Computer Simulation of Complex Economic Systems

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My Background

- International Political Economy, International Business, Global Economic Systems

- Why Asian Tigers? Korea, Taiwan, Singapore, Hong Kong, Japan, China, Malaysia, Vietnam, INDIA
- Divergence to Convergence

- Economic Growth
  - Knowledge and Economic Growth
  - Increasing returns

- Global Economic Interdependence
  - Varieties of Economic Interdependence – 1814, 1914, 2014
  - Shallow and Deep Interdependence
  - Strategic Interaction in a World of Deep Interdependence

- Complex Systems – analysis of growth and interdependence
  - New Wealth Distribution

Introduction

- There are very substantial potential benefits from Agent Based Modeling (ABMs) of economic systems
  - Redefine and extend theories
  - Resolve paradoxes

- Barrier is created by the meta-theoretical principles of neoclassical economics
  - Rationality at the micro level
  - Equilibrium at the macro level

- Gains can be achieved by applying new theoretical perspectives of complex systems theory to economic systems as basis for ABMs

- Purpose of this talk is to describe some the promising theoretical directions in complex systems and how these could be used to create ABMs

- Specify some of the parameters of agents, rules, forms of interaction

- Follow thinking on simulating economic systems from Tesfatsion, Page, Axelrod, Axtell, and Epstein

What is a complex economic system?

- Economic systems **<u>are</u>** complex systems
  - Individuals, firms, institutions, knowledge, technology, products and markets
- Set of economic agents engaged in trade, investment, complementary production, knowledge trading, competition, strategic interaction, and rules setting and enforcement
- Economic agents are heterogeneous
  - Variation within type (different by degree of type)
  - Diversity of type (specialization)
- Economic systems are in a continuous temporal process of development, novelty, evolution and change
- Equilibrium outcomes require explanation
  - Local attractors within a state space
  - "equilibrium economics is a special case of nonequilibrium and hence complexity economics."

Meta-theoretical Implications of Increasing Returns

- Increasing Returns is the "Holy Grail" of Complexity Economics
- Knowledge is a structure or system of rules of action that yields capabilities for affecting and understanding the environment at a price.
- Increasing returns refers to an increase in output that is not commensurate with the increase in effort and cost necessary to bring it about.
- Increasing returns refers to various processes in a system by which increases in the value of a particular property invoke relationships that generate additional cumulating increases in the value of that property and/or the value of some other property.
- Equilibrium economics requires constant or diminishing returns
- Complexity economics is based on increasing returns

Knowledge, technology, increasing returns and economic complexity

- Knowledge and increasing returns generate dynamic forms of development and change
- Autocatalytic sets flow from increasing returns, promoting self-organizing processes of agent formation and development, innovative mutation, and systemic growth and development.
- Processes of sustained economic growth, development, innovation and systemic transformation are a result of virtuous cycles of increasing returns from knowledge and technology, generating investment cascades.
- Agent interaction leads to emergence of macro patterns, which then affect agent interaction, thereby producing recursive cycles
- “agents, organizations and technology do not steadily proceed toward a global optimum; rather, they are linked to one another and their interactions create (and also ban) pathways for their future development. To use Kauffman’s metaphor, they move around a fitness landscape made of rubber so that everything gets deformed each time a step is taken.”

Knowledge, Increasing Returns and Economic Growth

- Economic growth as a process of cumulative changes in technology and knowledge driving increases in investment and consumption through changes in the capacity to produce.
- Sustained economic growth is driven by the increasing returns from knowledge, which consists of a system of actual and potential gains available to agents able to capture, apply, organize, and innovate in relation to economic production.
- This cumulative change is linked to expansion in the capacity to produce and is primarily a result of investment chasing the gains from the increasing returns from knowledge and technology.
- This conception of economic growth as a system experiencing dynamic change differs dramatically from traditional economic theory, which focuses on systems in equilibrium.

Origins of Increasing Returns in Economic Systems

- Increasing returns to knowledge and technology arise from:
- Reuse (what Arrow calls cumulation) at falling marginal/average cost
- Cumulation (learning) – agent knowledge and system knowledge base create a necessary condition for agent learning, thereby expanding the individual and social base of knowledge
  - Knowledge leads to more knowledge
  - Expands scope of agent capabilities
- Innovation – goods, services, social technologies that previously did not exist and which expand total factor productivity
  - Novelty
  - Recombinant
- Network Effects
- Changes in relative prices – new applications for knowledge
- The scale and scope of increasing returns is directly related to the complementarity and fungibility of knowledge in the system and to the complexity of the networks – nodes and links – that organize the flows of knowledge.
- The scale and scope of changes in relative prices affects the complementary and fungibility of knowledge.

Simulating increasing returns

- Increasing returns in existing simulations
- IR as environmentally generated gains from knowledge reuse and expansion, technology, networks and price changes
- Agents seek to capture IR from environment
  - Variable agent capabilities for knowledge capture, reuse , learning, innovation
  - IR as gains available from knowledge application and changing relative prices
  - Innovation gains are relatively large but rare
- Model learning (capacity for knowledge cumulation) and innovation (generate new products, processes, social technology) in sequence
- Model the capacity to create technology/knowledge standards leading to network effects
- Model interaction effects

Simulating Knowledge, Increasing Returns and Economic Growth

- Agents are differentiated by type:
  - Knowledge agents – identify, organize, recombine, innovate and diffuse
  - Knowledge users – product producers, recombine for products, innovate
  - Investor agents
  - Knowledge is differentiated by degree of complementarity and fungibility
- Knowledge resources of producers
  - Specific algorithms for combining bits of knowledge, plus rules for recombining knowledge, that together form a product
  - Recombinant properties of knowledge: Each bit of knowledge has varying properties of complementarity (how well knowledge combines with other knowledge to generate new ideas and innovations – general purpose technologies) and fungibility (degree of applicability of product or process knowledge to other products or processes)
  - Agents vary by knowledge possessed - varying amount and value of knowledge [complementarity/fungibility scores]; ability to recognize recombinant potential in knowledge; scale of knowledge processing power
- Agents are organized into networks
  - Networks vary by number and type of agents, connectedness, and the volume and type [complementarity and fungibility] of knowledge being diffused
  - Knowledge diffuses across networks

Simulating Economic Growth from Increasing Returns to Knowledge and Technology

- Build a series of simulations for each of source of increasing returns
- Agents as producers of products based on algorithms for combining bits of knowledge
- Agents search for knowledge to improve products
- Agents possess a variety of algorithms for combining knowledge into products and for search
- Agents exist in networks of knowledge production and flows
- Simulate reuse and learning:
  - Agents must invest resources for production, search
  - Reuse of knowledge comes at low rate of resource use
- Simulating innovation
  - How do we distinguish innovation?
  - High value to knowledge complementarities and fungibility

Simulation Operation

- Knowledge diffuses across networks
- Producer agents engage in search across varying parts of the network to gain knowledge that can be recombined with existing knowledge resources
- Knowledge is recombined based on producer algorithms
- Small amount of knowledge has high complementarity and fungibility scores
- Recombined knowledge (products) are subjected to a fitness test.
- Agents retain and discard recombinant algorithms
- Investor agents inject resources (knowledge, recombinant algorithms) into producer agents based on fitness tests
- Knowledge diffuses across the network and cycle restarts
- Simulation tweaks variables in agents, knowledge, networks, and knowledge diffusion for effects on innovation system

Simulating AI-based agents and small-N strategic interaction

- Agents as cooperators in sharing knowledge and competitors in selling products
- AI as learning mechanism for agents in mixing cooperative (share and recombine knowledge) with competitive (withhold knowledge) strategies
- Elements of deep interdependence
  - Complementarities
  - Chains of tightly linked production processes
  - Volume and density of global flows
- Deep interdependence and cooperation among agents
  - Axelrod and Prisoner's Dilemma
  - Creating "shadow of the adaptive future" via additional forms of interdependence among agents
  - Does AI in agents lead to cooperative learning?

Simulating turbulence, inflection points and phase transitions in economic systems

- How changes in the interactions among agents leads to the emergence of distinctive macrosystemic properties
  - Interdependence
  - Inflection points
  - Turbulence
- Tightly coupled, complementary, asymmetrically interdependent, and functionally differentiated agents
- Modifying Wolf-Sheep-Grass
  - Add additional food chain(s) with new points of interdependence
  - Rising numbers of functionally differentiated agents
- Link increasing returns to W-S-G
- Shifts from equilibrium to dis-equilibrium
- Effects of general purpose knowledge (high complementarity and fungibility)
- Macro system outcomes

Economic Dynamics

- Economic Dynamics – Divergence to Convergence
- 1820-1970 = divergence
- 1970 – 2016 = convergence
- Divergence is easy – wealth distribution leads to power law
- Convergence is hard
- Really hard is simulating a system that shifts from divergence to convergence
- Does this system reflect phase transitions linked to knowledge and political power, outside of market relations?

Simple simulation of market booms and busts

- A very simple model of financial markets can generate the oscillations, booms and busts typically found in real markets but which most existing simulations fail to replicate.
- Model markets via leaders, followers (positive and negative), exogenous inputs of money, and information about growth rates for the economy.
- Small fluctuations in monetary policy plus increased growth can lead to large changes in market prices.
- Get overshooting above and below growth rates for the economy
- How much herd behavior is required to generate overshooting?

Simulating the distribution of firm size in economic systems

- Does the empirical distribution of firm size in a capitalist system of free markets conform to a power law distribution?
- Wealth distribution reworked for firm size
- Small variation in firm capabilities in markets = large concentration in size
- Power Law

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