive approach to economic theory. Retrieved from: http://www2.econ.iastate.edu/tesfatsi/hbintlt.pdf

Tesfatsion, L. (2012, February 25). Notes on the Lucas critique, time inconsistency, and related issues. Retrieved from: http://www2.econ.iastate.edu/tesfatsi/luccrit.pdf

Tubaro, P. (2009, July). Agent-based computational economics: A methodological appraisal. *Working Paper 2009-42*, University of Paris. Retrieved from: http://www2.econ.iastate.edu/tesfatsi/ACEMethodologicalAppraisal.PaolaTubaro.2009.pdf

U.S. Bureau of Labor Statistics. (2011, October 19). Consumer price index: Frequently asked questions. Retrieved from: http://www.bls.gov/cpi/cpifaq.htm

Value. (2012, December). In *Oxford English Dictionary.* Retrieved from http://www.oed.com/view/Entry/221253?rskey=uSgHCy&result=1