Agent-Based Computational Economics

Modeling Economies as Complex Adaptive Systems

Presenter:

Leigh Tesfatsion

Professor of Econ, Math, and

Electrical & Computer Engineering

Iowa State University, Ames, Iowa 50011-1070

http://www.econ.iastate.edu/tesfatsi/

tesfatsi@iastate.edu

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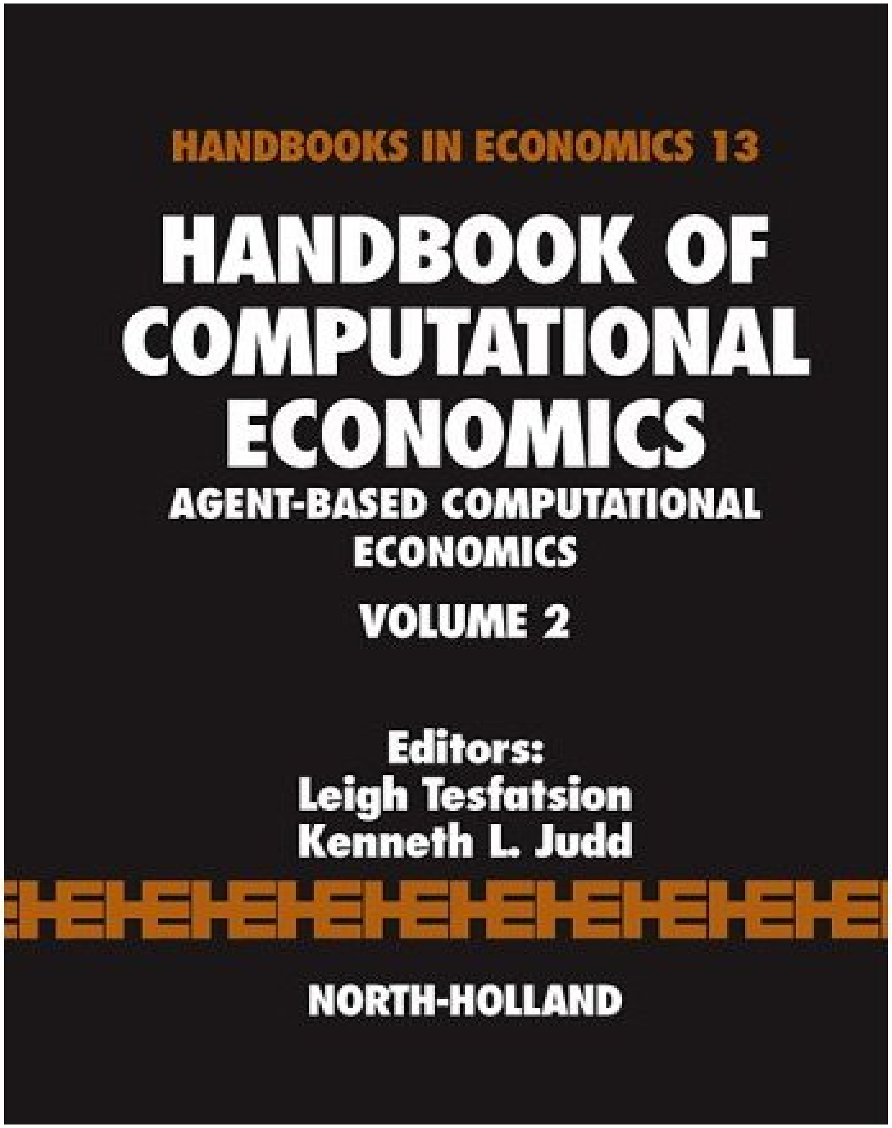
Outline

- **Complexity of Economic Processes**
- **Agent-Based Computational Economics (ACE)**
- **ACE Market Modeling: Examples**
  1. Double-Auction Market Model
  2. Two-Sector Trading World (Hash & Beans)
  3. Eurace: National Economy Modeling
  4. Labor Market Networks Study
  5. Trade Network Game (TNG)
  6. Restructured Electricity Market Study
- **Potential Advantages/Disadvantages of ACE**

ACE Resources

- ACE Website
  www.econ.iastate.edu/tesfatsi/ace.htm

- ACE Handbook (Tesfatsion & Judd, Handbooks in Economics Series, North-Holland, 2006, 904pp)
  www.econ.iastate.edu/tesfatsi/hbace.htm


HANDBOOKS IN ECONOMICS 13
HANDBOOK OF COMPUTATIONAL ECONOMICS
AGENT-BASED COMPUTATIONAL ECONOMICS
VOLUME 2
Editors:
Leigh Tesfatsion
Kenneth L. Judd
NORTH-HOLLAND

Current ACE Research Areas

(http://www.econ.iastate.edu/tesfatsi/aapplic.htm)

- Learning and embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies (labor, electricity, finance…)
- Industrial organisation
- Technological change and growth
- Multiple-market economies
- Market design
- Automated markets and software agents
- Development of computational laboratories
- Parallel experiments (real and computational agents)
- Empirical validation…. ***and many more areas as well!***

The Complexity of Economic Processes

- Large numbers of economic agents involved in ***distributed local interactions***
- ***Two-way feedback*** between microstructure and macro regularities mediated by agent interactions
- Potential for ***strategic behaviour***
- ***Pervasive behavioural uncertainty***
- Possible existence of ***multiple equilibria***
- ***Critical role of institutional arrangements***

What is Agent-Based Computational Economics (ACE)?

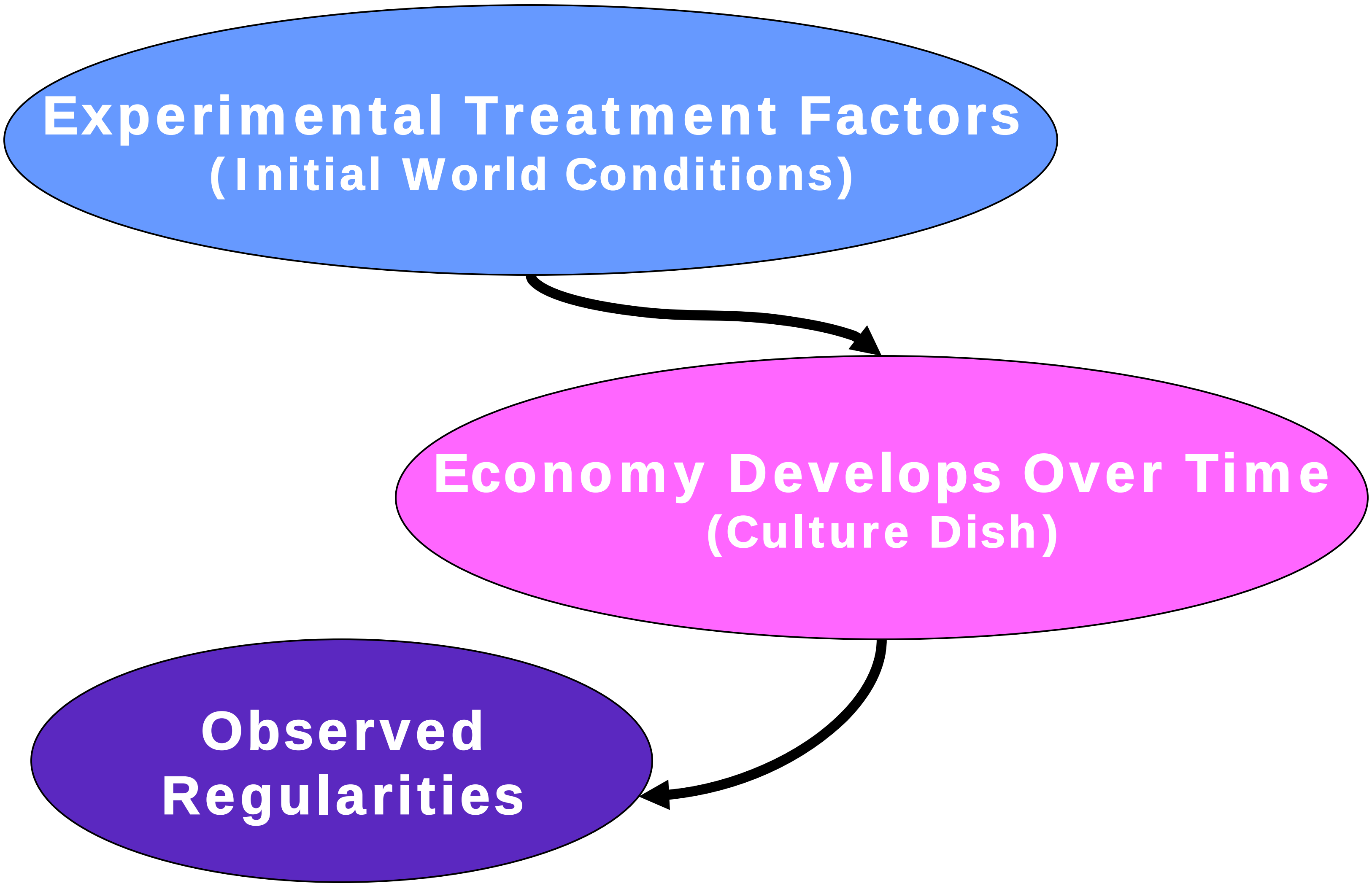
- **Culture-dish approach** to the study of decentralized market processes

- **Computational study** of economic processes modeled as dynamic systems of interacting agents

ACE Modeling: Culture Dish Analogy

- Modeler constructs a **virtual economic world** populated by various agent types (economic, social, biological, physical)
- Modeler sets **initial world conditions**
- Modeler then steps back to observe how the **world develops over time** (no further intervention by the modeler is permitted)
- *World events are* ***driven by agent interactions***

ACE Modeling:
Culture Dish Analogy



Key Characteristics of ACE Models

- **Agents** are encapsulated software entities capable (in various degrees) of
  - ***Adaptation*** to environmental conditions
  - ***Social communication*** with other agents
  - ***Goal-directed learning***
  - ***Autonomy*** (self-activation and self-determinism based on private internal processes)
- Agents can be situated in **realistically rendered problem environments**
- **Behaviour and interaction patterns can develop/evolve over time**

Four Main Strands of ACE Research

- **Empirical Understanding**
  (possible reasons for observed regularities)
- **Normative Understanding**
  (market design, fiscal/monetary policy design,...)
- **Qualitative Insight/Theory Generation**
  (self-organization of decentralized markets,...)
- **Methodological Advancement**
  (representation, visualization, validation,...)

ACE and Observed Regularities

Key Issue: Is there a causal explanation for a ***persistently observed regularity?***

ACE Approach:

- Construct an ***agent-based world*** capturing salient aspects of the empirical situation.
- Investigate whether the observed regularity can be ***reliably generated*** as an outcome in this agent-based world.
- ***Example:*** ACE financial market research
  www.econ.iastate.edu/tesfatsi/afinance.htm

ACE and Institutional Design

Key Issue: Does a proposed or actual institutional design ensure **efficient, fair, and orderly social outcomes over time** despite repeated attempts by traders to "game" the design for their own personal advantage?

ACE Approach:

- Construct an ***agent-based world*** capturing salient aspects of the institutional design.
- ***Introduce self-interested agents with learning capabilities.*** Let the world evolve. Observe/evaluate resulting social outcomes.

ACE and Qualitative Analysis

A Key Issue: What are the performance capabilities of decentralized markets?

(Adam Smith, F. Hayek, ...)

ACE Approach:

- Construct an ***agent-based world*** qualitatively capturing key aspects of decentralized market economies (circular flow, limited information, ...)
- ***Introduce self-interested traders with learning capabilities.*** Let the world evolve. Observe the degree of coordination that results.

Example 1: Study of a Relatively Simple Double-Auction Market Design

- J. Nicolaisen, V. Petrov, and L. Tesfatsion, *IEEE Transactions on Evolutionary Computation*, 5(5), 2001, pp. 504-523 (C++/MatLab)

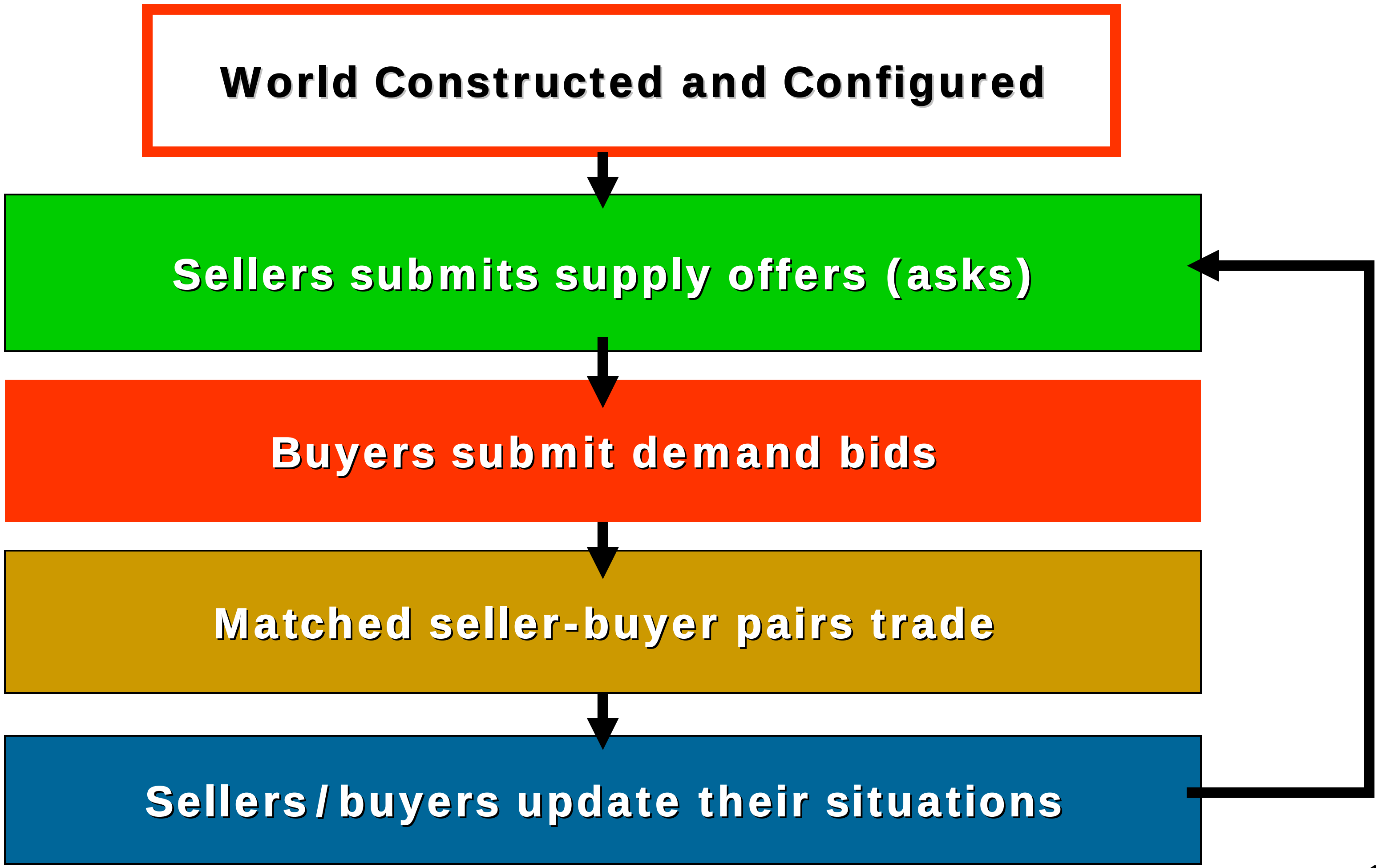
  www.econ.iastate.edu/tesfatsi/mpeieee.pdf

- **Key Issue Addressed:**

  Relative role of **structure vs. learning** in determining the performance of a double-auction design for a day-ahead electricity market.

Double-Auction Electricity Market

(Nicolaisen, Petrov, Tesfatsion, IEEE-TEC, Vol. 5, 2001)



Key Issue Addressed

Relative role of **structure vs. learning** in determining double-auction performance.

* Sensitivity of market efficiency and market power outcomes to changes in market structure

  RCON = Relative seller/buyer concentration

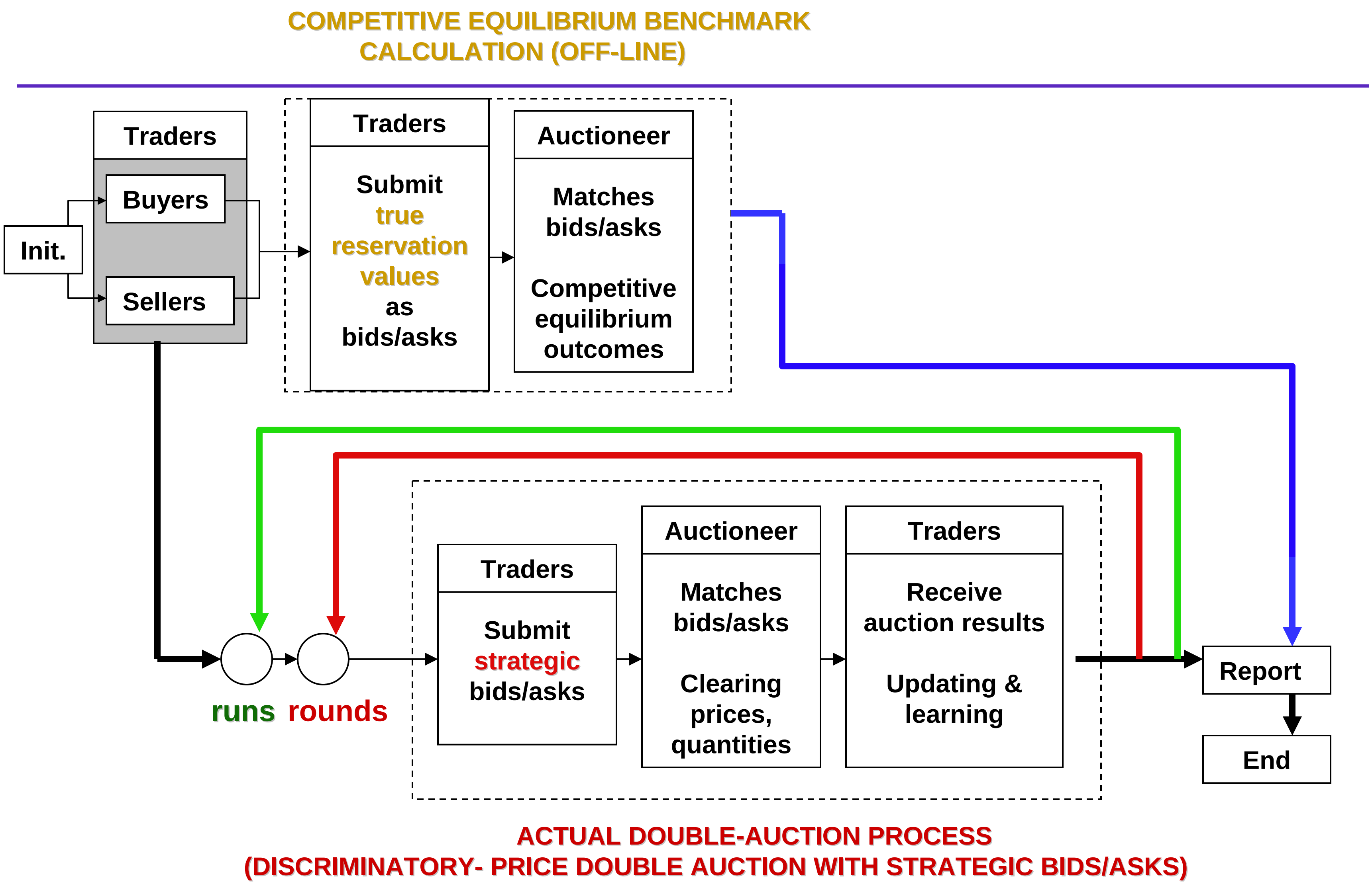
  RCAP = Relative demand/supply capacity

* Sensitivity of market efficiency and market power outcomes to changes in trader learning representations: Reinforcement Learning (RL) vs. social mimicry via Genetic Algorithms (GAs).

Market Efficiency, Market Power, and Market Concentration

- ***Market Efficiency:*** *the degree to which market participants succeed in extracting maximum total net benefits from the market.*
- ***Market power:*** the degree to which a market participant can profitably influence prices away from competitive levels.
- ***Market concentration:*** the degree to which the majority of market activity is performed by a minority of the market participants.

Activity Flow for the Double Auction (DA)



The Computational World

Public Access:

// **Public Methods**

The ***World Event Schedule,*** i.e., a system clock that permits inhabitants to time and synchronize activities (e.g., submission of asks/bids into the DA market);

Protocols governing trader collusion;

Protocols governing trader insolvency;

Methods for receiving data;

Methods for retrieving World data.

Private Access:

// **Private Methods**

Methods for gathering, storing, and sending data;

// **Private Data**

World attributes (e.g., spatial configuration);

World inhabitants (DA market, buyers, sellers);

World inhabitants' methods and data.

The Computational DA Market

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
Protocols governing the public posting of asks/bids;
Protocols governing matching, trades, and settlements;
Methods for receiving data;
Methods for retrieving Market data.

Private Access:

// **Private Methods**

Methods for gathering, storing, and sending data.

// **Private Data**

Data recorded about sellers (e.g., seller asks);
Data recorded about buyers (e.g., buyer bids);
Address book (communication links).

A Computational DA Trader

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
getWorldProtocols (collusion, insolvency);
getMarketProtocols (posting, matching, trade, settlement);
Methods for receiving data;
Methods for retrieving Trader data.

Private Access:

// **Private Methods**

Method for calculating my expected profit assessments;
Method for calculating my actual profit outcomes;
Method for updating my ask/bid strategy (**LEARNING**).

// **Private Data**

Data about me (history, profit function, current wealth,…);
Data about external world (rivals' asks/bids, …);
Address book (communication links).

Dynamic Flow of DA Market

World Constructed. World configures DA Market and Traders, and starts the clock.

↓

Traders receive time signal and submit asks/bids to DA Market

↓

DA Market matches sellers with buyers and posts matches

↓

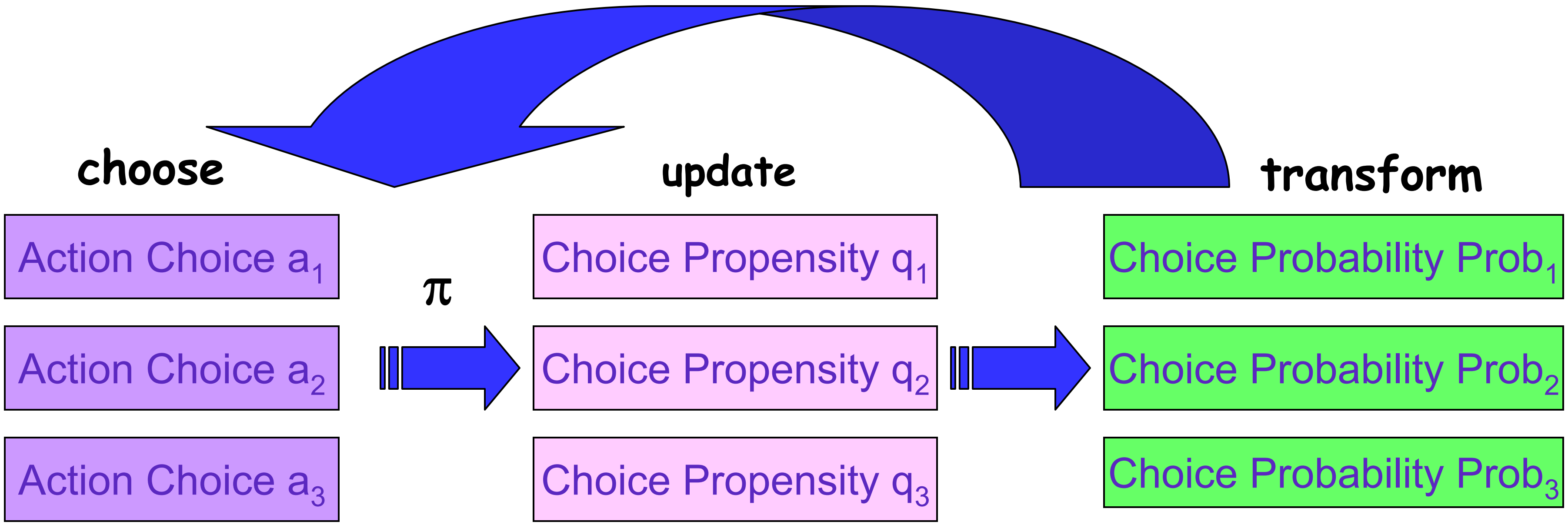
Traders receive posting, conduct trades, and calculate profits

↓

Traders update their exp's & trade strategies

(loop back to "Traders receive time signal")

Traders Learn to Select Asks/Bids ("Actions") via Modified Roth-Erev RL



- Action choice a leads to profits π, followed by updating of action choice propensities q based on these profits, followed by transformation of these propensities into action choice probabilities Prob

Roth-Erev Algorithm Outline

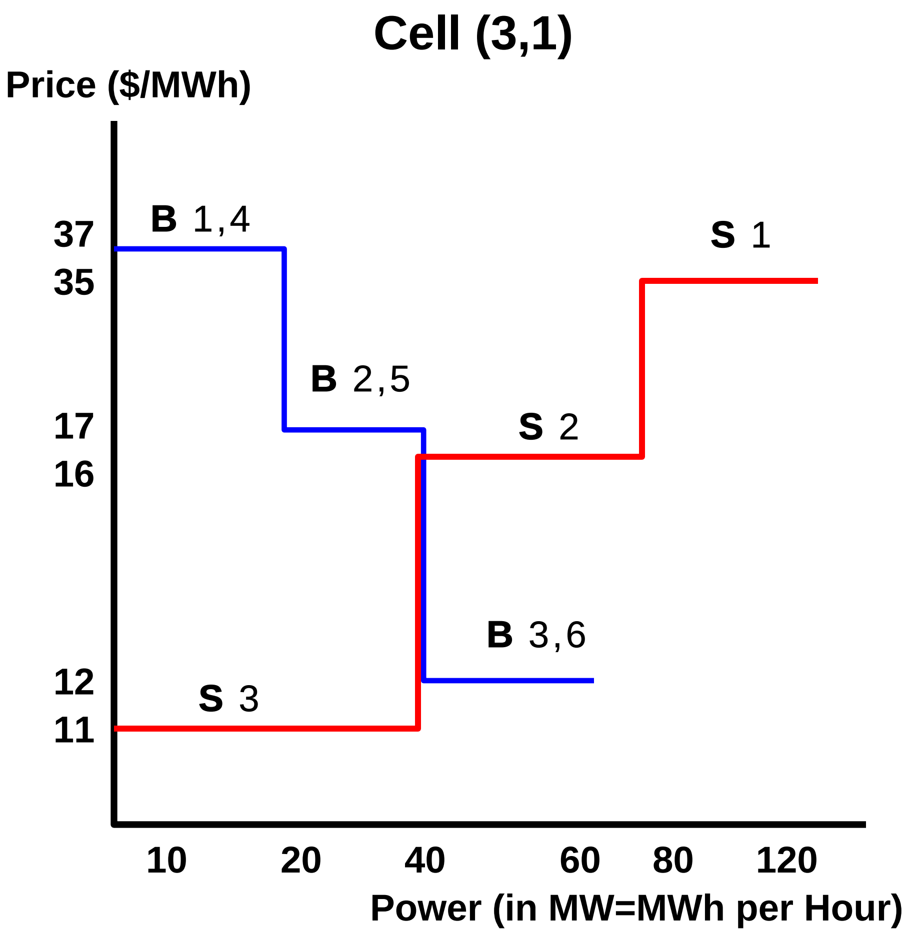
1. **Initialize** action propensities to an initial propensity value.
2. **Generate** choice probabilities for all actions using current propensities.
3. **Choose** an action according to the current choice probability distribution.
4. **Update** propensities for all actions using the reward (profits) for the last chosen action.
5. **Repeat** from step 2.

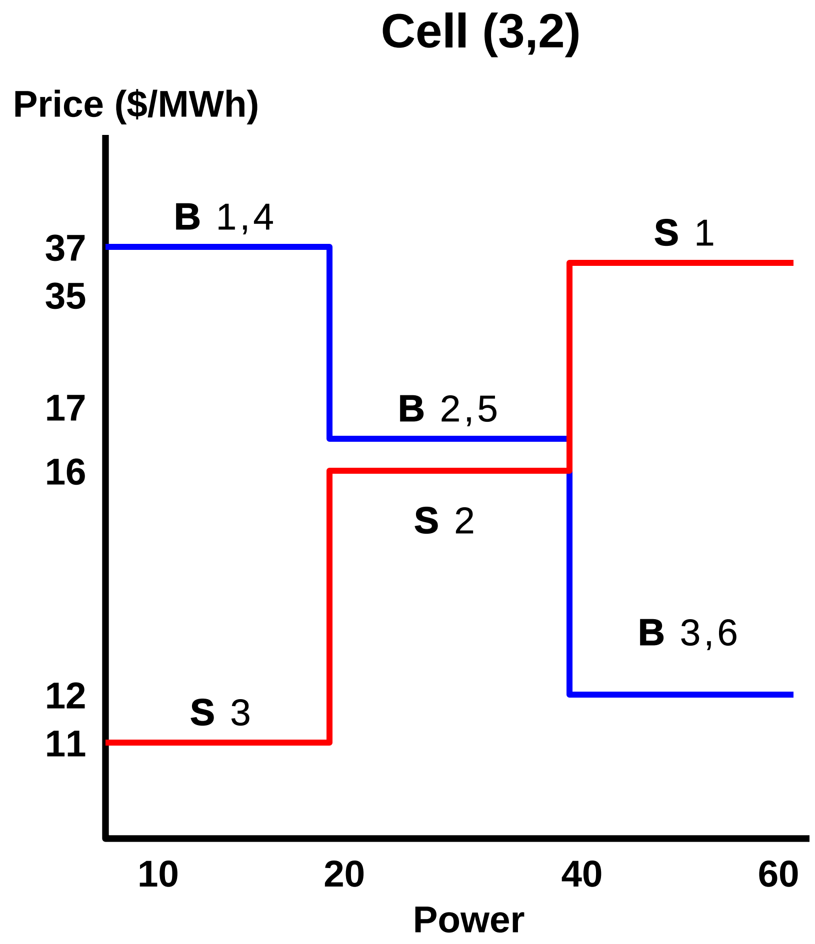
Structural Treatment Factor Values (tested for each learning treatment)

Ns = Number of Sellers
Nb = Number of Buyers
Cs = Seller Supply Capacity
Cb = Buyer Demand Capacity

		RCAP		
		1 / 2	1	2
RCON	2	Ns = 6 Nb = 3 Cs = 10 Cb = 10	Ns = 6 Nb = 3 Cs = 10 Cb = 20	Ns = 6 Nb = 3 Cs = 10 Cb = 40
RCON	1	Ns = 3 Nb = 3 Cs = 20 Cb = 10	Ns = 3 Nb = 3 Cs = 10 Cb = 10	Ns = 3 Nb = 3 Cs = 10 Cb = 20
RCON	1 / 2	Ns = 3 Nb = 6 Cs = 40 Cb = 10	Ns = 3 Nb = 6 Cs = 20 Cb = 10	Ns = 3 Nb = 6 Cs = 10 Cb = 10

Aggregate True Demand and Supply per Hour





Summary of Policy-Relevant DA Findings

- **Market Efficiency:** Generally high when traders use Roth-Erev individual reinforcement learning **but not** when traders use GA social mimicry (***type of learning can matter***).
- **Structural Market Power:** Microstructure of the DA market is strongly predictive for the relative market power of traders (***rule details matter***).
- **Strategic Market Power:** Traders are **not** able to change their relative market power through learning (***importance of countervailing power***).

Example 2: From Standard General Equilibrium to an ACE Trading World

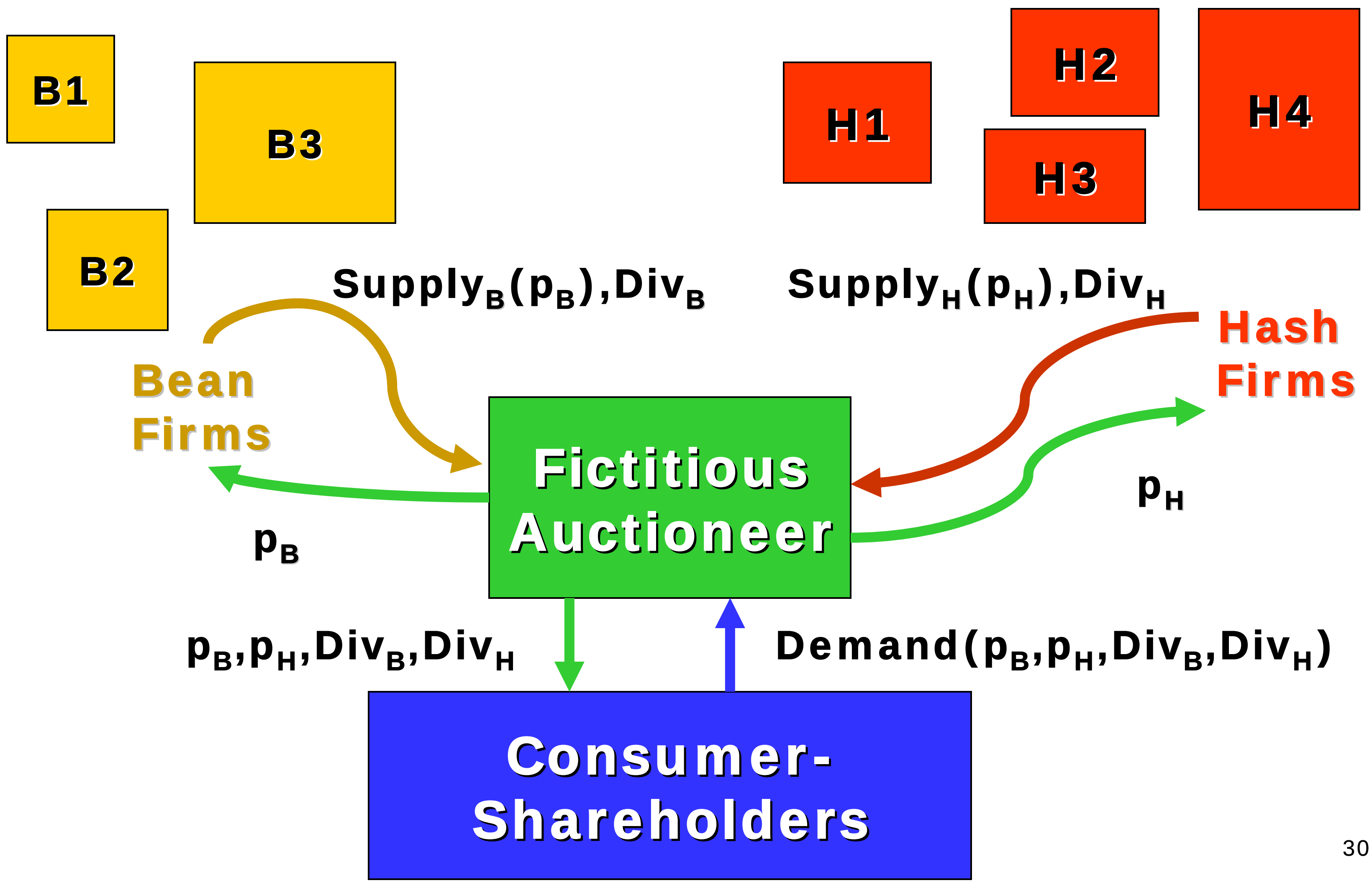
Starting Point:

Two-Sector General Equilibrium (GE) Economy

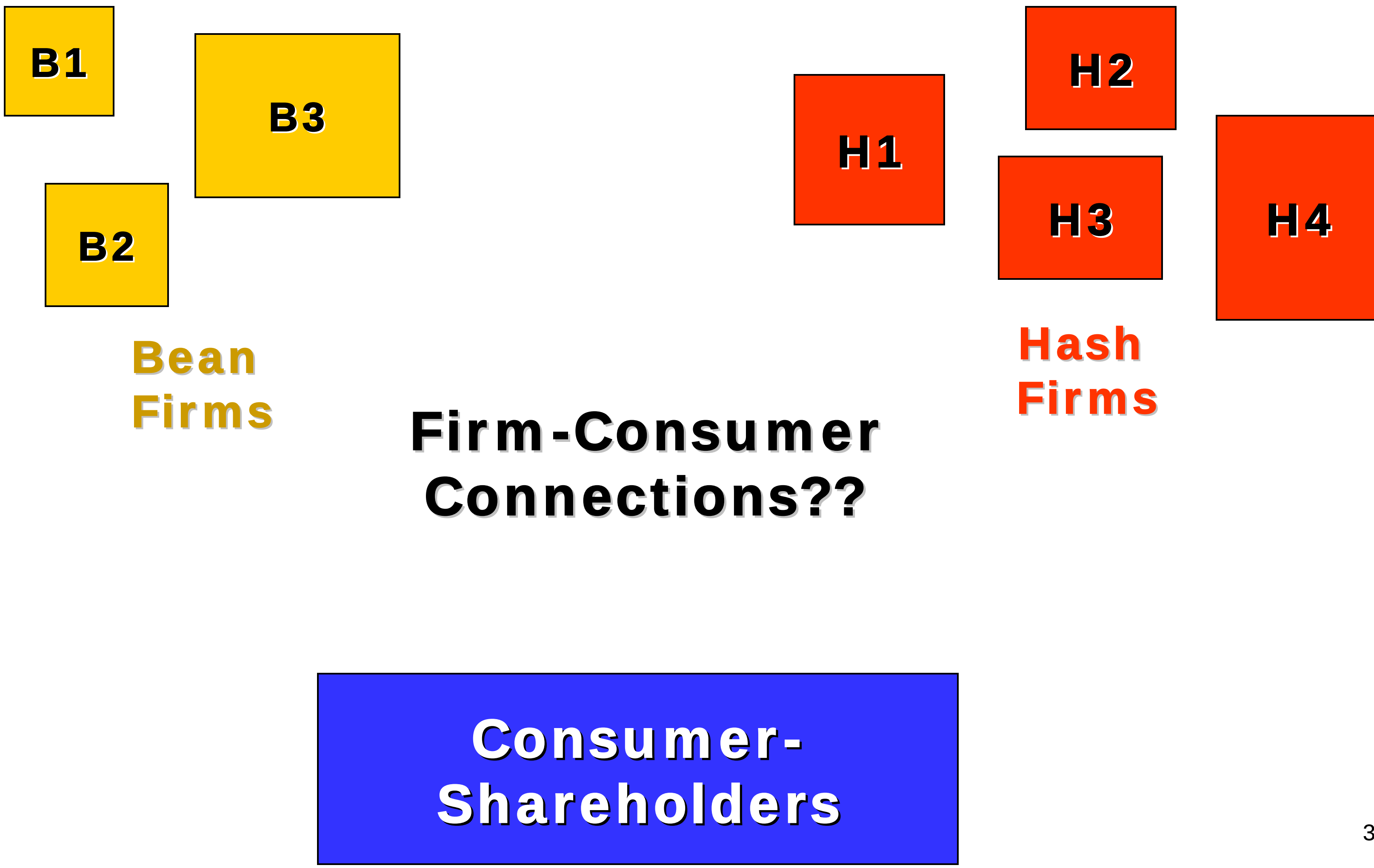
Exercise:

- **Remove** all imposed ***equilibrium*** conditions (e.g., market clearing, correct expectations,…)
- **Introduce** minimal ***agent-driven*** production, pricing, and trade processes needed to re-establish complete circular flow among firms and consumers
- **Experiment** to see if/when resulting economy is able to attain an “equilibrium” state over time

Starting Point:
Gen Equilibrium Hash & Beans Economy



Plucking Out the Fictitious Auctioneer

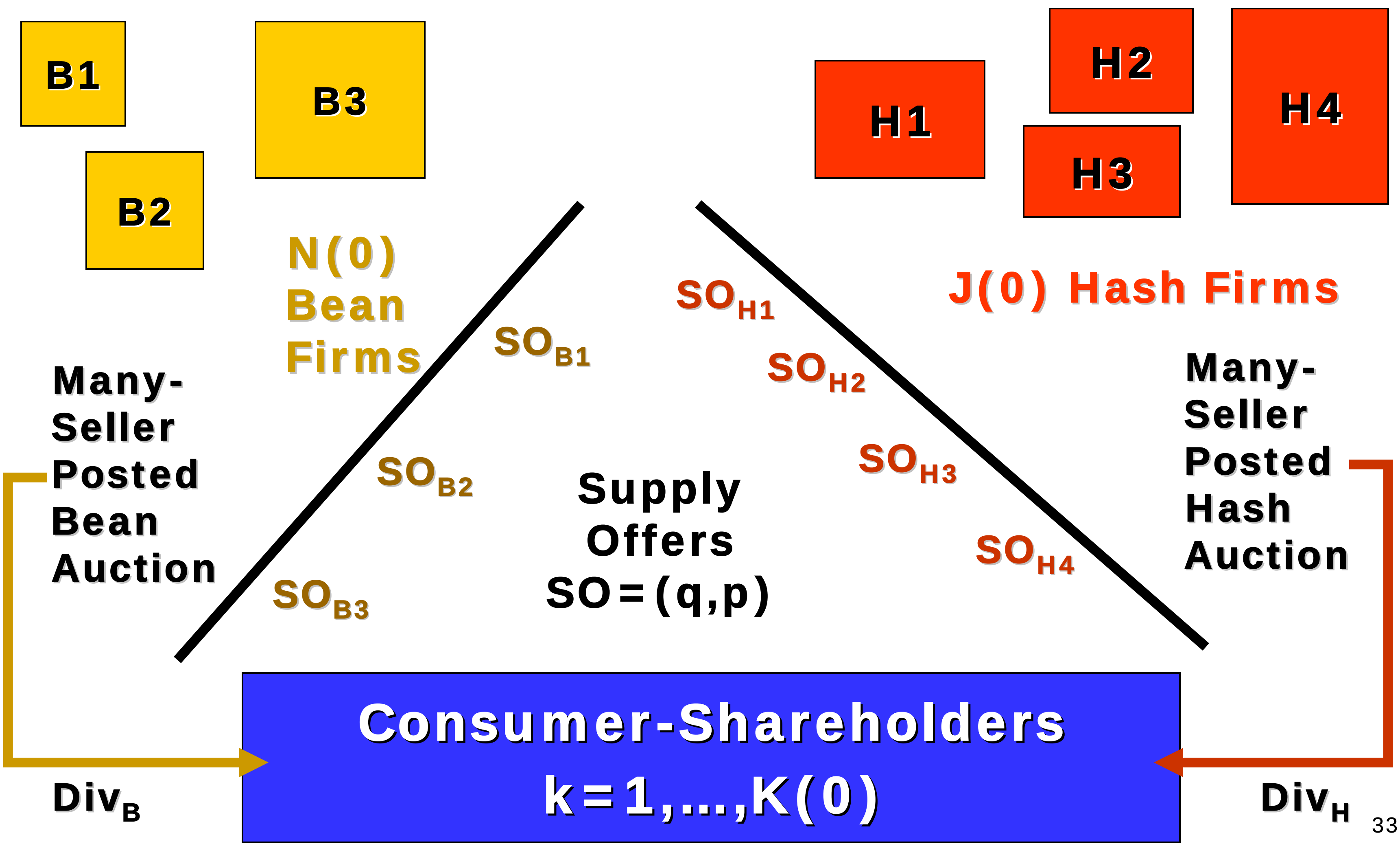


Plucking Out the Fictitious Auctioneer

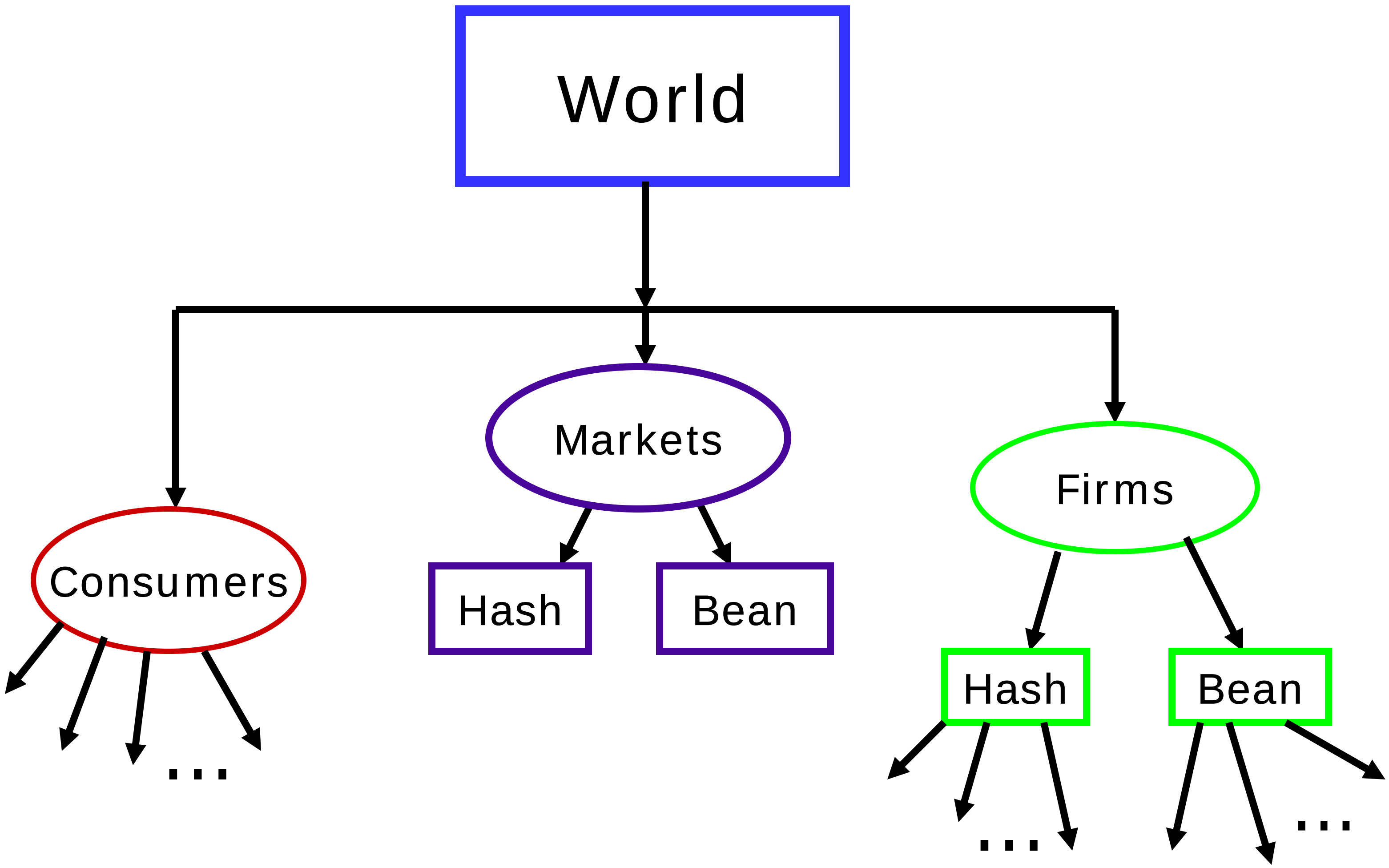
Focus must now be procurement processes

- ***Terms of Trade:*** Set production and price levels
- ***Seller-Buyer Matching:***
  - Identify potential suppliers/customers
  - Compare/evaluate opportunities
  - Submit demand bids/supply offers
  - Select suppliers/customers
  - Negotiate supplier/customer contracts
- ***Trade:*** Transactions carried out
- ***Settlement:*** Payment processing and shake-out
- ***Manage:*** Long-term supplier/customer relations

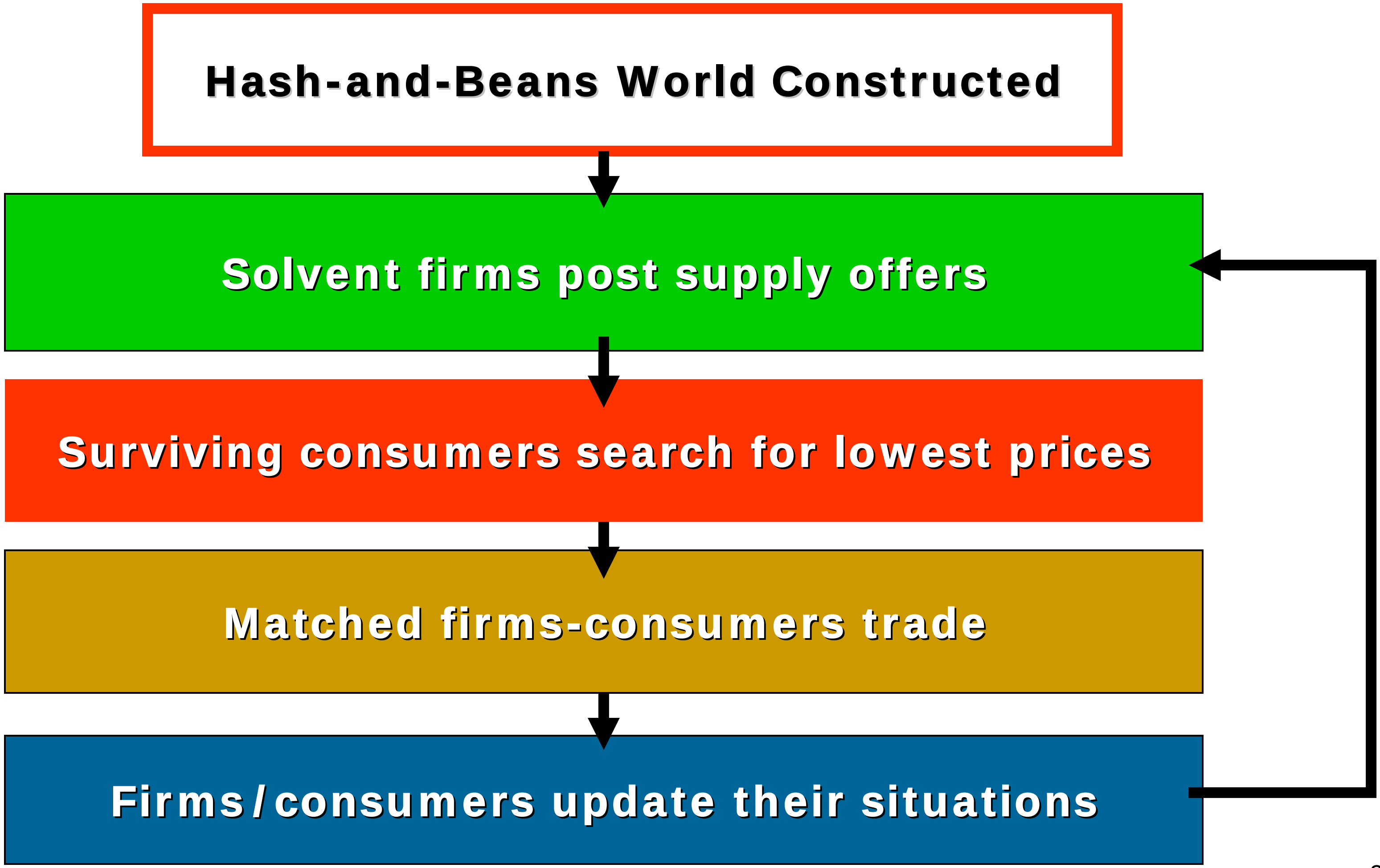
Illustration:
An ACE Hash & Beans Economy



ACE Hash & Beans Economy: Agent Hierarchy



ACE Hash & Beans Economy: Dynamic Activity Flow



ACE Hash and Bean Firms

- Each firm f starts out (T=0) with ***money $M_f(0)$*** and a ***production capacity $Cap_f(0)$***
- Firm f's ***pro-rated fixed cost $FC_f(T)$*** in each $T \geq 0$ is proportional to its current capacity $Cap_f(T)$
- At beginning of each $T \geq 0$, firm f posts a ***supply offer = (production level, unit price)***
- At end of $T \geq 0$, firm f is ***solvent*** if it has $NetWorth(T) = [Profit(T)+M_f(T)+ValCap_f(T)] > 0$
- If solvent, firm f ***allocates its profits*** (+ or -) between M_f , CAP_f, and dividend payments.

ACE Consumer-Shareholders

- Each consumer k starts out (T=0) with a ***lifetime money endowment profile***

  $$(Mk_{youth} ,\ Mk_{middle} ,\ Mk_{old})$$

- In each T ≥ 0, consumer k's **utility** is measured by $U_k(T) = (hash(T) - h_k^*)^{\alpha_k} \bullet (bean(T) - b_k^*)^{[1-\alpha_k]}$
- In each T ≥ 0, consumer k seeks to secure maximum utility by ***searching*** for bean and hash to buy at ***lowest possible prices***.
- At end of each T ≥ 0, consumer k ***dies*** unless consumption meets subsistence needs (b_k^*, h_k^*).

Experimental Design Treatment Factors

- **Initial size of consumer sector** [K(0)]
- **Initial concentration** [N(0), J(0), Cap(0) values]
- **Learning** (supply offer/profit allocation decisions)
- **Cost functions**
- **Firm initial money holdings** [$M_f(0)$]
- **Market rationing protocol** (for excess demand)
- **Consumer search process**
- **Consumer money endowment profiles/TMax** (rich, poor, ↗ , ↘ , life cycle u-shape)
- **Preferences** (θ values)
- **Subsistence needs** (b*,h*)

Marc Oeffner's implementation of Agent Island: an Extended ACE H&B Economy with Labor & Banking (Thesis, 2008, Julius-Maximilians-Universitat Wurzburg)

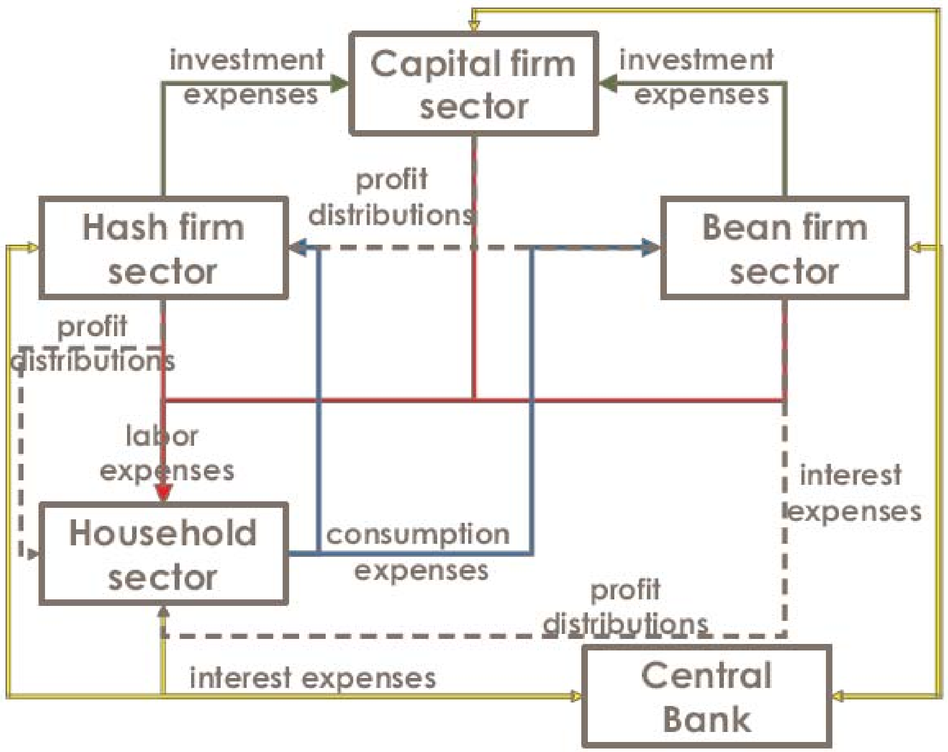


Figure 2.1: Markets and transactions on Agent Island

Thesis/Code (SeSAm) Available At:
www.iastate.edu/tesfatsi/amulmark.htm

Equity and Loan Financing in Agent Island

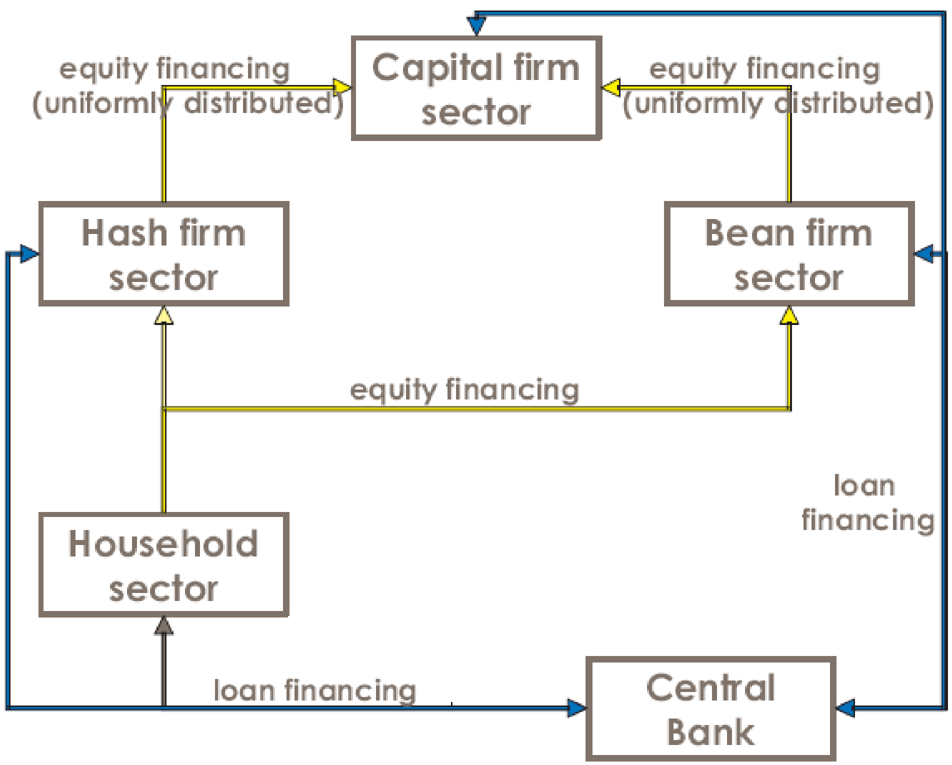


Figure 2.2: Financing contracts on Agent Island

Daily Activity Flow in Agent Island

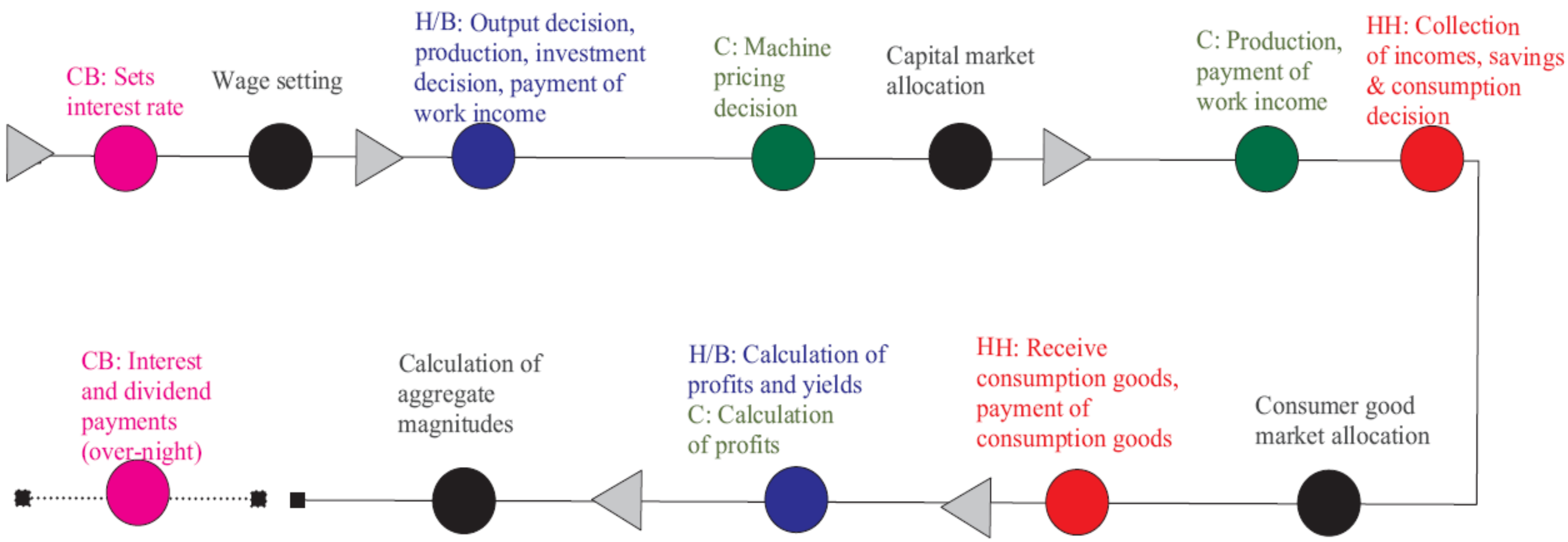


Figure 2.3: Intra–period sequence of decisions and actions

Sample Outcomes for Agent Island

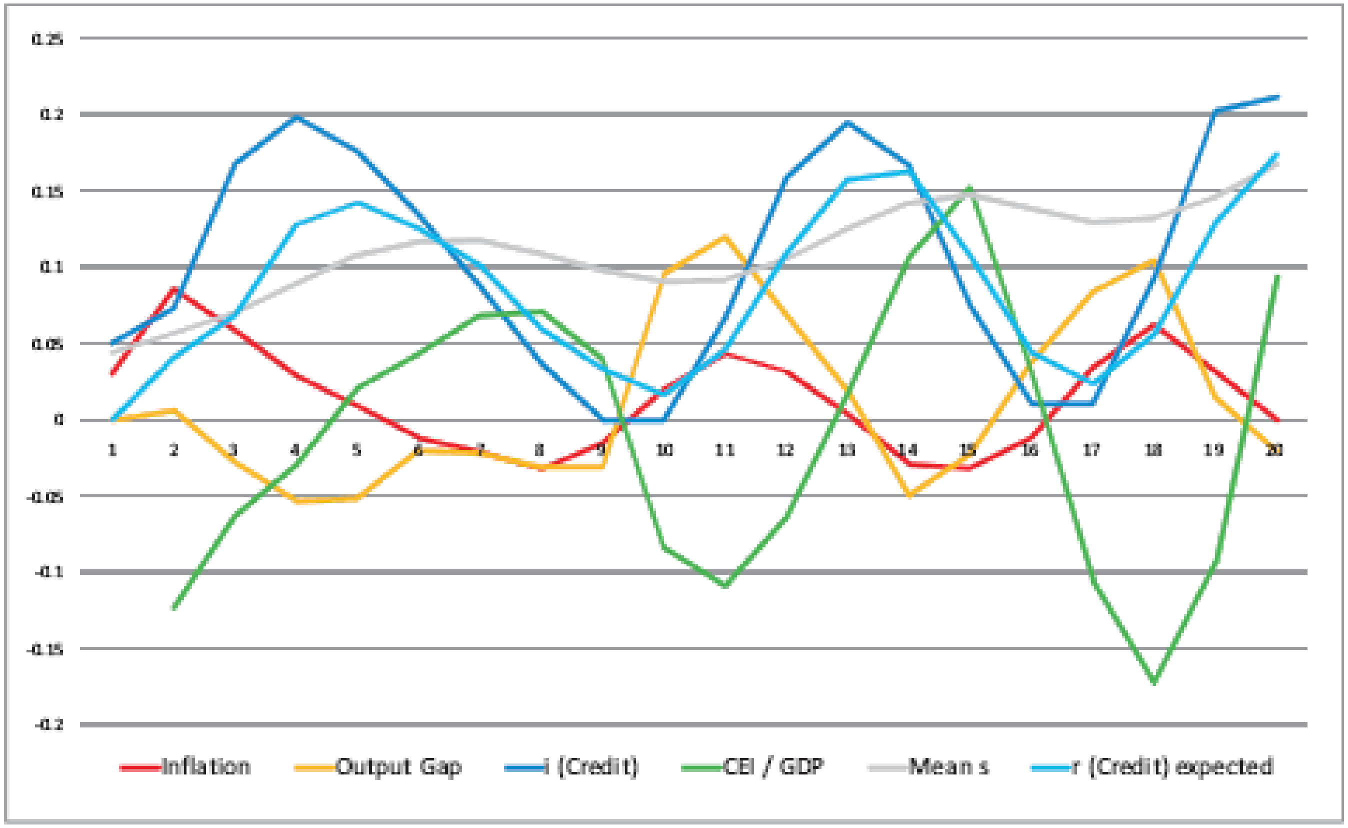
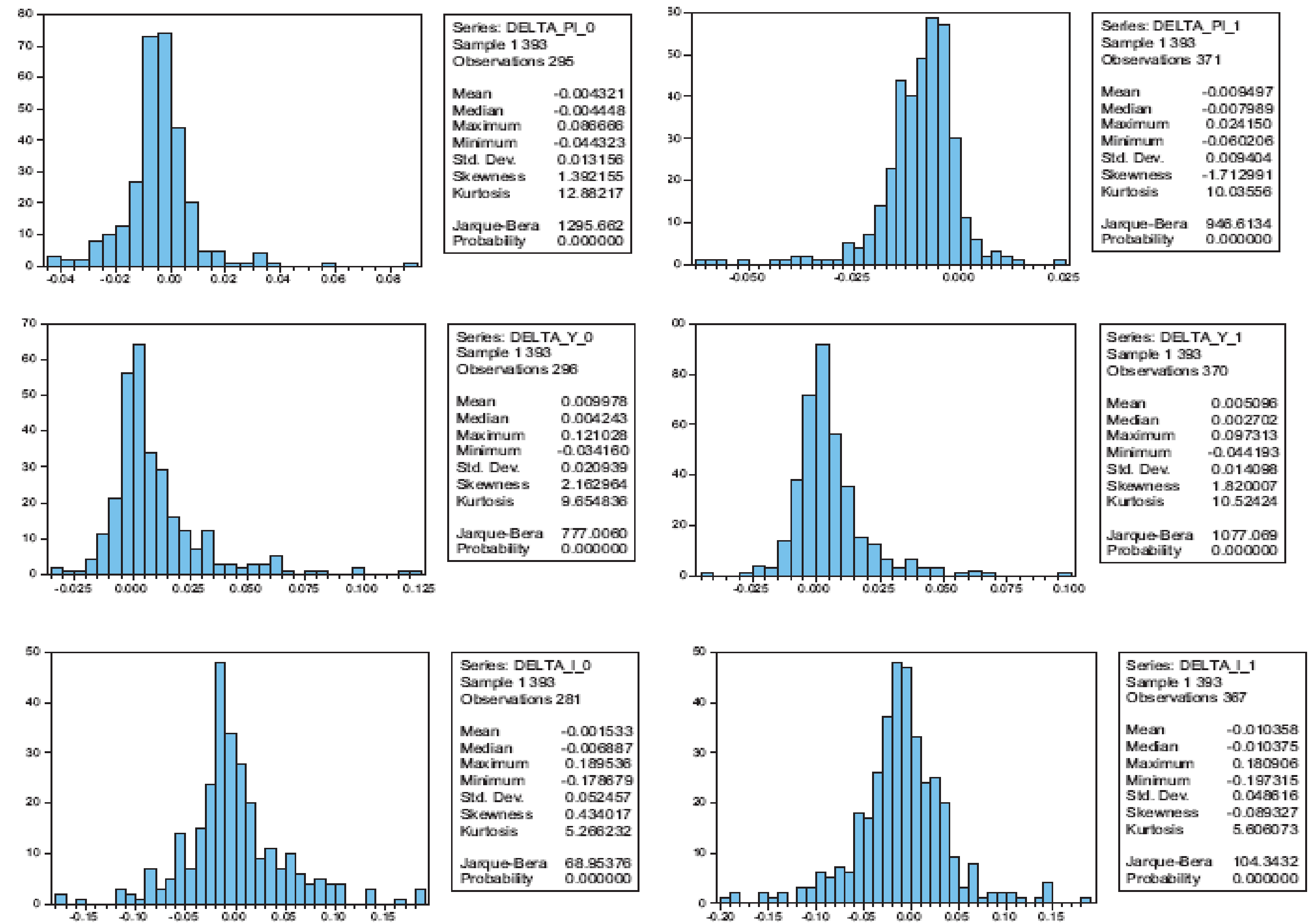


Figure 3.33: Stylized facts of the second rerun in the baseline case



Note: Left panels illustrate the effect in the period of the shock, right panels illustrate the effect one period after the interest rate shock.

Figure 3.30: Baseline case – effects of an increase of credit interest rates by 1 percentage point in the simulation data depicted by histograms for inflation rates (upper panels), real output (central panels), and investment demand (lower panels)

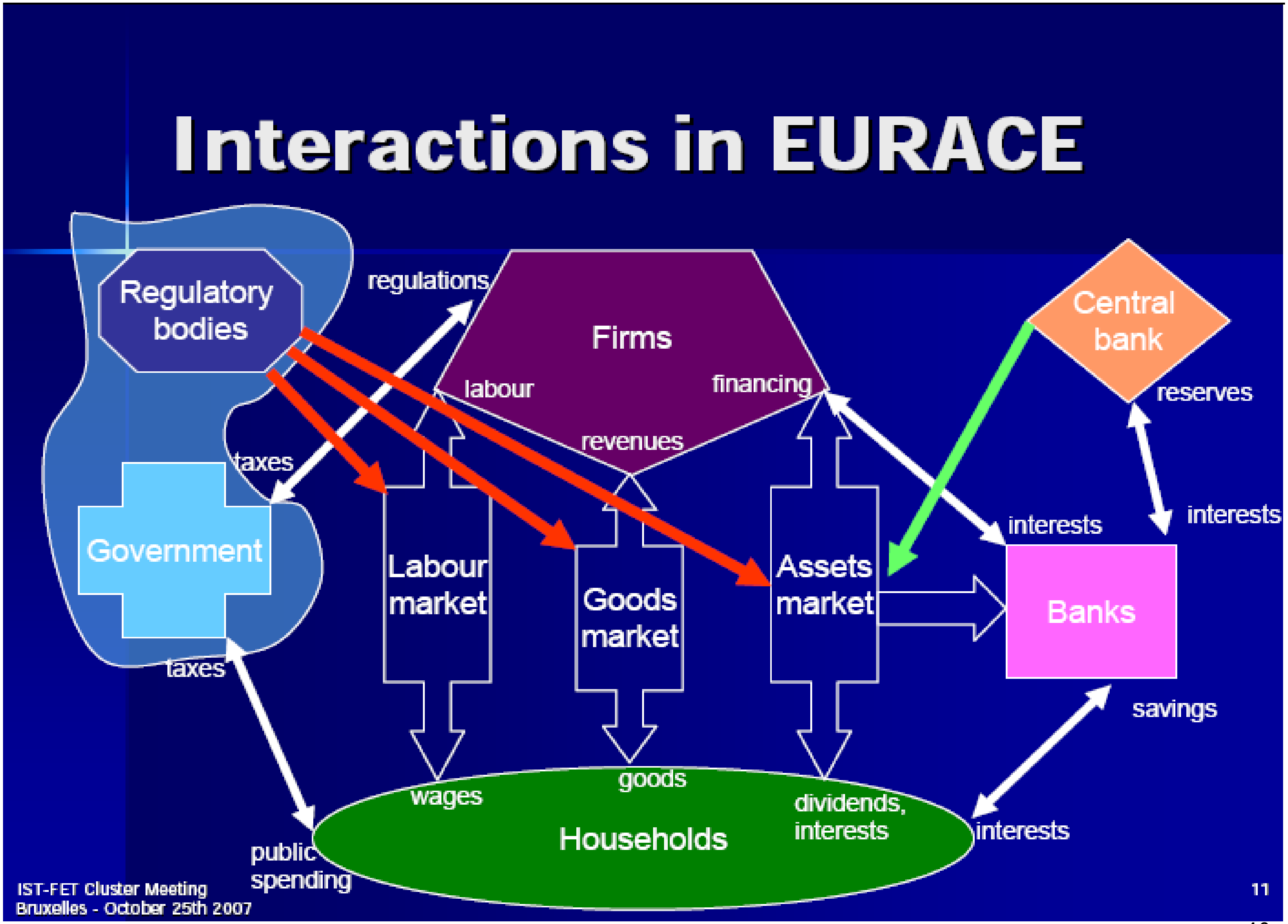
Example 3: EURACE -- Large-Scale ACE Model of the EU

EURACE Objectives

- From a scientific point of view
  - The study and the development of multi-agent models that reproduce, at the aggregate economic level, the emergence of global features as a self-organized process from the complex pattern of interactions among heterogeneous individuals
- From a technological point of view
  - The development, with advanced software engineering techniques, of a software platform in order to realize a powerful environment for large-scale agent-based economic simulations
- From a societal point of view
  - Outstanding impact on the economic policy design capabilities of the European Union, allowing "what-if" analysis in order to optimize the impact of regulatory decisions that will be quantitatively based on European economy scenarios

EURACE Consortium 2/3

Participant	Country	Role	Research Unit Head	Competences
University of Genoa	Italy	Coordinator	Silvano Cincotti	Agent-based computational economics and software engineering. Economic policy design
University of Bielefeld	Germany	Partner	Herbert Dawid	Agent-based computational economics. Economic policy design
Université de la Méditerranée	France	Partner	Christophe Deissenberg	Agent-based computational economics. Economic policy design
National Research Institute of Electronics and Cryptology	Turkey	Partner	Kaan Erkan	Software engineering
University of Ancona	Italy	Partner	Mauro Gallegati	Agent-based computational economics. Economic policy design
University of Sheffield	UK	Partner	Mike Holcombe	Software engineering and computer science
University of Cagliari	Italy	Partner	Michele Marchesi	Software engineering
Rutherford Appleton Laboratory (STFC), was CCLRC until April 2007	UK	Partner	Christopher Greenough	Computer science


Interactions in EURACE
Regulatory bodies
regulations
Firms
labour
financing
revenues
Central bank
reserves
taxes
Government
interests
interests
Labour market
Goods market
Assets market
Banks
taxes
savings
wages
goods
dividends, interests
interests
Households
public spending
IST-FET Cluster Meeting
Bruxelles - October 25th 2007
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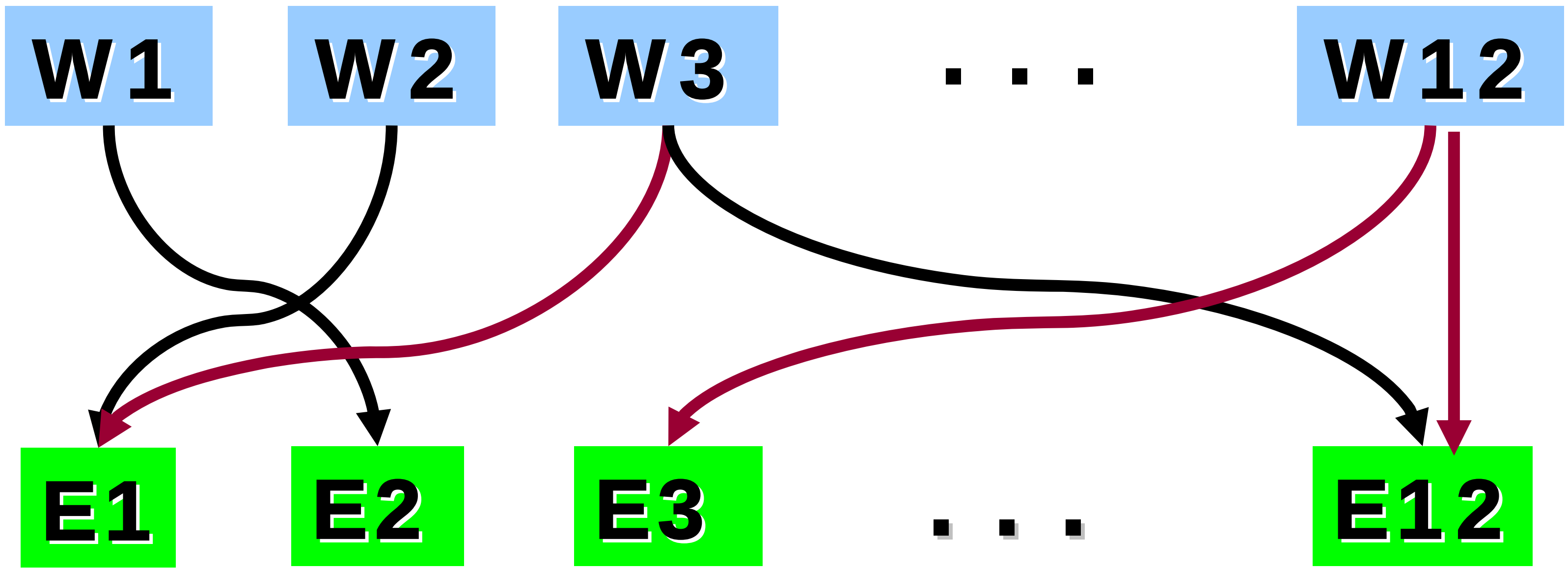
Example 4: ACE Labor Market

- **Joint work with M. Pingle (U of Nevada-Reno)**
- Published in *New Directions in Networks,* 2003, Edward-Elgar volume, edited by A. Nagurney

  M. Pingle and L. Tesfatsion, "Evolution of Worker-Employer Networks and Behaviors under Alternative Non-Employment Benefits: An Agent-Based Computational Economics Study"

- Pre-print available at **www.econ.iastate.edu/tesfatsi/alabmplt.pdf**
- Parallel human-subject experiments conducted

ACE Labor Market Framework



Preferential job search with choice/refusal of partners:
Red directed arrow indicates **refused work offer**.

Focus on Interaction Effects ➔ Endogenous Heterogeneity of Agents

- 12 workers with **same observable attributes** in initial period T=0
- 12 employers with **same observable attributes** in initial period T=0
- Each worker can work for at most one employer in each period T
- Each employer can provide at most one job opening in each period T
- **Worksite strategies** in initial period T=0 are **random and private info**

Each worker and employer has...

- ***Publicly available information*** about various market/policy protocols, e.g., knowledge that each non-employed worker and vacant employer receives a ***Non-Employment Payment (NEP)***
- ***Private behavioral methods*** that can evolve over time
- ***Privately stored data*** that can change over time

A Worker Agent

Public Access:

// **Public Methods**

Protocols governing job search;
Protocols governing negotiations with potential employers;
Protocols governing non-employment payments program;
Methods for communicating with other agents;
Methods for retrieving stored Worker data;

Private Access Only:

// **Private Methods**

Method for calculating own expected utility assessments;
Method for calculating own actual utility outcomes;
Method for updating own worksite strategy **[learning]**;

// **Private Data**

Data about own self (history, utility fct., current wealth…);
Data recorded about external world (employer behaviors,…);
Addresses for other agents **[permits agent communication]**

An Employer Agent

Public Access:

// **Public Methods**

Protocols governing search for workers;
Protocols governing negotiations with potential workers;
Protocols governing non-employment payments program;
Methods for communicating with other agents;
Methods for retrieving stored Employer data;

Private Access Only:

// **Private Methods**

Method for calculating own expected profit assessments;
Method for calculating own actual profit outcomes;
Method for updating own worksite strategy **[learning]**;

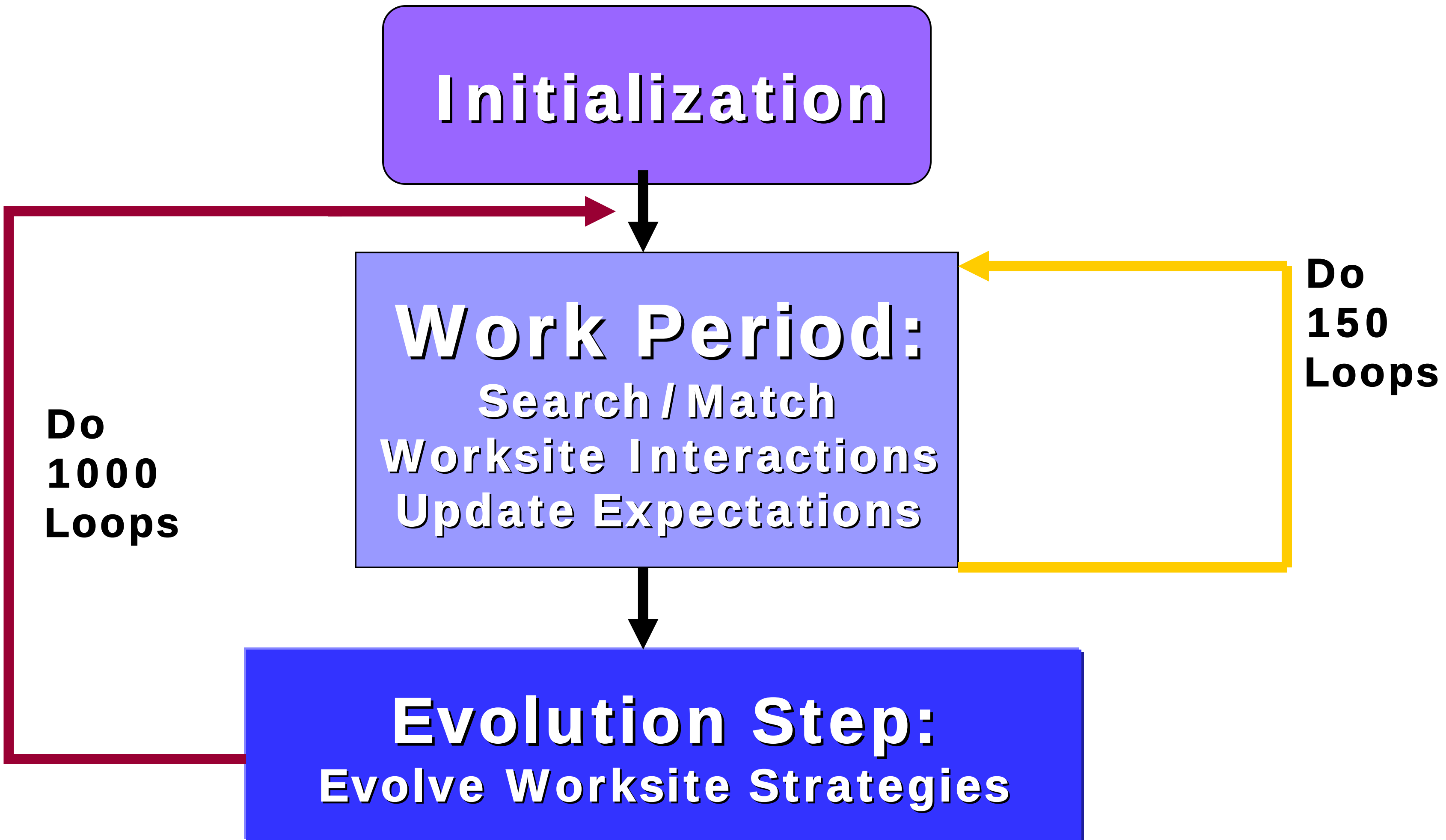
// **Private Data**

Data about own self (history, profit fct., current wealth...);
Data recorded about external world (worker behaviors,...);
Addresses for other agents **[permits agent communication]**

Flow of Activities in the ACE Labor Market

- Workers make offers to preferred employers at a small cost per offer (**quits allowed**)
- Employers accept or refuse received work offers (**firings allowed**)
- Each matched pair engages in one worksite interaction (**PD - cooperate or defect**)
- After 150 work periods, each worker (employer) updates its iterated prisoner's dilemma strategy for interactions with each potential employer (worker).

Flow of Activities in the ACE Labor Market



Worksite Interactions as Prisoner's Dilemma (PD) Games

Employer

Worker		C	D
	C	(40,40)	(10,60)
	D	(60,10)	(20,20)

D = Defect (Shirk); C = Cooperate (Fulfill Obligations)

Key Issues Addressed

How do **changes** in the level of the non-employment payment (NEP) affect…

- **Worker-Employer Interaction Networks**
- **Worksite Behaviors:** Degree to which workers/employers shirk (defect) or fulfill obligations (cooperate) on the worksite
- **Market Efficiency** (total surplus net of NEP program costs, unemployment/vacancy rates,…)
- **Market Power** (distribution of total net surplus)

Experimental Design

- **Treatment Factor:**

  Non-Employment Payment (NEP)

- **Three Tested Treatment Levels:**

  NEP=0, NEP=15, NEP=30

- **Runs per Treatment:**

  20 (1 Run = 1000 Generations;

  1 Gen.=150 Work Periods Plus Evolutionary Step)

- **Data Collected Per Run:** Network patterns, behaviors, and market performance (reported in detail for generations 12, 50, 1000)

Three NEP Treatments in Relation to PD Payoffs

① **NEP=0** < L=10

② L=10 < **NEP=15** < D=20

③ D=20 < **NEP=30** < C=40

NOTE: Work-site PD payoffs given by:

L (Sucker)=10 < D (Mutual-D) = 20
< C (Mutual-C) = 40
< H (Temptation) = 60

Market Efficiency Findings

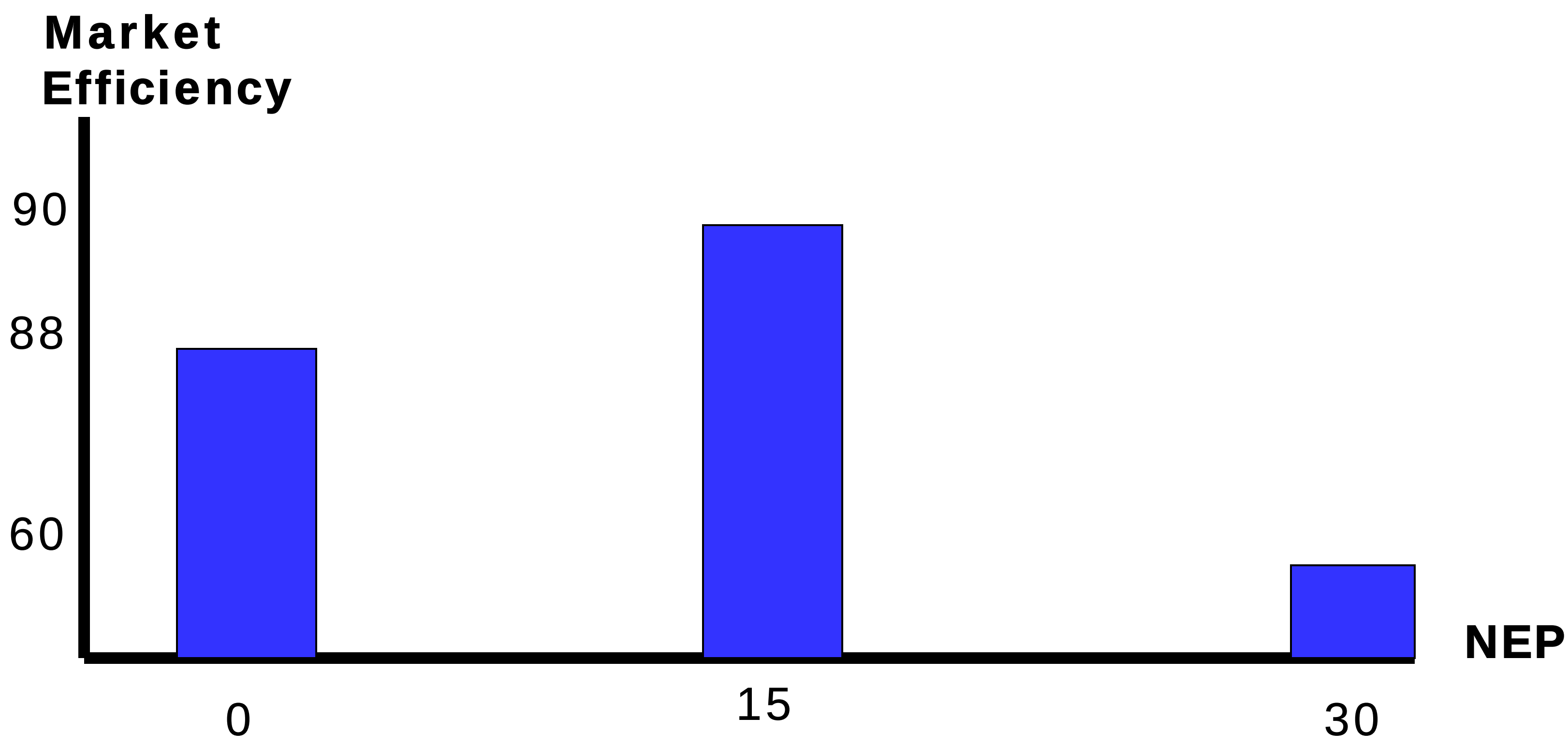
As NEP level **increases** from 0 to 30...

- ***higher*** average unemployment and vacancy rates are observed;← **KNOWN EFFECT**
- ***more*** work-site cooperation observed on average among workers & employers who match. ← **NEW EX POST EFFECT**

Note: These outcomes have ***potentially offsetting*** effects on market efficiency.

Efficiency Findings…

Market Efficiency *(utility less NEP program costs) averaged across generations 12, 50, and 1000 for three different NEP treatments*



Efficiency Findings...

- NEP=15 yields ***highest efficiency***
- NEP=0 yields ***lower*** efficiency
  (too much shirking)
- NEP=30 yields ***lowest efficiency***
  (program costs too high)

Multiple Attractors

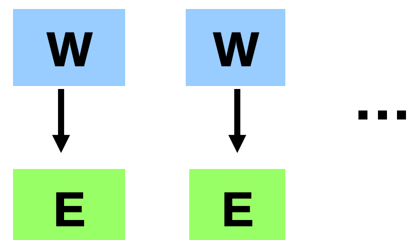
- Two distinct "attractors" observed for each NEP treatment...
  - **NEP=0 and NEP=15:**
    - First Attractor = Latched network supporting ***mutual cooperation***;
    - Second Attractor = Latched network supporting ***intermittent defection***
  - **NEP=30:**
    - First Attractor = Latched network supporting ***mutual cooperation***
    - Second Attractor = Disconnected network reflecting ***total coordination failure***

The Following Diagrams Report...

① **Types of networks distinguished by "Network Distance" ND ranging across**

ND=0 : Stochastic fully connected network

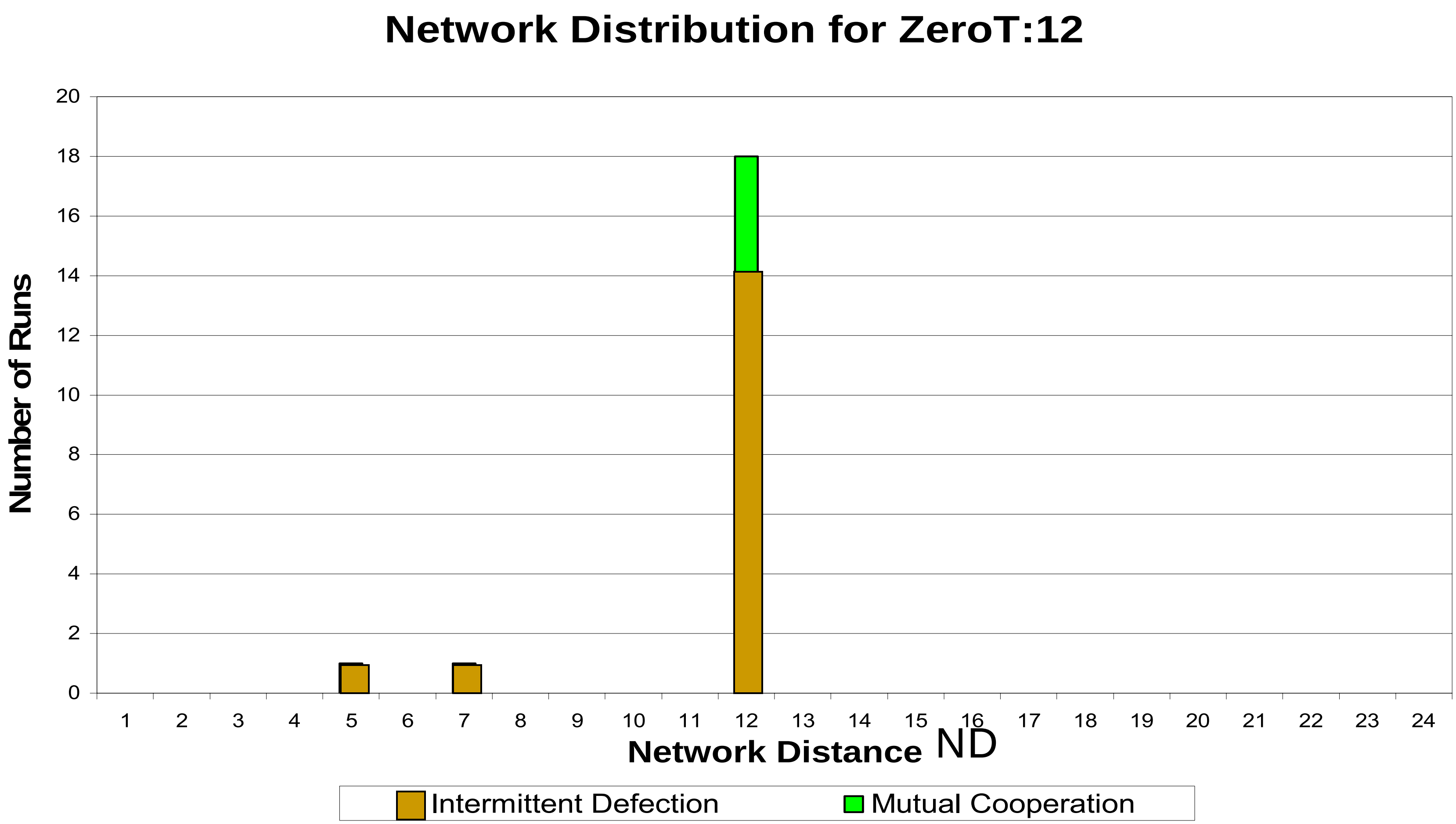
ND=12: Latched in pairs



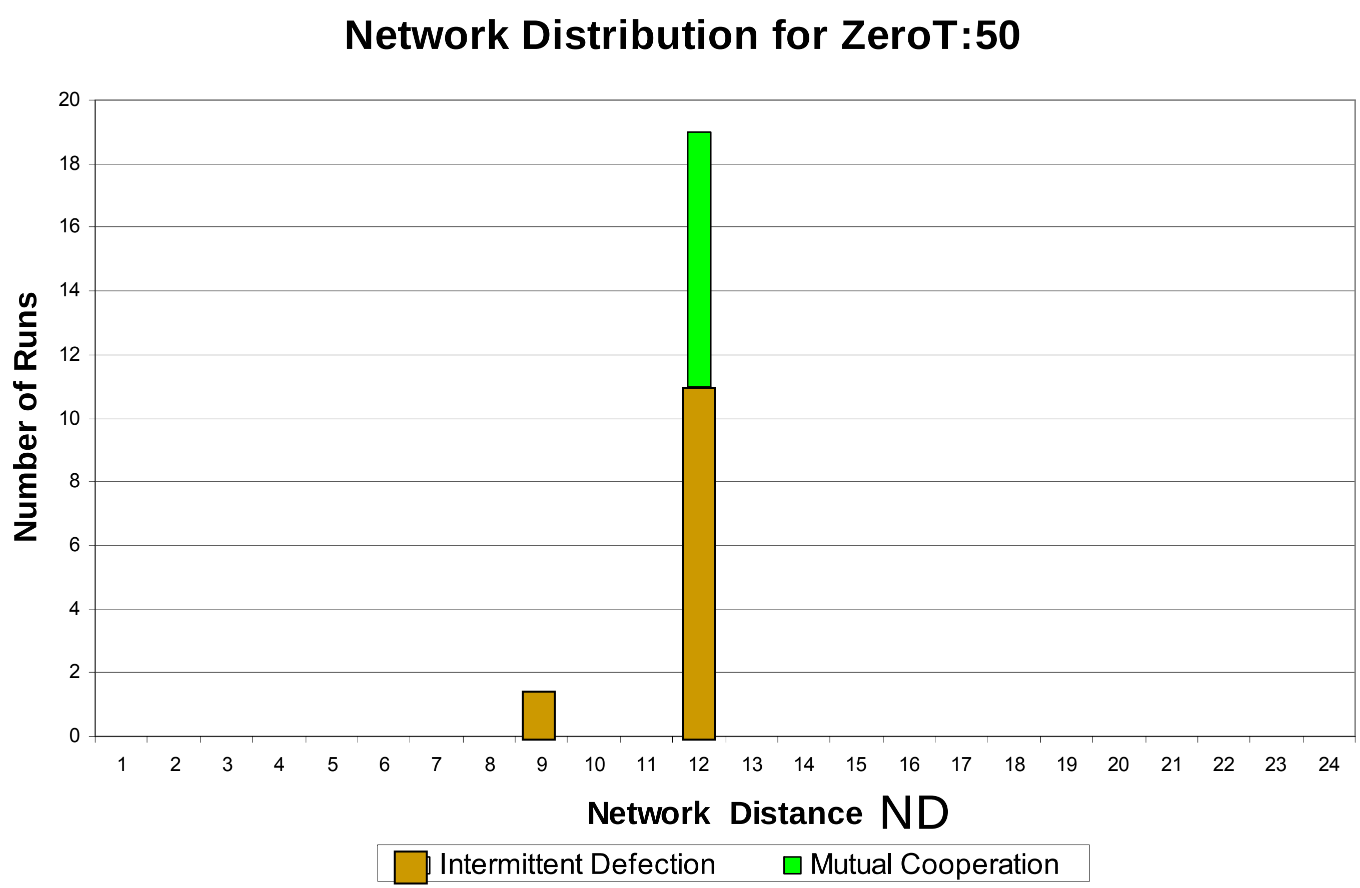
ND=24: Completely disconnected

② **Types of worksite behaviors that are supported by these network outcomes**

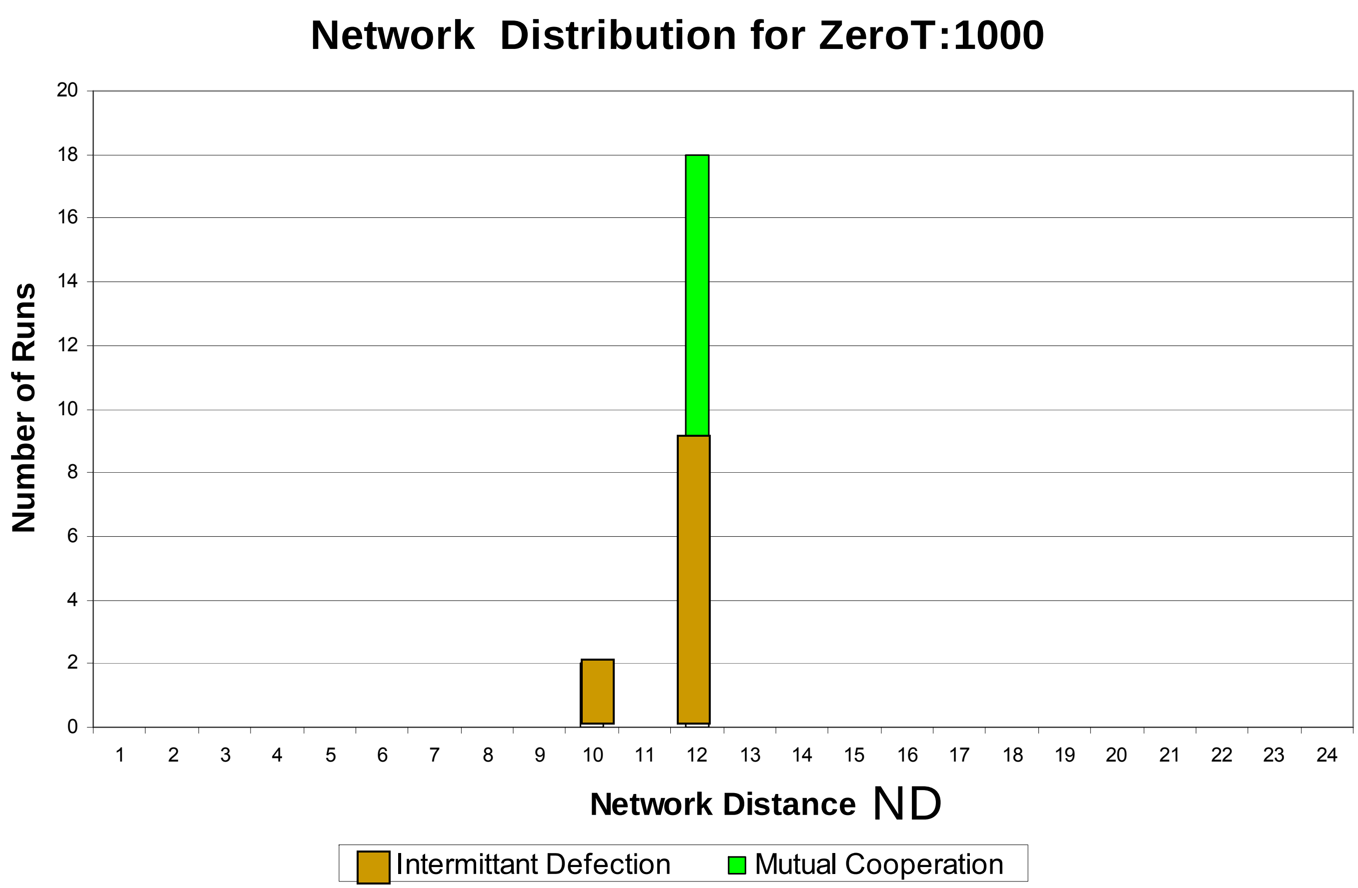
Network Distribution for NEP=0 Sampled at End of Generation 12



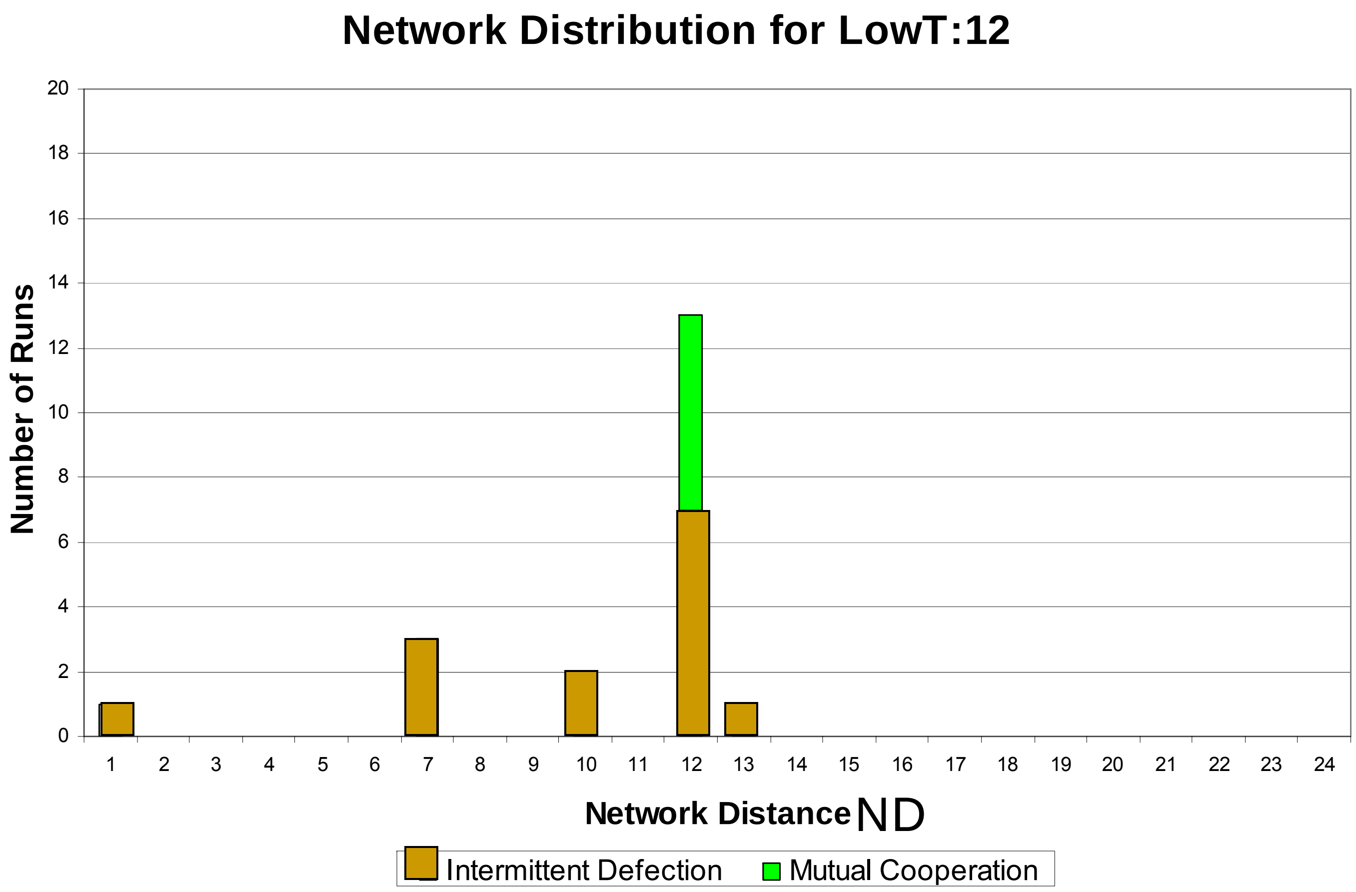
Network Distribution for **NEP=0** Sampled at End of **Generation 50**



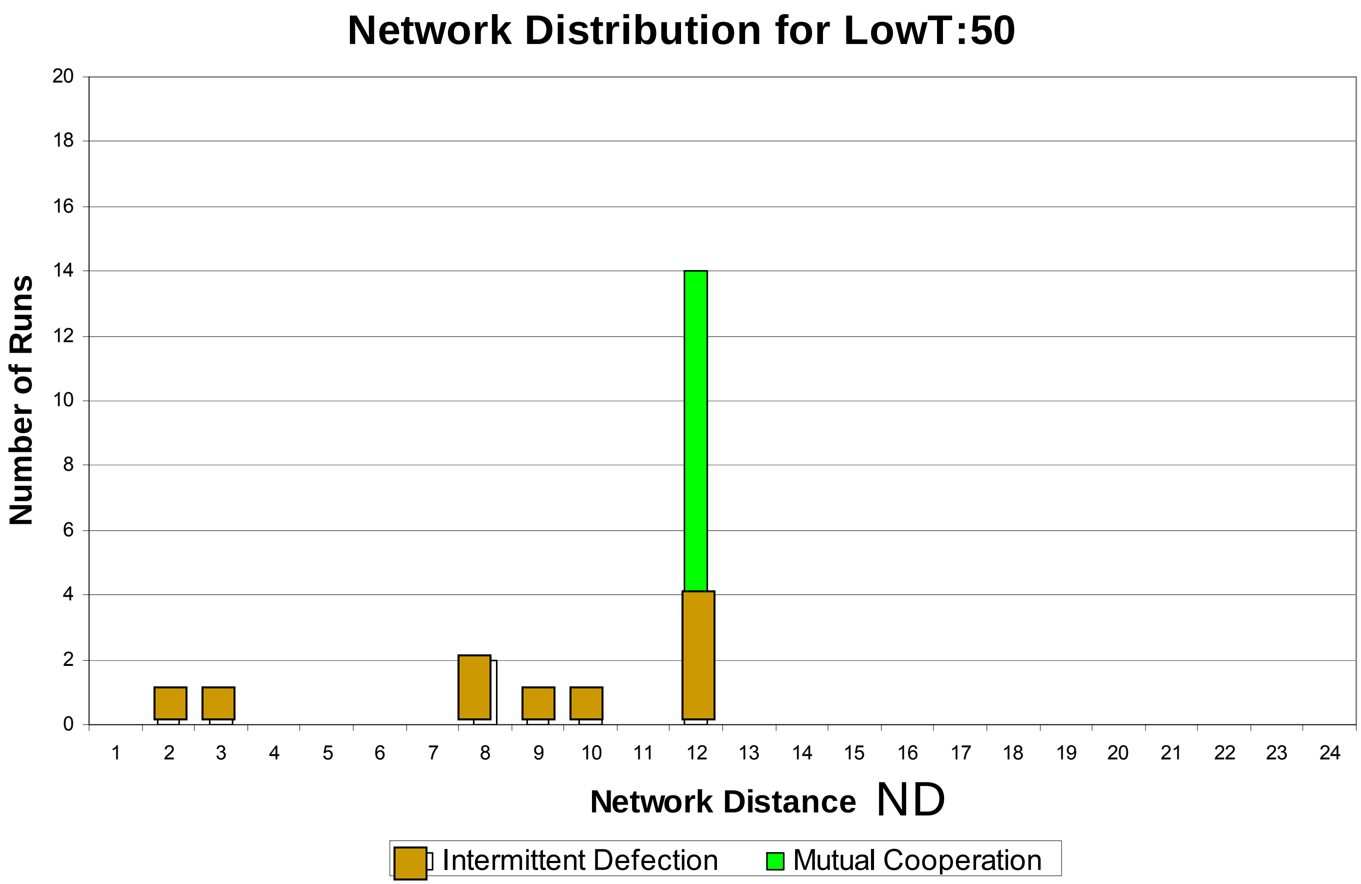
Network Distribution for **NEP=0** Sampled at End of **Generation 1000**



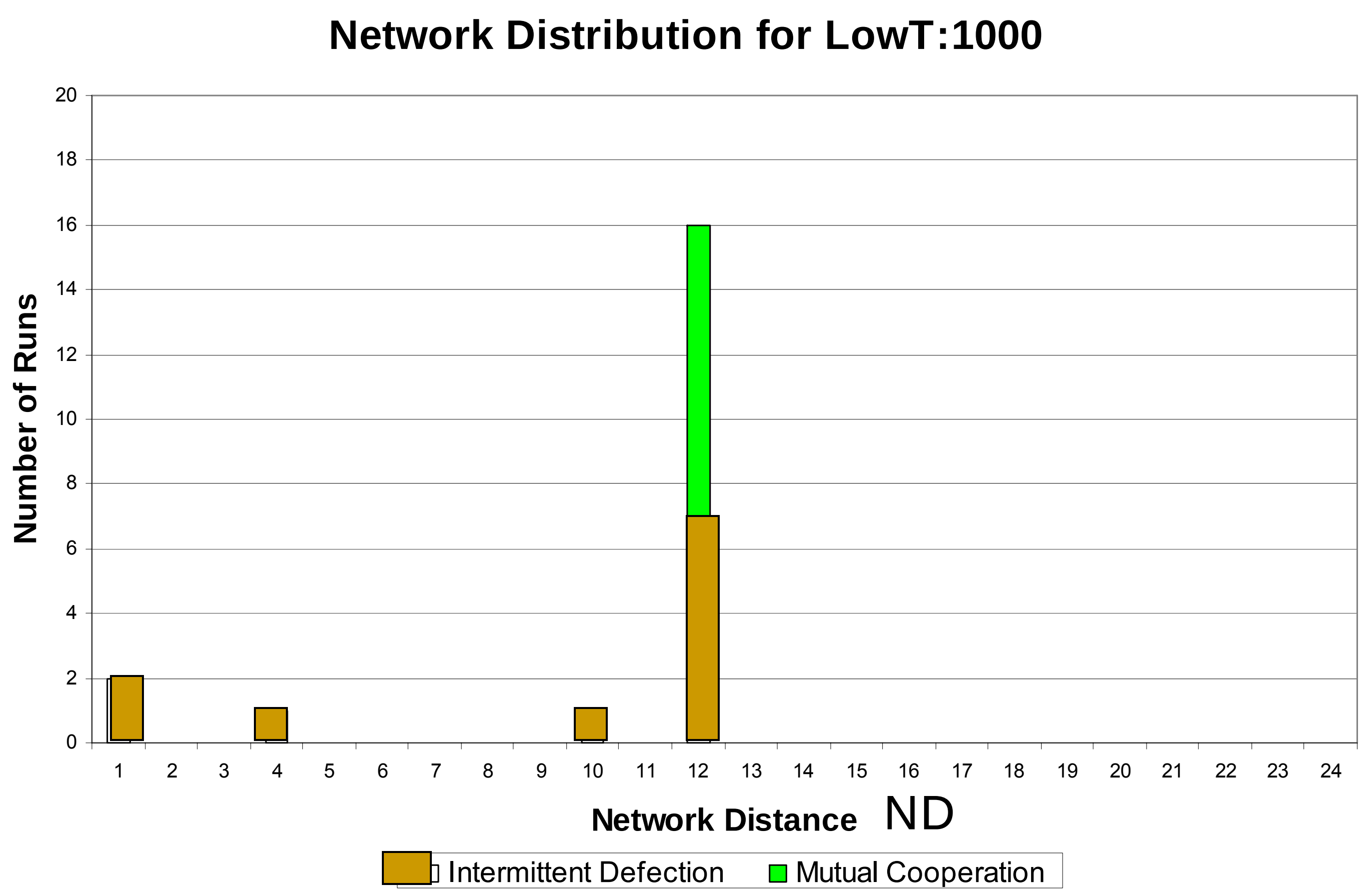
Network Distribution for NEP=15 Sampled at End of Generation 12



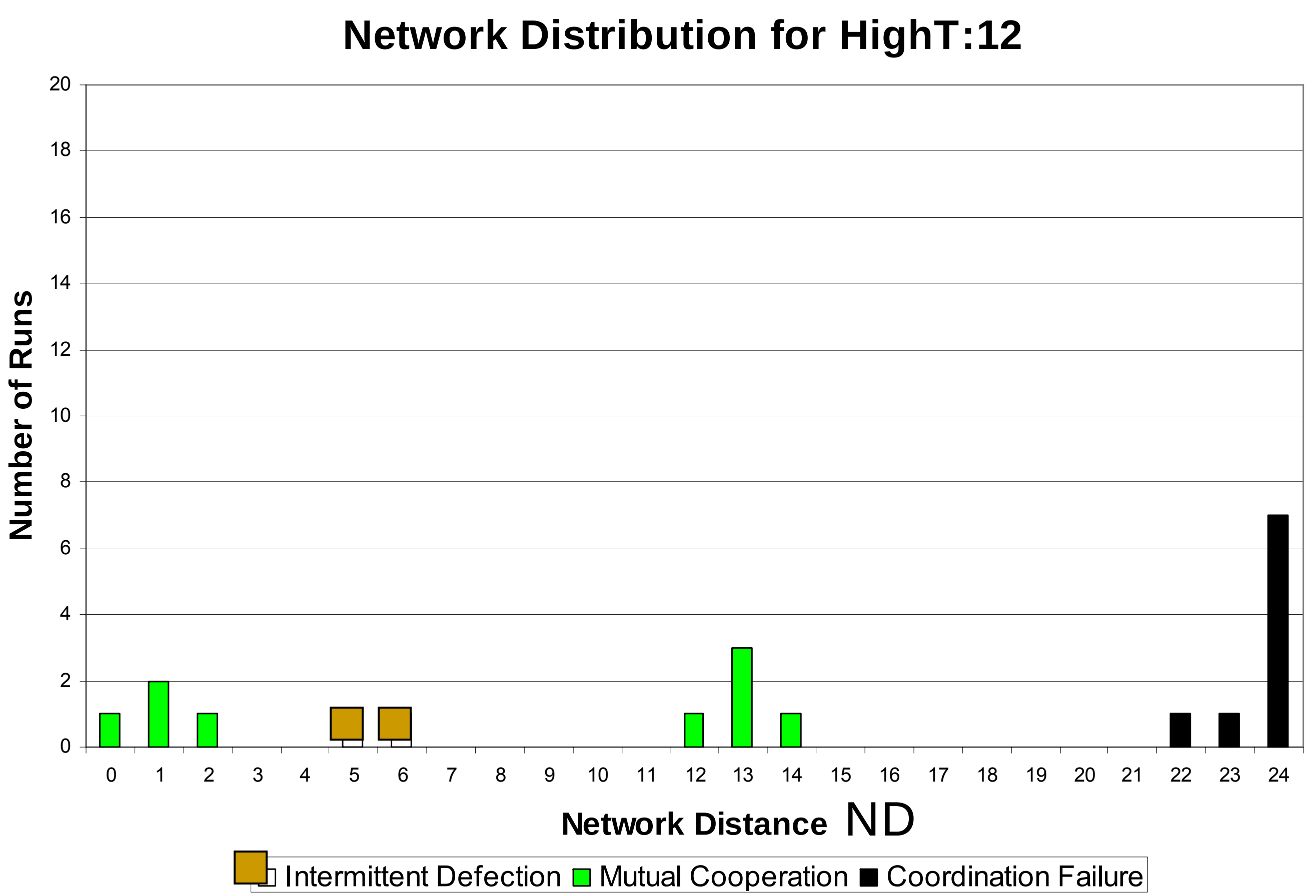
Network Distribution for **NEP=15** Sampled at End of **Generation 50**



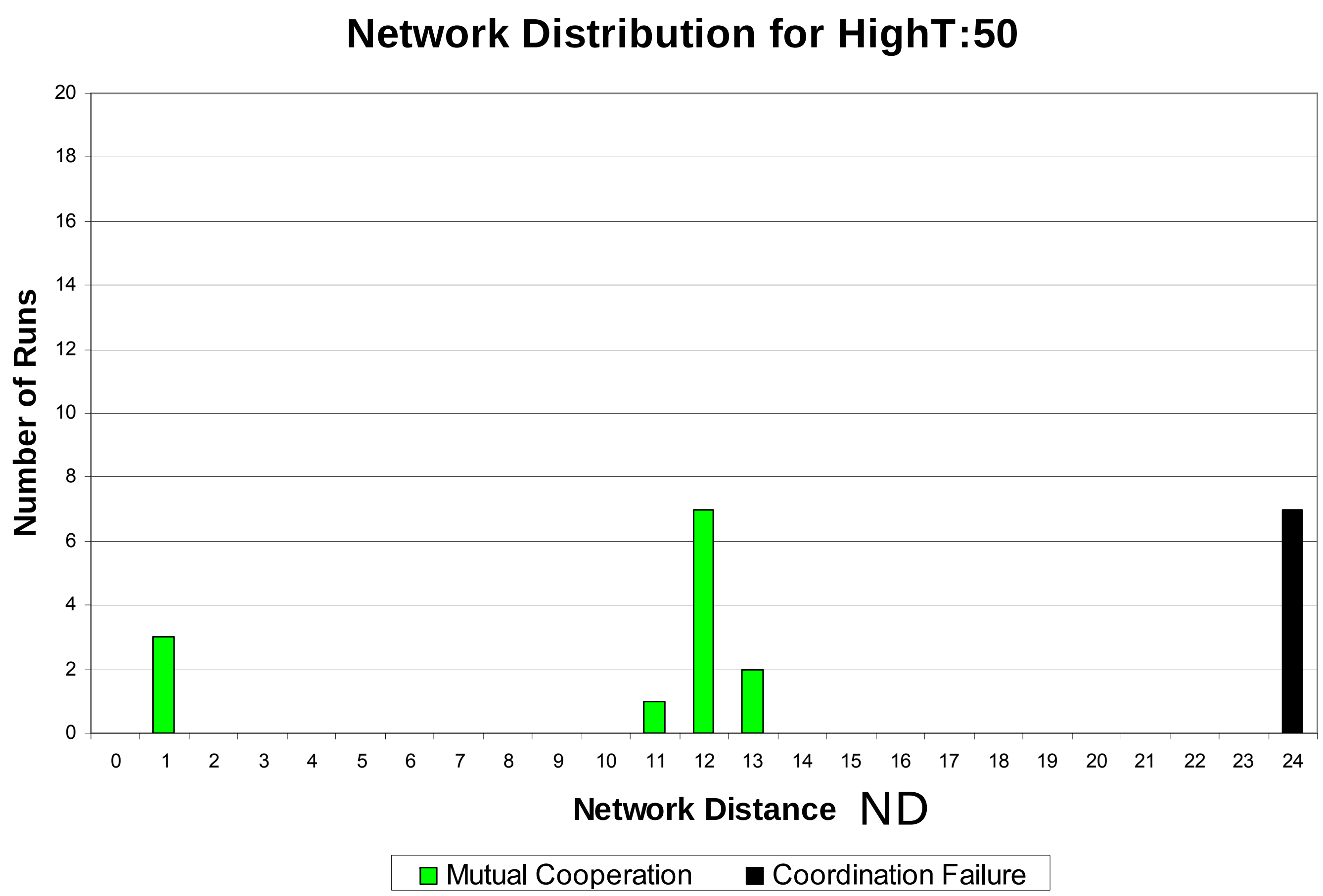
Network Distribution for **NEP=15** Sampled at End of **Generation 1000**



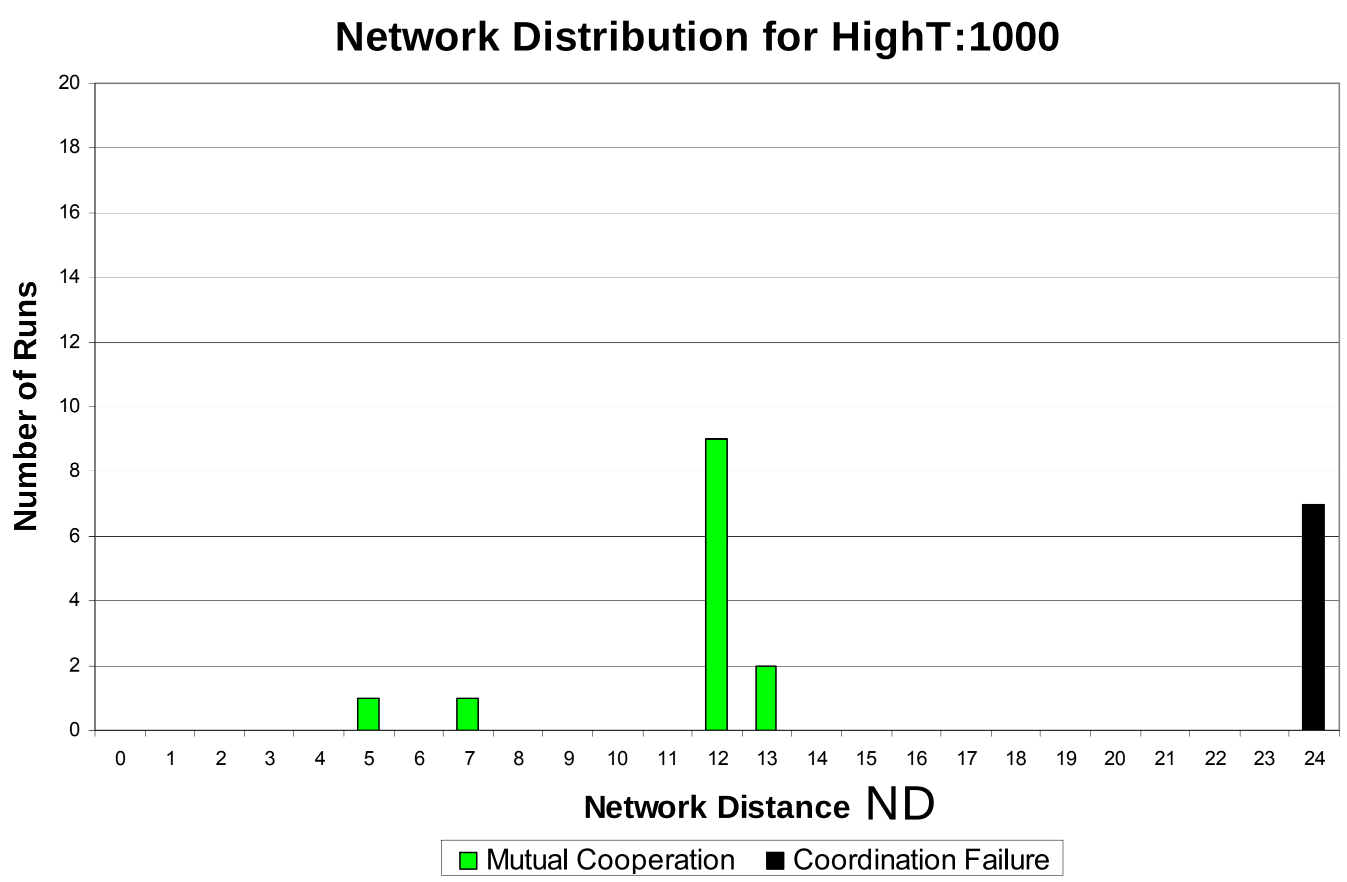
Network Distribution for **NEP=30** Sampled at End of **Generation 12**



Network Distribution for NEP=30 Sampled at End of Generation 50



Network Distribution for **NEP=30** Sampled at End of **Generation 1000**



Summary of Findings

- Changes in NEP ***systematically*** affect unemployment, vacancy, worksite behaviors, and welfare outcomes
- Worker-employer networks tend to be either ***fully latched in pairs*** (ND=12) or ***completely disconnected*** (ND=24)
- But... even fully latched networks (ND=12) can support ***multiple*** types of behavior across different runs ranging from full coop to mixed coop & defection

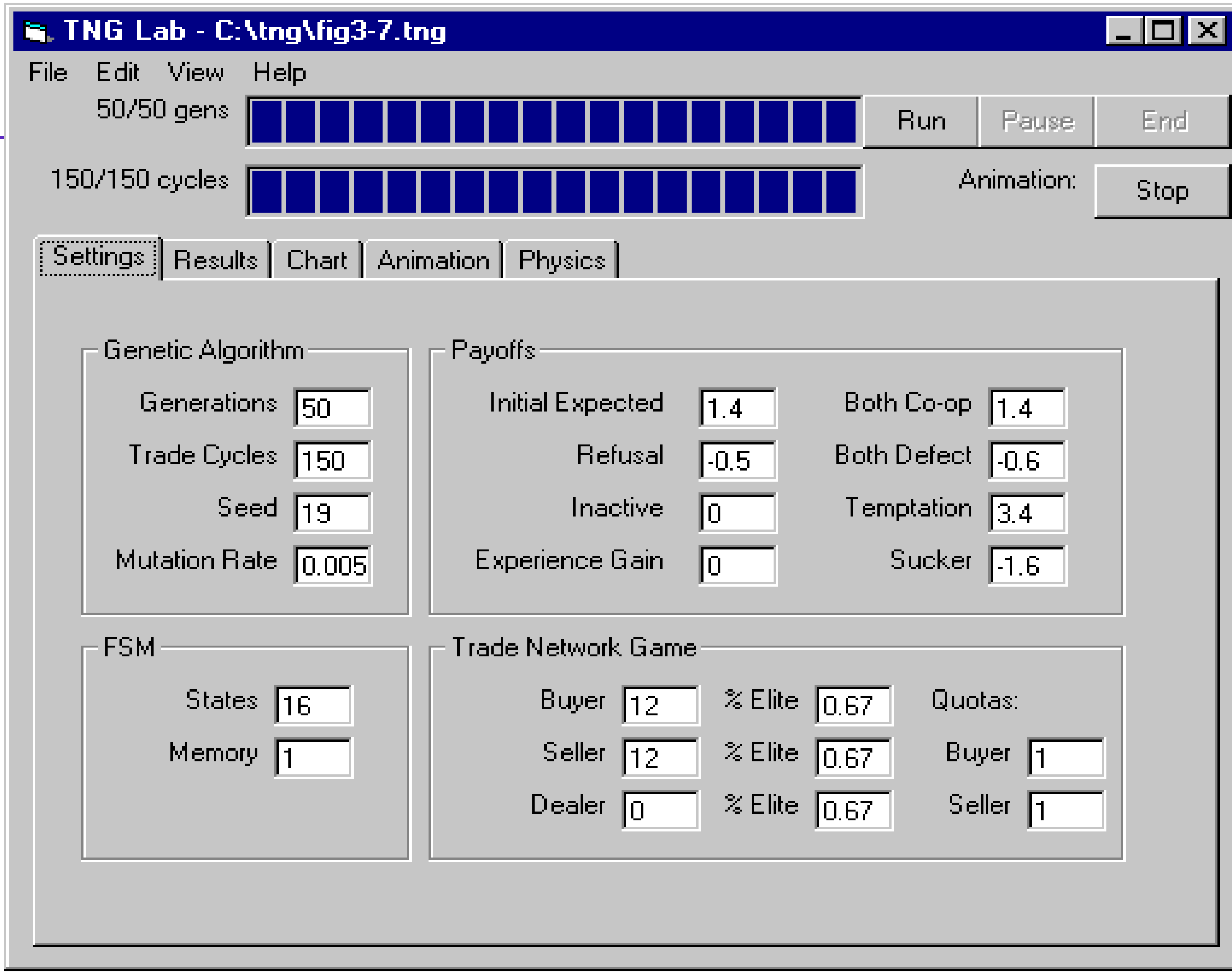
Example 5: The Trade Network Game (TNG)

www.econ.iastate.edu/tesfatsi/tnghome.htm

- **Evolution of trade networks** among strategically interacting traders (buyers, sellers, dealers) with trades=PD games
- **Traders instantiated as *tradebots*** (autonomous software entities) using TNG Lab
- **Event-driven communication** among traders to determine their trade partners
- **Tradebots evolve trade strategies** starting from *initially random* strategies

Tesfatsion(1996,1997); Mcfadzean/Tesfatsion(1999); McFadzean,Stewart,Tesfatsion (IEEE TEC, 2001)

TNG Settings Screen



TNG Results Screen

TNG Lab - C:\tng\fig3-7.tng

File Edit View Help

50/50 gens

150/150 cycles

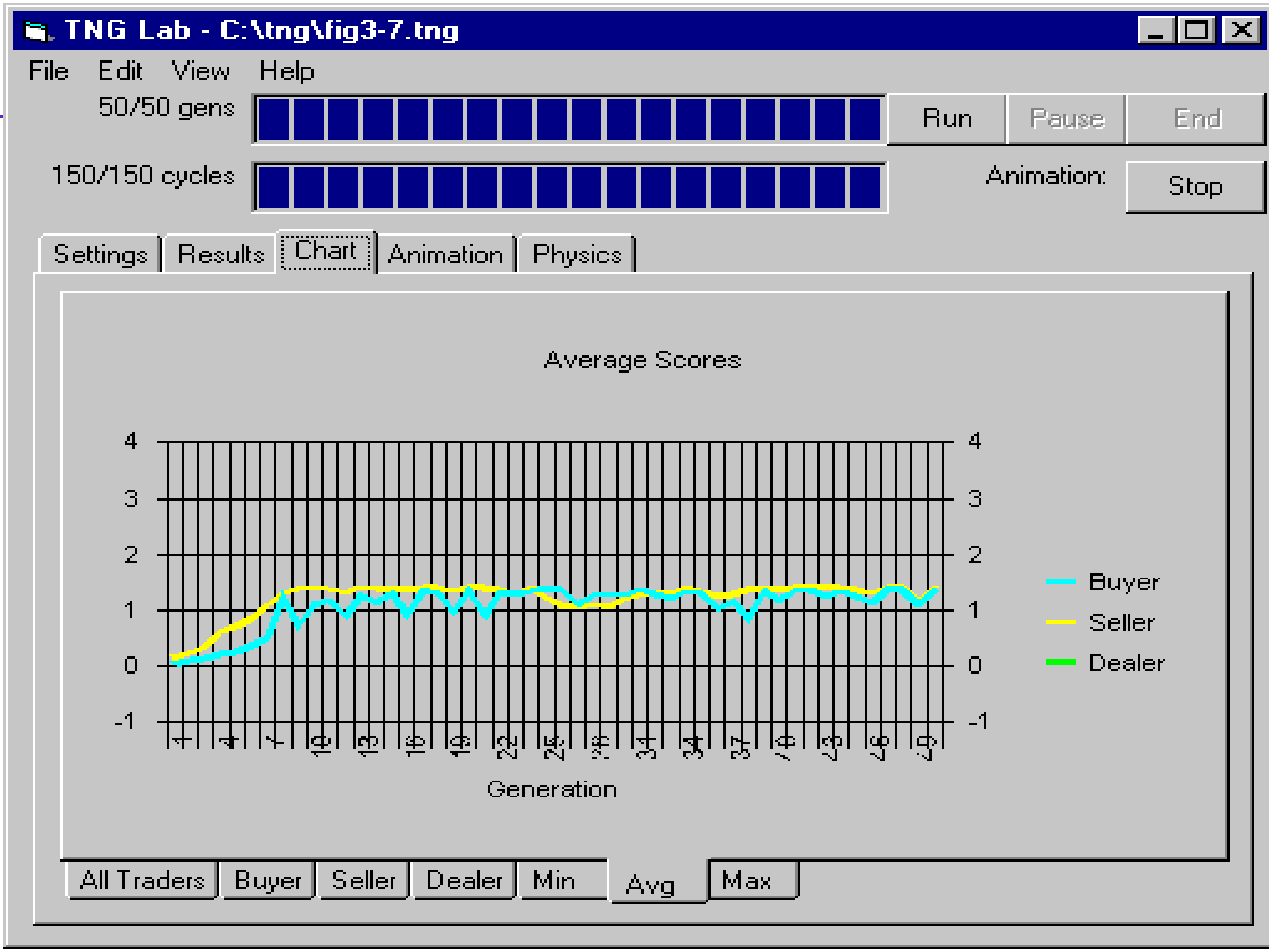
Run Pause End

Animation: Stop

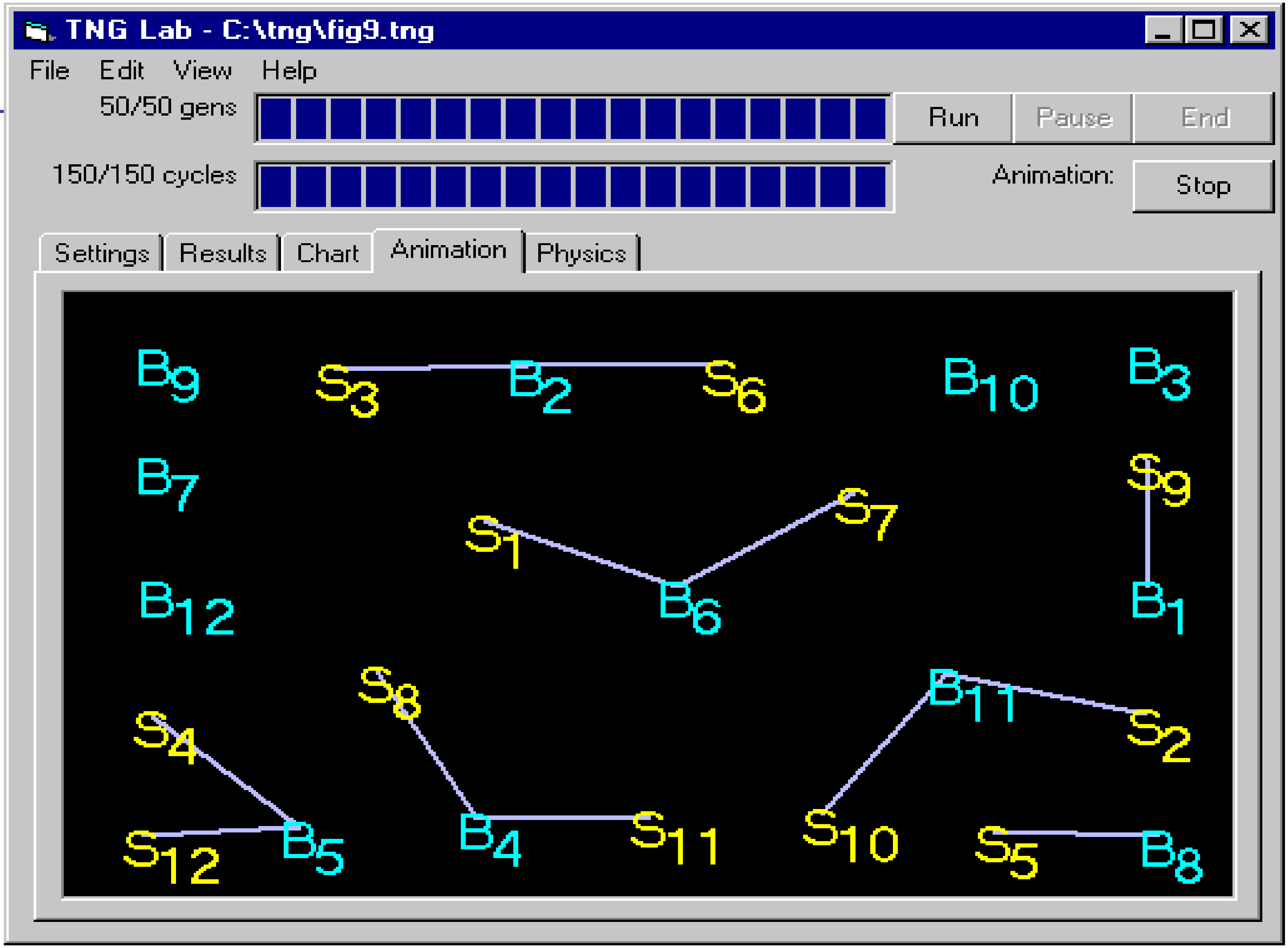
Settings | Results | Chart | Animation | Physics

Generation	Buyer Average	Buyer Minimum	Buyer Maximum	Buyer Std Dev	Seller Average	Seller Minimum
37	+1.1713	-0.1307	+1.3233	+0.3930	+1.2902	+0.2160
38	+0.8433	+0.7000	+0.9500	+0.0700	+1.3639	+0.9667
39	+1.3542	+1.3333	+1.3633	+0.0098	+1.4000	+1.4000
40	+1.1678	+0.7033	+1.2700	+0.1451	+1.3706	+1.0467
41	+1.3386	+1.2800	+1.3633	+0.0232	+1.4000	+1.4000
42	+1.3581	+1.3433	+1.3633	+0.0069	+1.4000	+1.4000
43	+1.2500	+1.1267	+1.2967	+0.0453	+1.3972	+1.3667
44	+1.3400	+1.3000	+1.3567	+0.0156	+1.4000	+1.4000
45	+1.2511	+0.6633	+1.3467	+0.1793	+1.3550	+0.8600
46	+1.1322	-0.1407	+1.2833	+0.3845	+1.3058	+0.3893
47	+1.3503	+1.3300	+1.3633	+0.0103	+1.4000	+1.4000
48	+1.3514	+1.3267	+1.3633	+0.0131	+1.4000	+1.4000
49	+1.0989	-0.1393	+1.3700	+0.5511	+1.1514	+0.4493
50	+1.3475	+1.3233	+1.3633	+0.0140	+1.4000	+1.4000

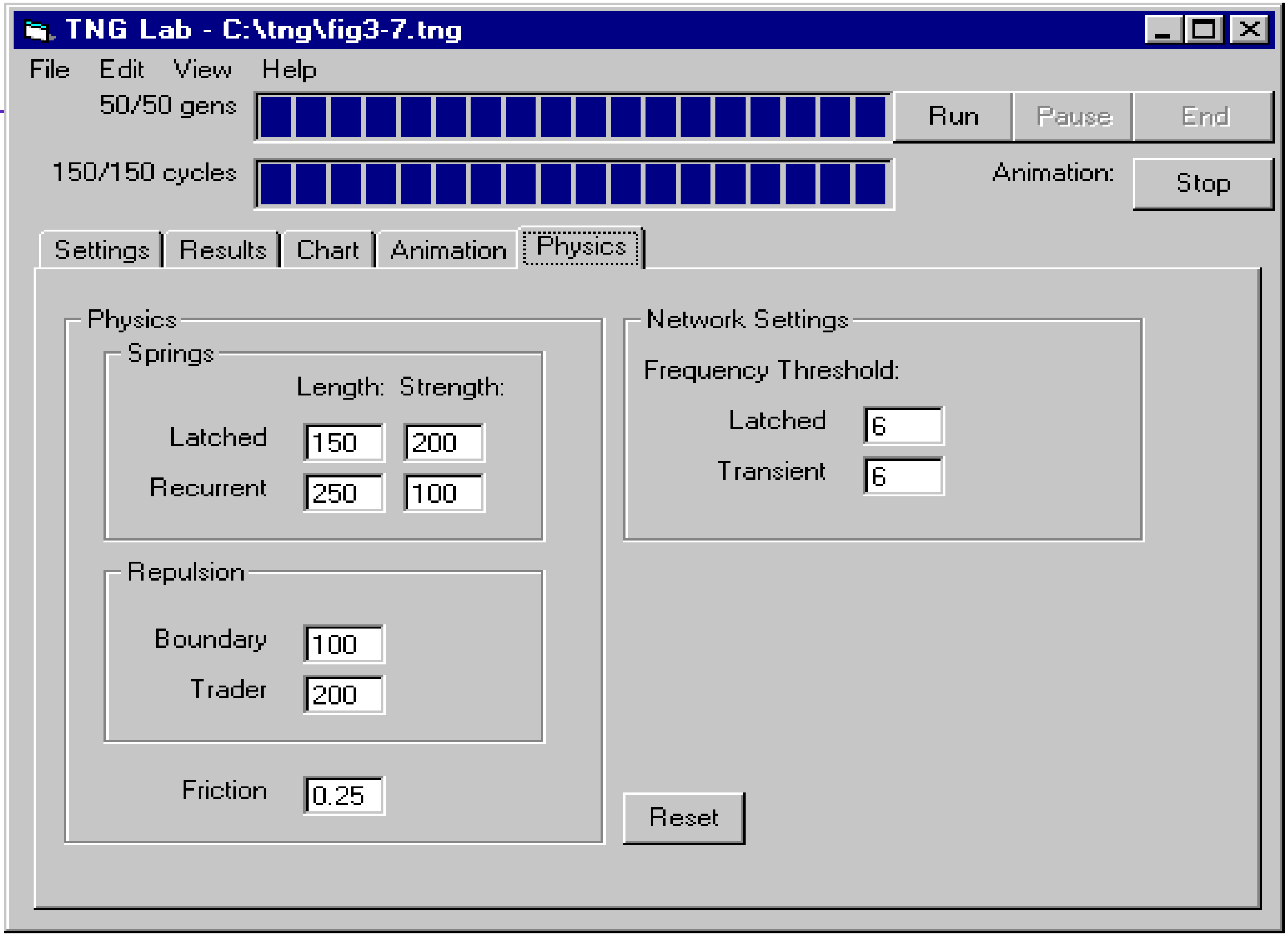
TNG Chart Screen



TNG Network Animation Screen



TNG Network Physics Screen



Example 6:
A Real-World Market Design Project

www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

AMES Market Package (Java): A Free Open-Source Test Bed for the Agent-Based Modeling of Electricity Systems

Project Director: Leigh Tesfatsion (Prof. of Econ, Math,& ECpE, ISU)
Research Assoc.: Junjie Sun (Financial Economist, OCC, U.S.Treasury)
Research Assoc: Hongyan Li (Consulting Engineer, ABB Inc., Raleigh, NC)

funded in part by the

National Science Foundation, DOE at Pacific Northwest National Lab, and the Electric Power Research Center (EPRC)

Work in Progress

Project Context

- In April 2003, U.S. FERC proposed a **Wholesale Power Market Platform (WPMP)** for common adoption by all U.S. wholesale power markets

- About 50% of electric power generating capacity in the U.S. is now operating under some version of the WPMP market design

Our Basic Project Goal: Systematically examine dynamic performance of the WPMP market design as implemented in the U.S.

Our Wholesale Power Market Framework
(AMES = Agent-based Modeling of Electricity Systems)

- **Target Features of our AMES Framework**
  - **Research/training grade model** (from 2 to 500 pricing nodes)
  - Operational validity (structure, rules, behavioral dispositions)
  - Permits dynamic testing with learning traders
  - Permits intensive sensitivity experiments
  - Open source (full access to implementation)
  - Easy modification (extensible/modular architecture)

- **Who should care?**
  - ***Academic researchers/teachers*** (qualitative understanding)
  - **Industry stakeholders** (learn rules, test business strategies)
  - **Policy makers** (efficient and reliable market design)

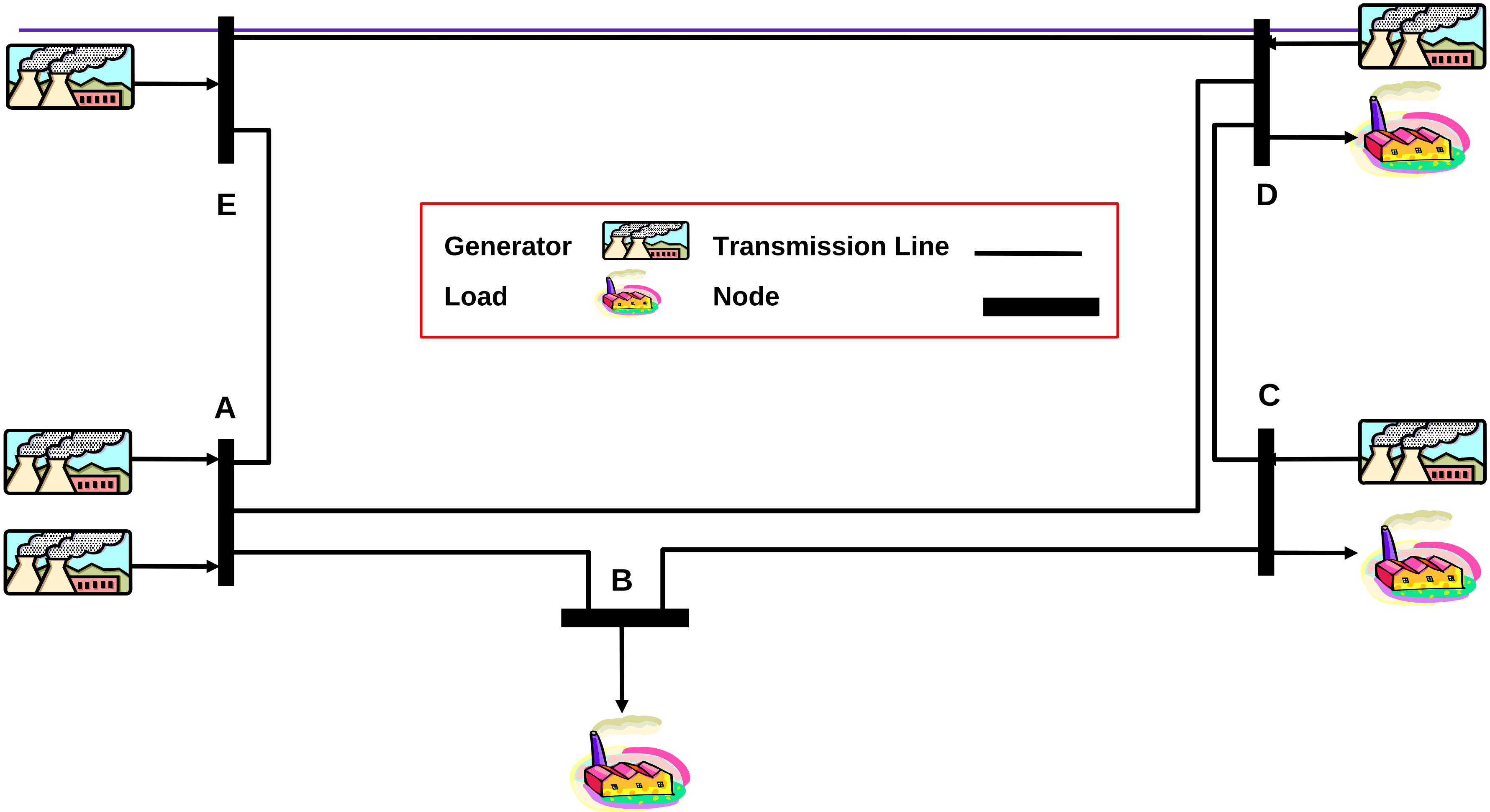
Basic Project Approach: Iterative Participatory Modeling

- See, e.g., Barreteau et al. (*JASSS* 2003)
- Stakeholders and researchers from multiple disciplines join together in a **repeated looping** through four stages of analysis:
  - Field work and data collection;
  - Role-playing games;
  - Agent-based model development (Java/RepastJ);
  - Intensive computational experiments.

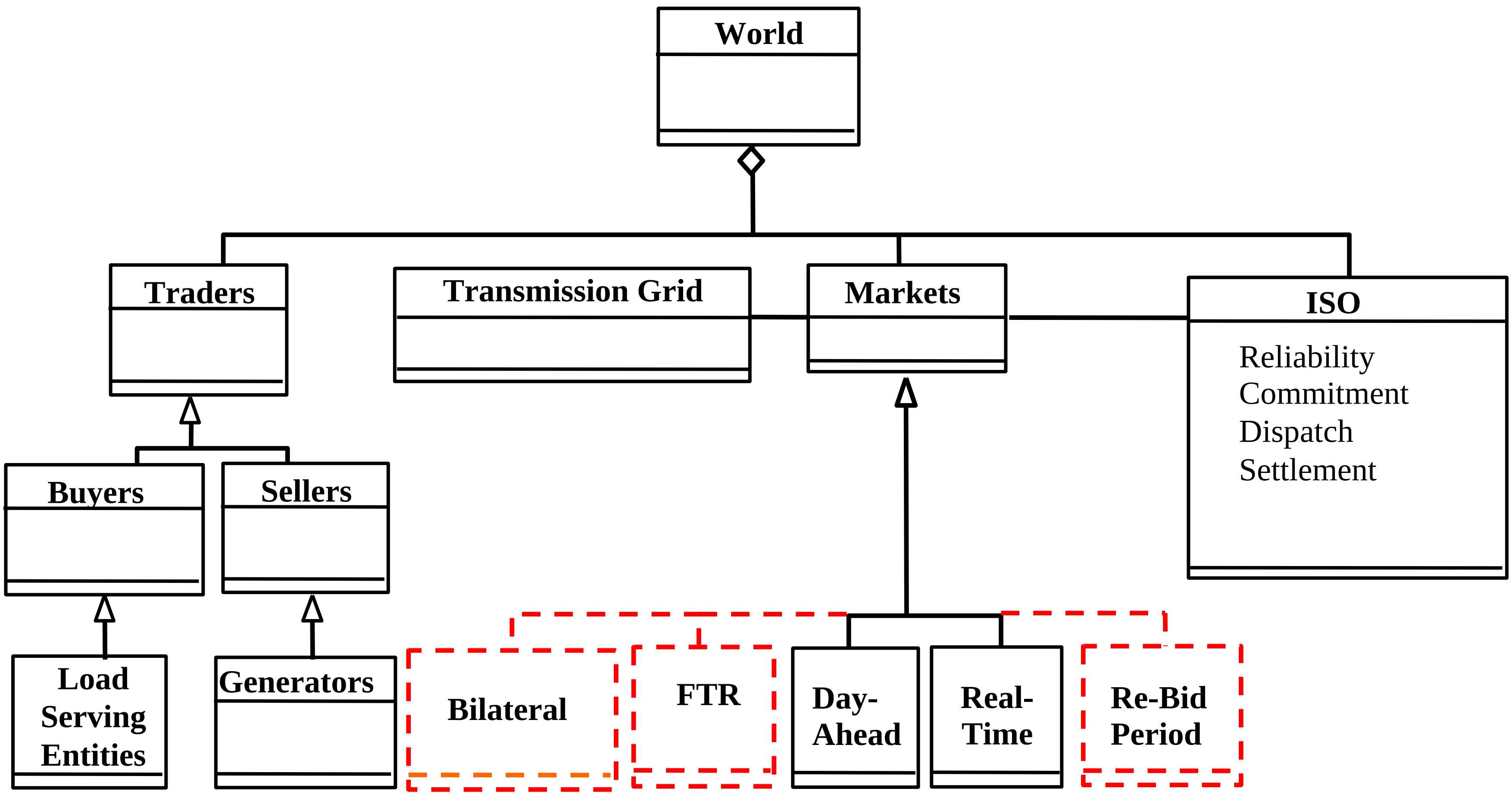
Key Components of Our AMES Framework
(Based on Business Practices Manuals for MISO/ISO-NE)

- **Traders**
  - Sellers and buyers
  - Follow market rules
  - **Learning abilities**
- **Independent System Operator**
  - System reliability assessments
  - Day-ahead bid-based unit commitment
  - Real-time dispatch
- **Two-settlement process**
  - Day-ahead market (double auction, financial contracts)
  - Real-time market (settlement of differences)
- **AC transmission grid**
  - Sellers/buyers located at various transmission nodes
  - Congestion managed via Locational Marginal Pricing (LMP)

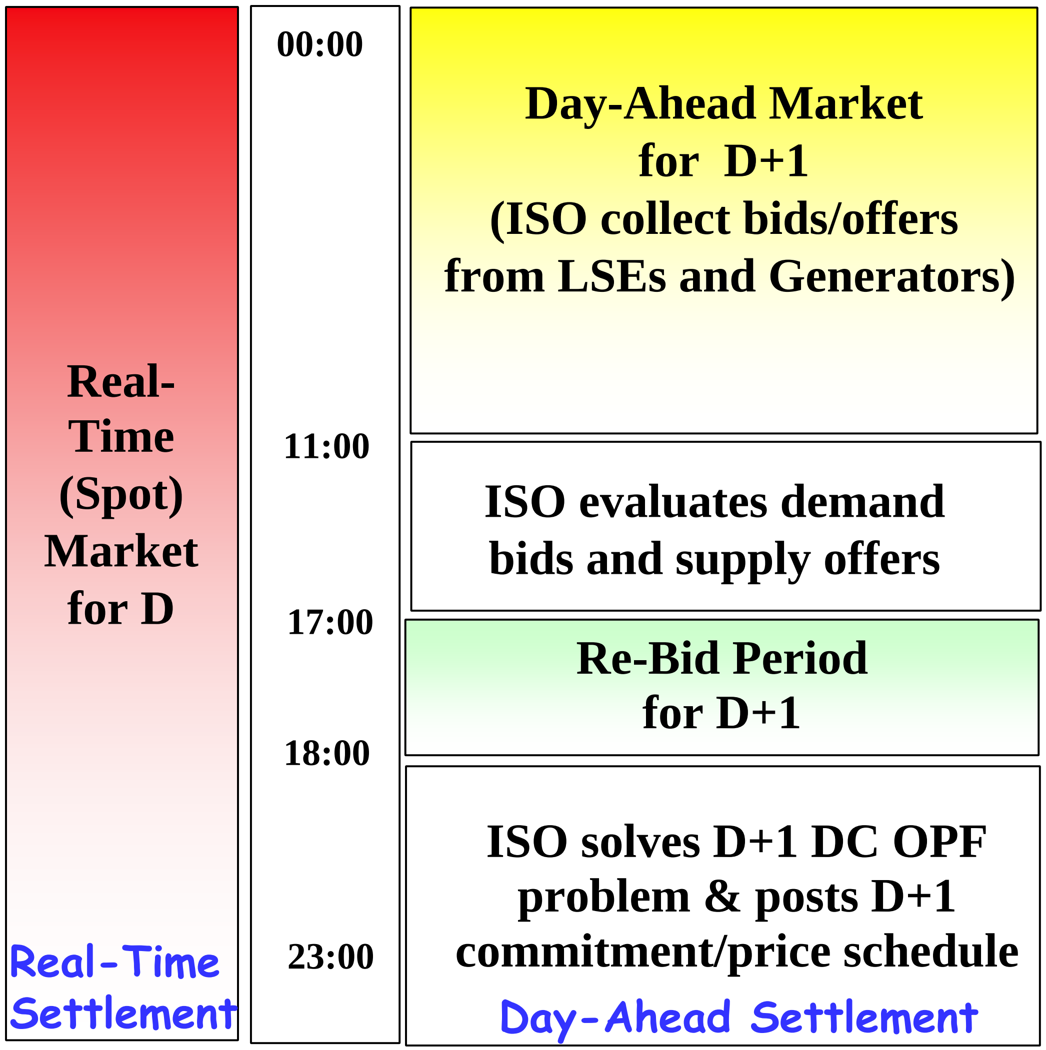
Example: 5-Node Transmission Grid



AMES Framework: Agent Hierarchy

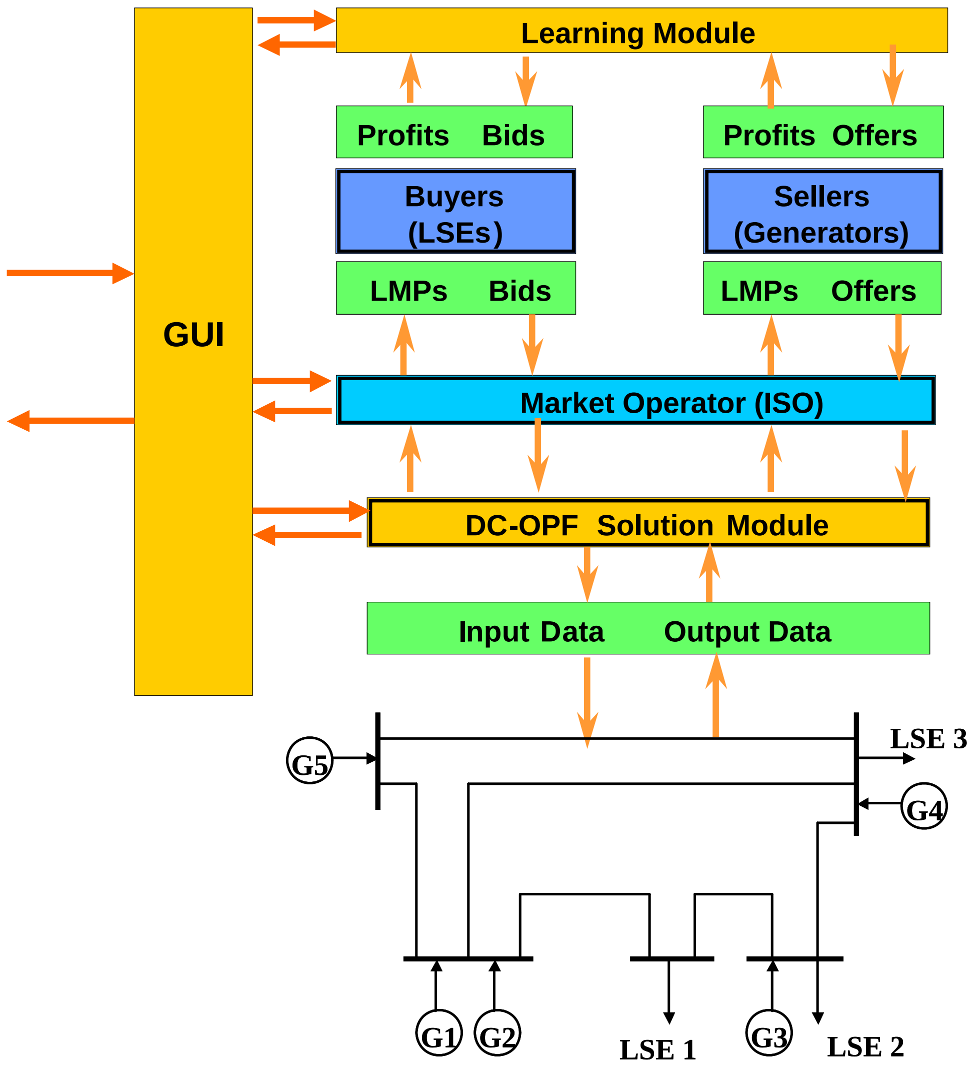


Activities of AMES ISO During Each Operating Day D

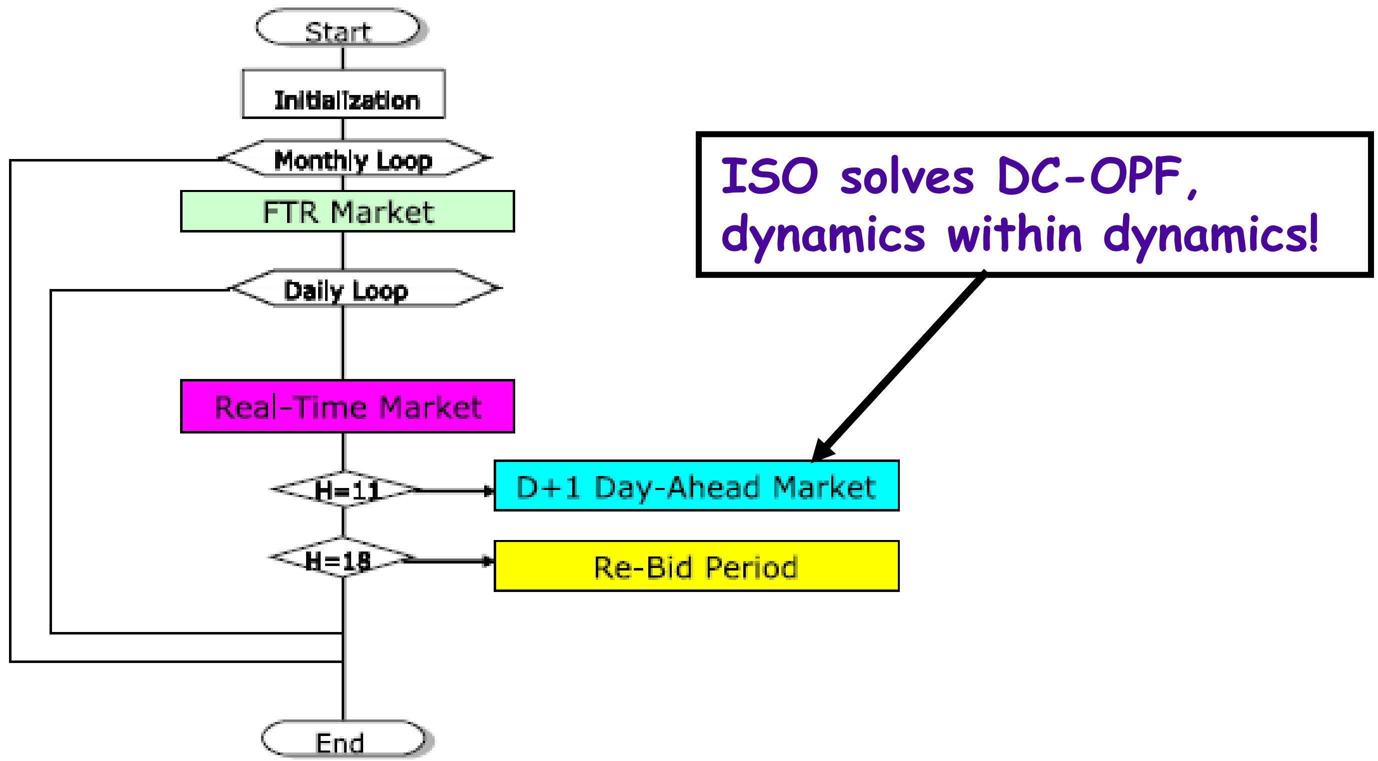


5-Node Illustration of AMES Market Dynamics in No-Shock Case

(Day-Ahead Market Contracts Carried Out As Planned)

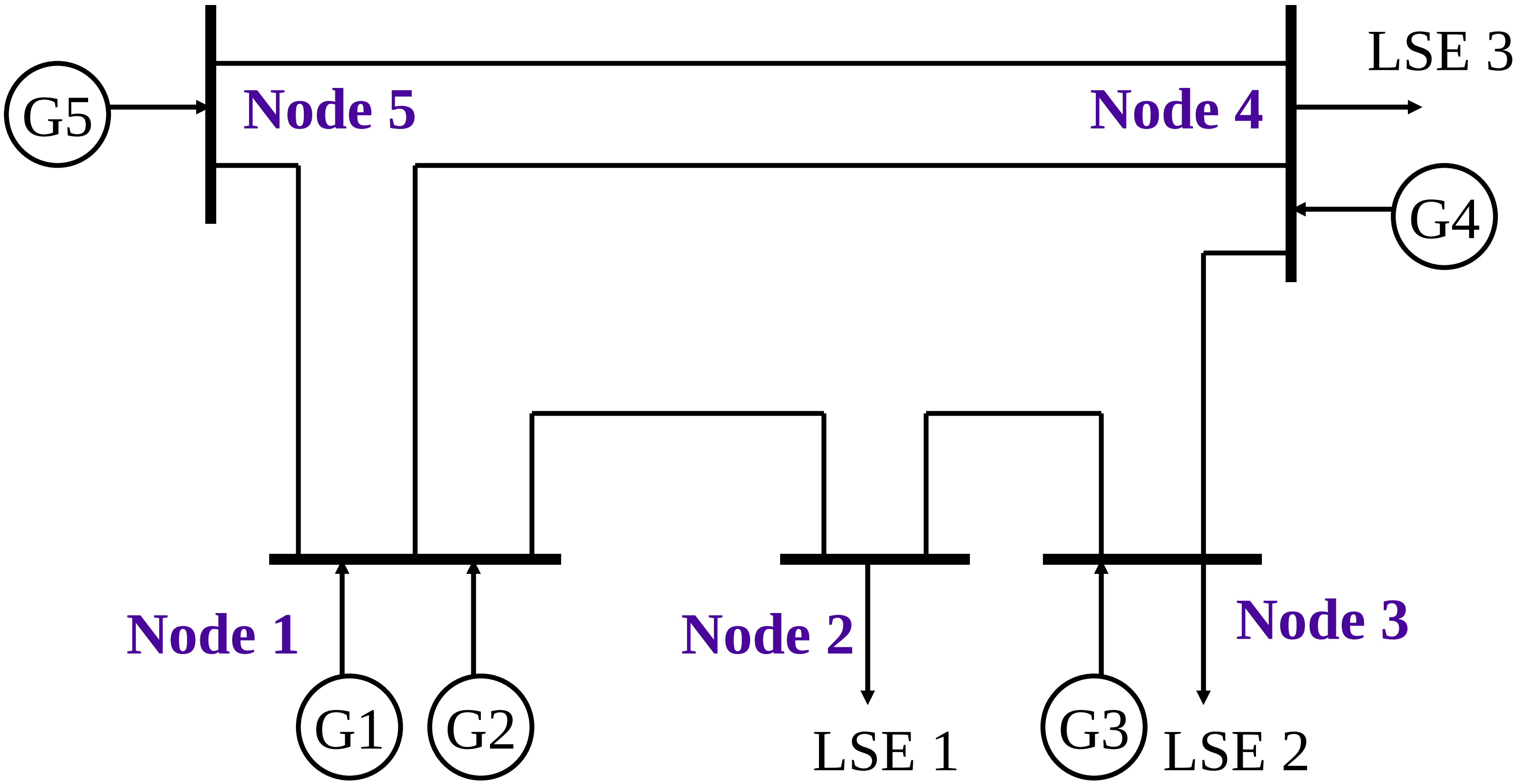


AMES Market Dynamics: Overview

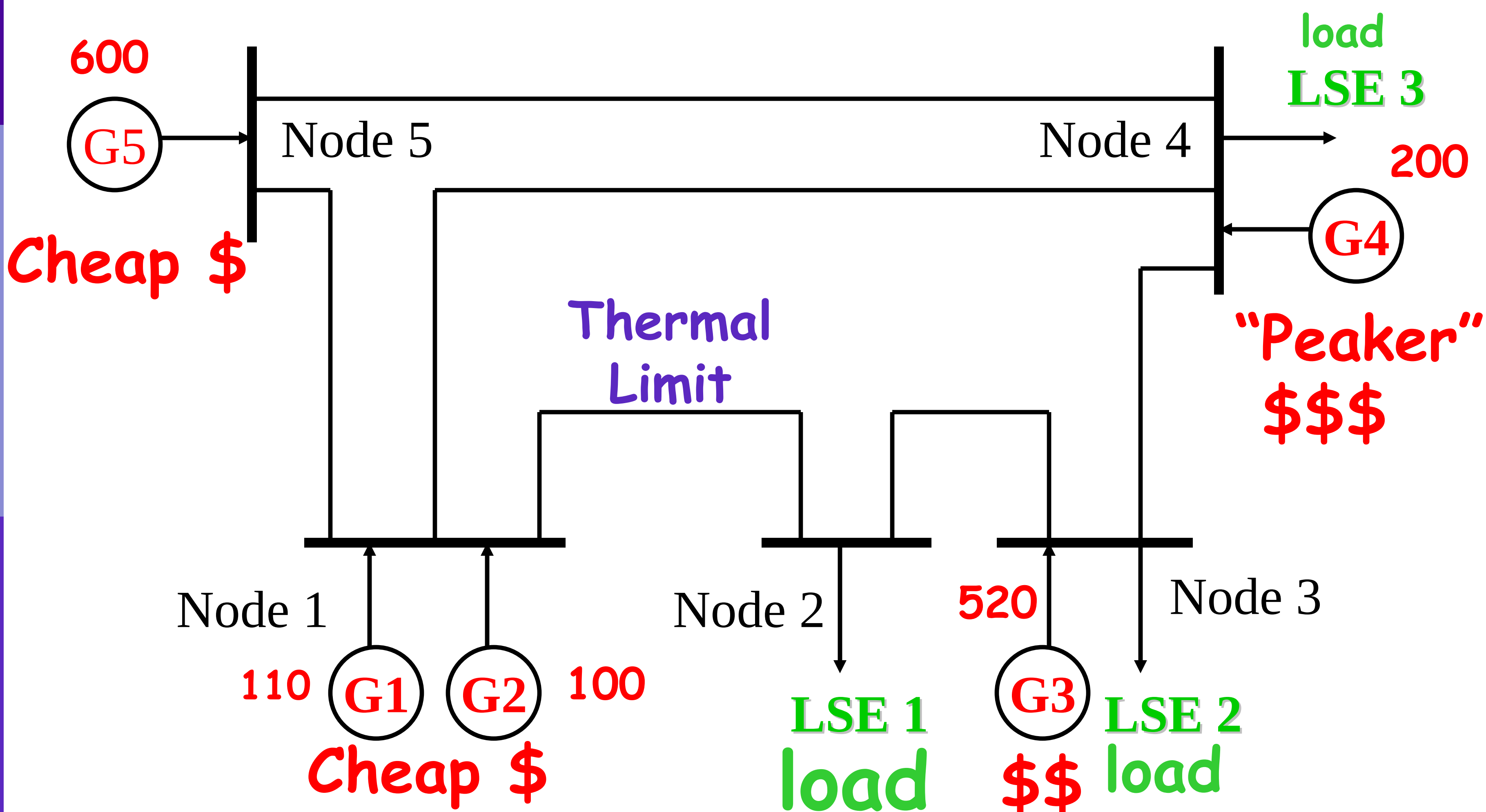


Illustrative Dynamic 5-Node Test Case

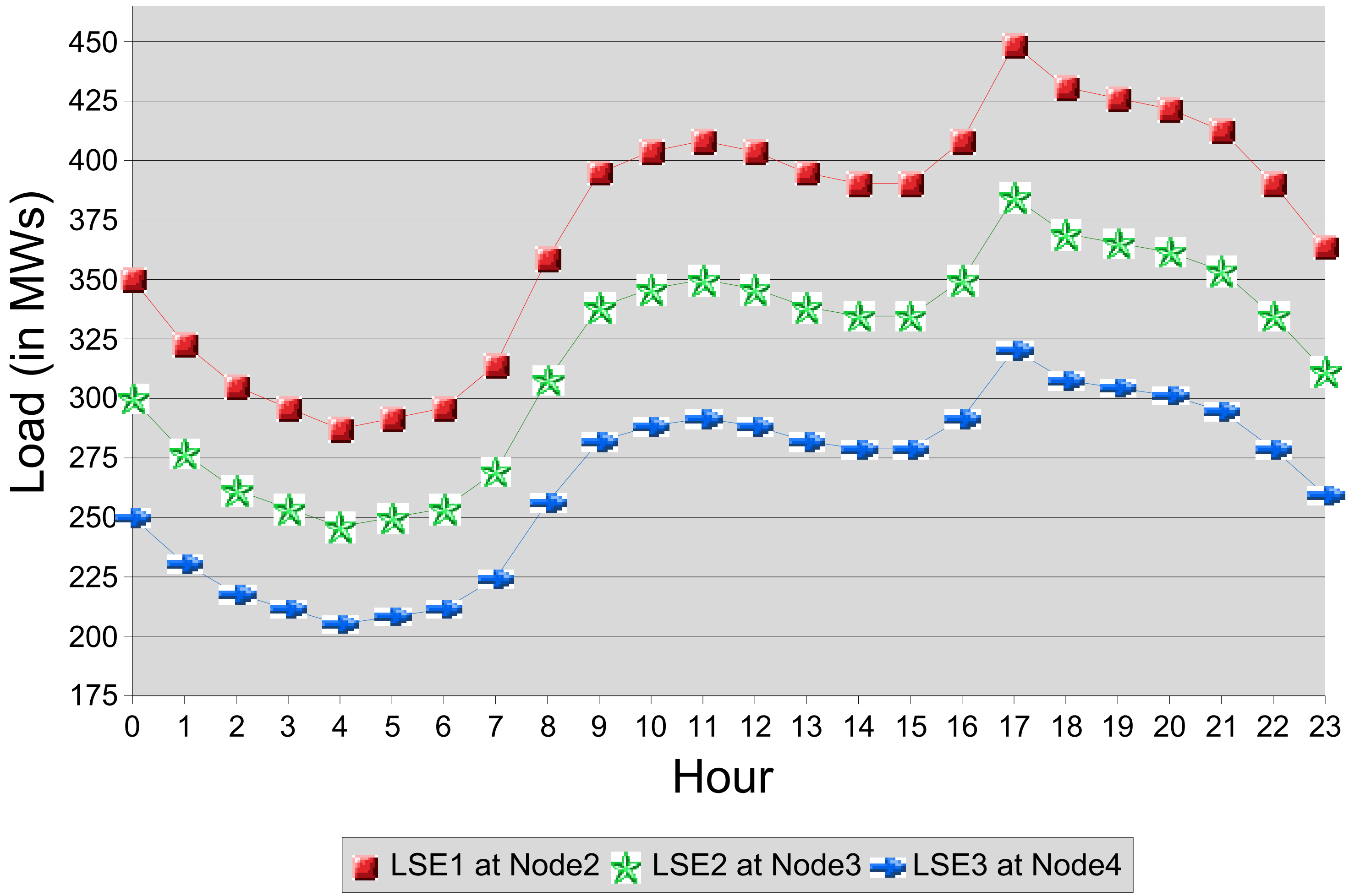
(Dynamic Extension of Static ISO-NE/MISO/PJM Training Example)



Illustrative Dynamic 5-Node Test Case…

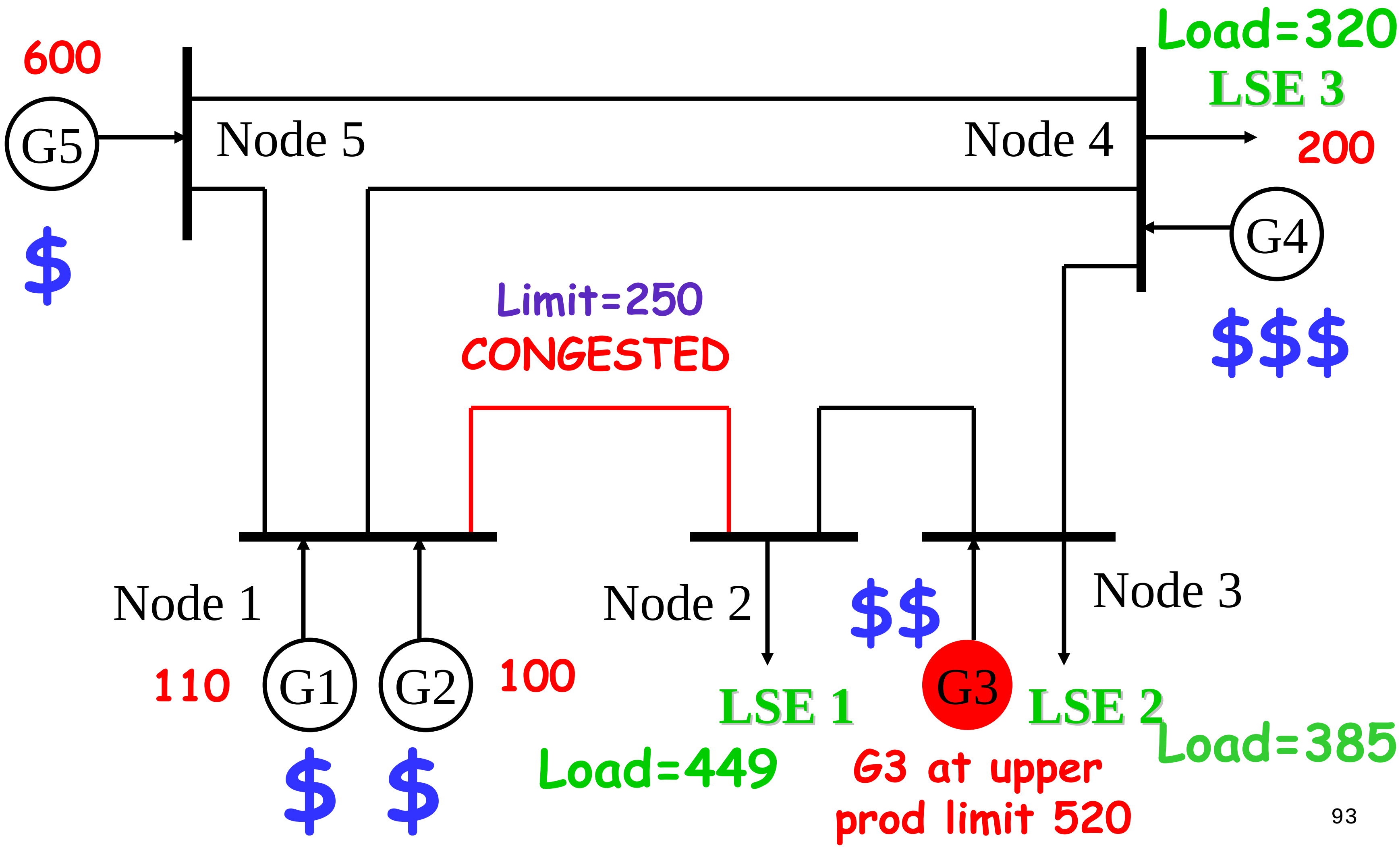


Daily LSE Load Profiles for Dynamic 5-Node Test Case



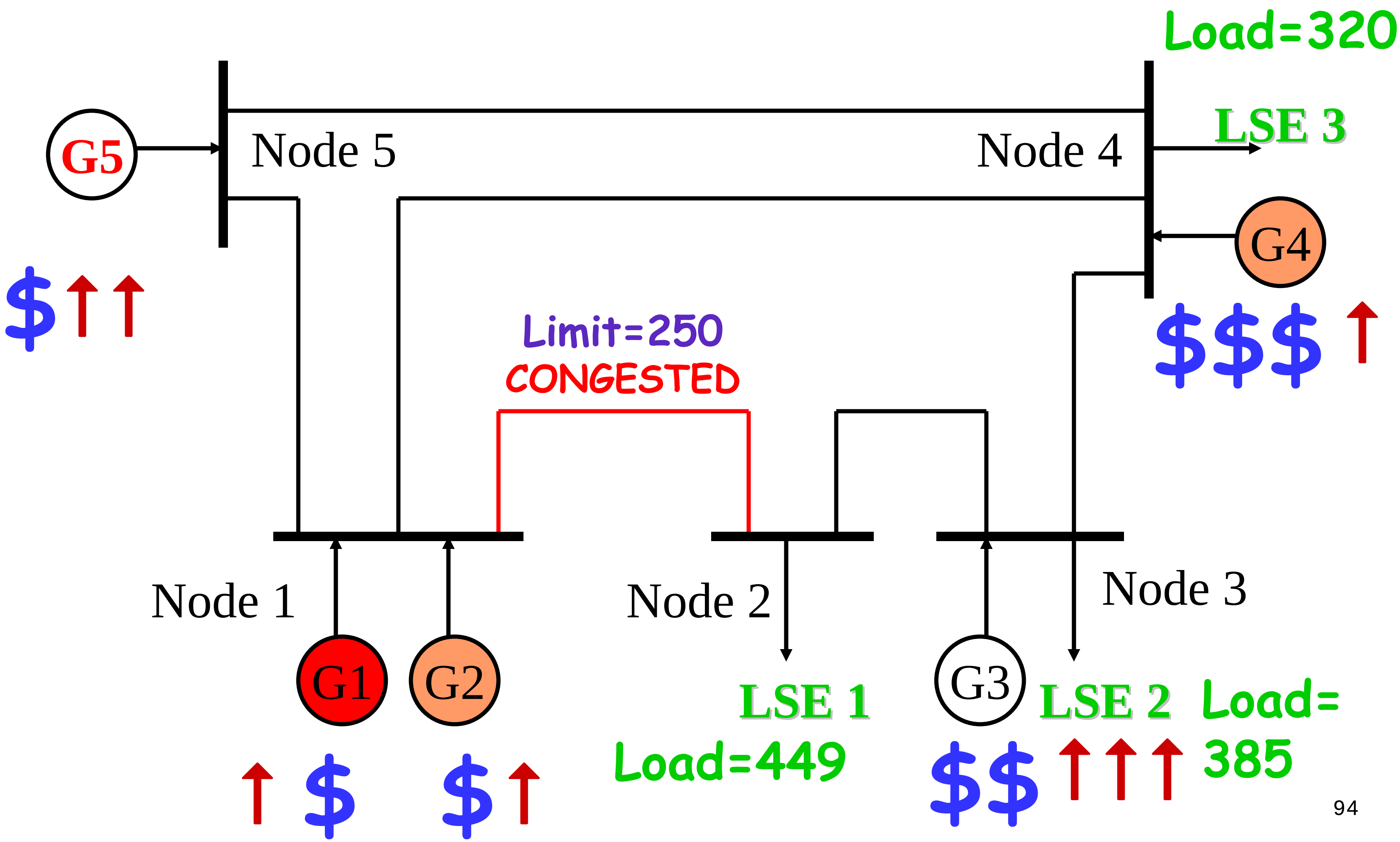
Hour 17 Constraints at No Learning Solution

(Generators report their true MC curves)

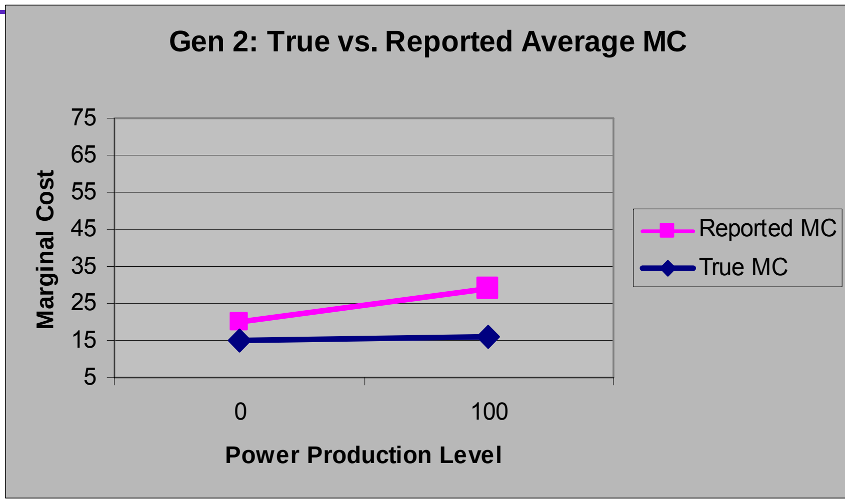


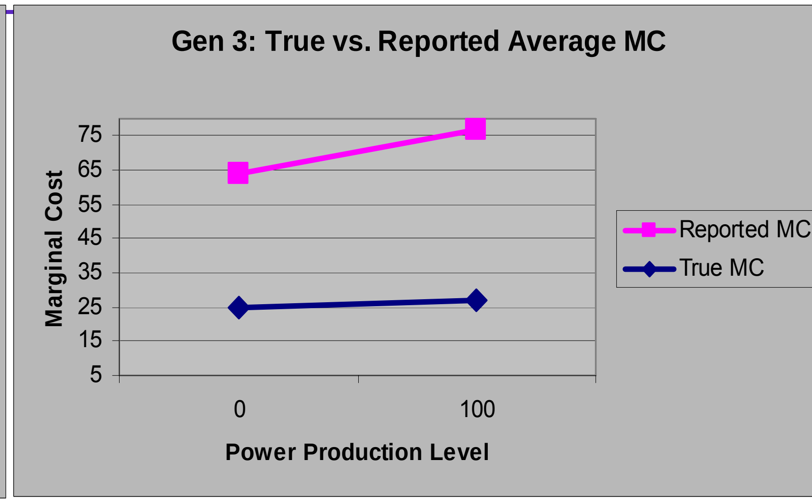
Day 422-Hour 17 Constraints With Gen Learning

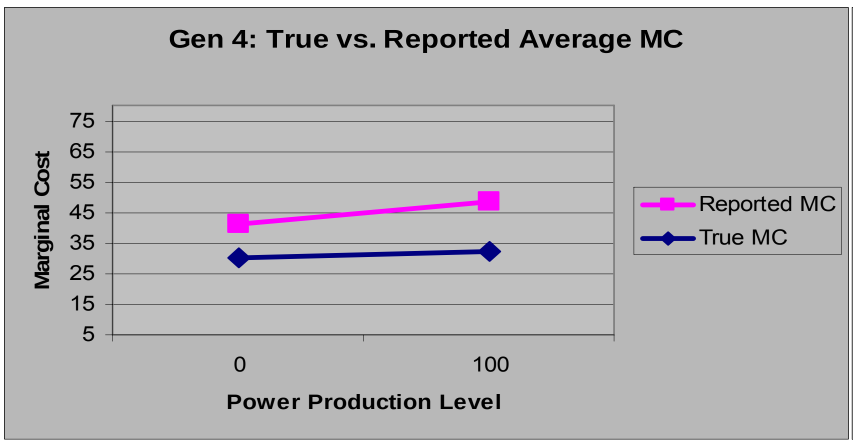
(Each Generator i has converged with Prob(a_i*) = 0.999)

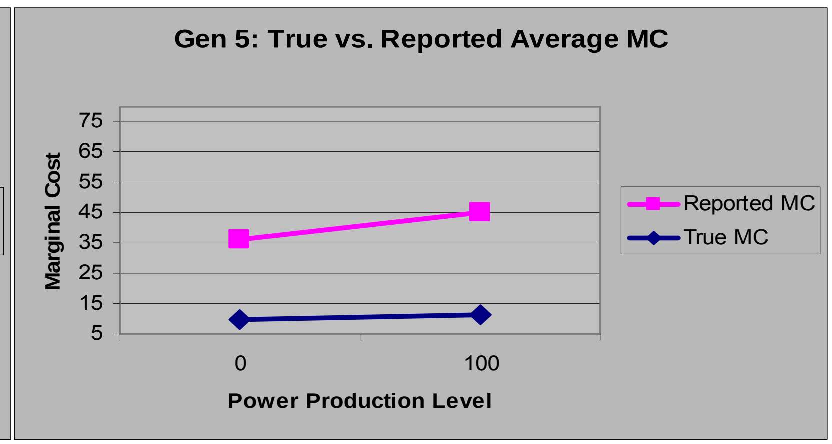


True Vs. Reported MC (Averaged)* on Day 422
(Each Generator i has converged with Prob(a_i') = 0.999)



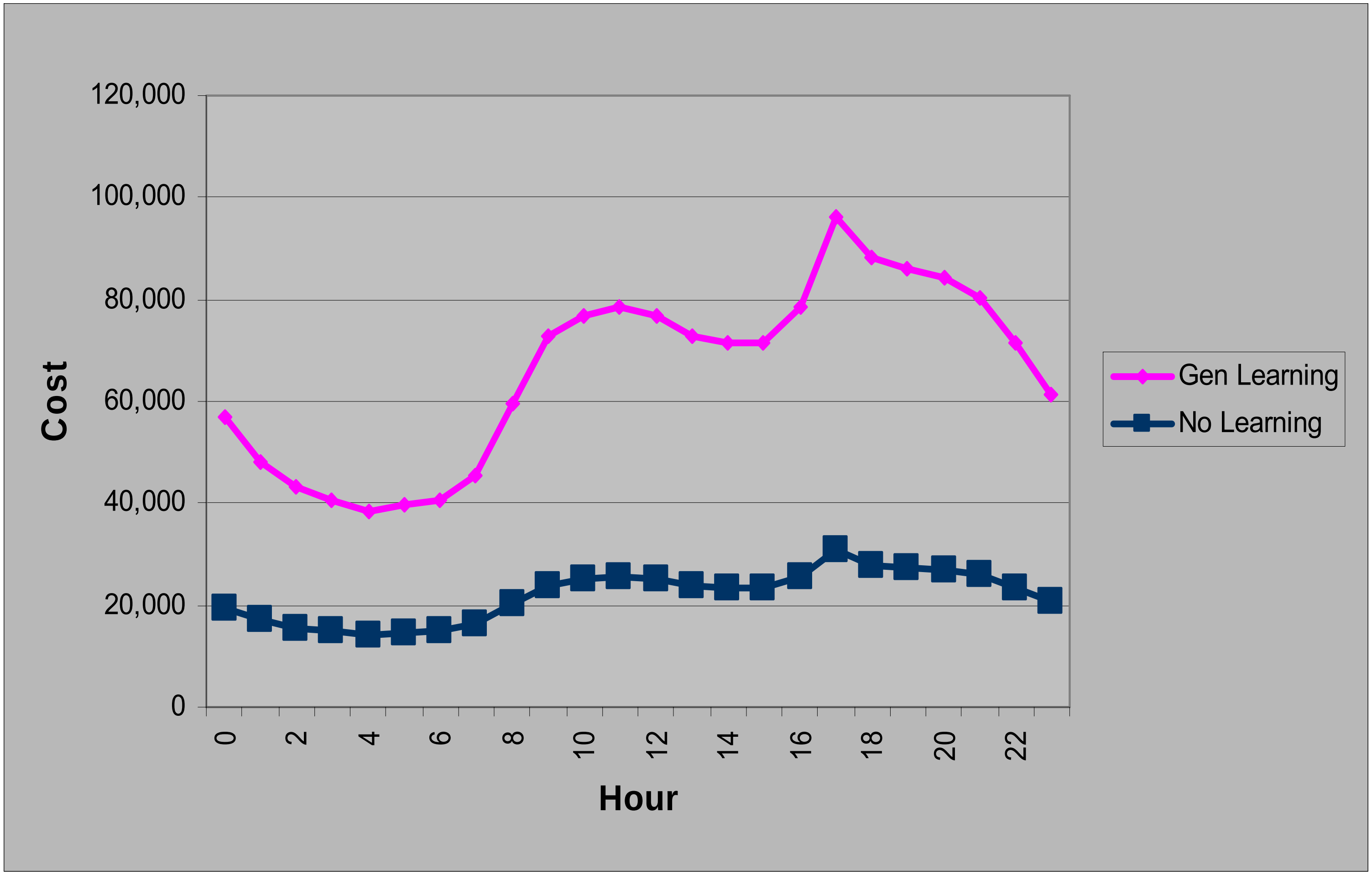






*NOTE: 20-run averages. Typical convergence time = 62 days, max time = 422. Omitted Gen 1 MC curve is similar to Gen 2's.

ISO-Minimized Total Market Operation Costs (Day 422): No Learning Compared With Generator Learning



Dynamic 5-Node Test Case…

- BOTTOM LINE:

Learning Matters !

AMES Software Development to Date

✸ Given supply behavior (Typical econ. lit. assumption)	→	Learned strategic supply behavior (Actual MISO/ISO-NE situation)
✸ No trans./cap. constraints (Typical econ. lit. assumption)	→	Transmission/capacity constraints (Actual MISO/ISO-NE situation)
✸ No market power mitigation (Typical econ. lit. assumption)	→	ISO oversight & MP mitigation (Actual MISO/ISO-NE situation)
✸ Price-inelastic demand (Typical econ. lit. assumption)	→	Demand bids with both fixed and price-sensitive portions (Actual MISO/ISO-NE situation)
✸ No GUI capability	→	GUI capability.

Potential Disadvantages of ACE

- Intensive experimentation with relevant parameter ranges needed to attain robust findings.
- Experiments often result in outcome *distributions* rather than outcome point predictions.
- Can be difficult to ensure results reflect aspects of the social/physical problem of interest and not simply the peculiarities of the programming implementation (hardware or software).
- Creative modeling (rather than use of pre-existing frameworks) can require heavy investment of time and effort to acquire programming skills.

Potential Advantages of ACE

- ACE facilitates empirical model validation since analytical tractability (requiring non-credible simplifications) is no longer an issue
- ACE permits controlled study of systems involving complex interplay of structural, institutional, and behavioral aspects.
- ACE test beds encourage creative experimentation.
- Researchers/students can evaluate interesting conjectures of their own devising, with immediate feedback and no original programming required
- Modular form of software permits relatively easy modification/extension of features.