Agent-Based Computational Economics

A Constructive Approach to Economic Theory

Presenter:

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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**

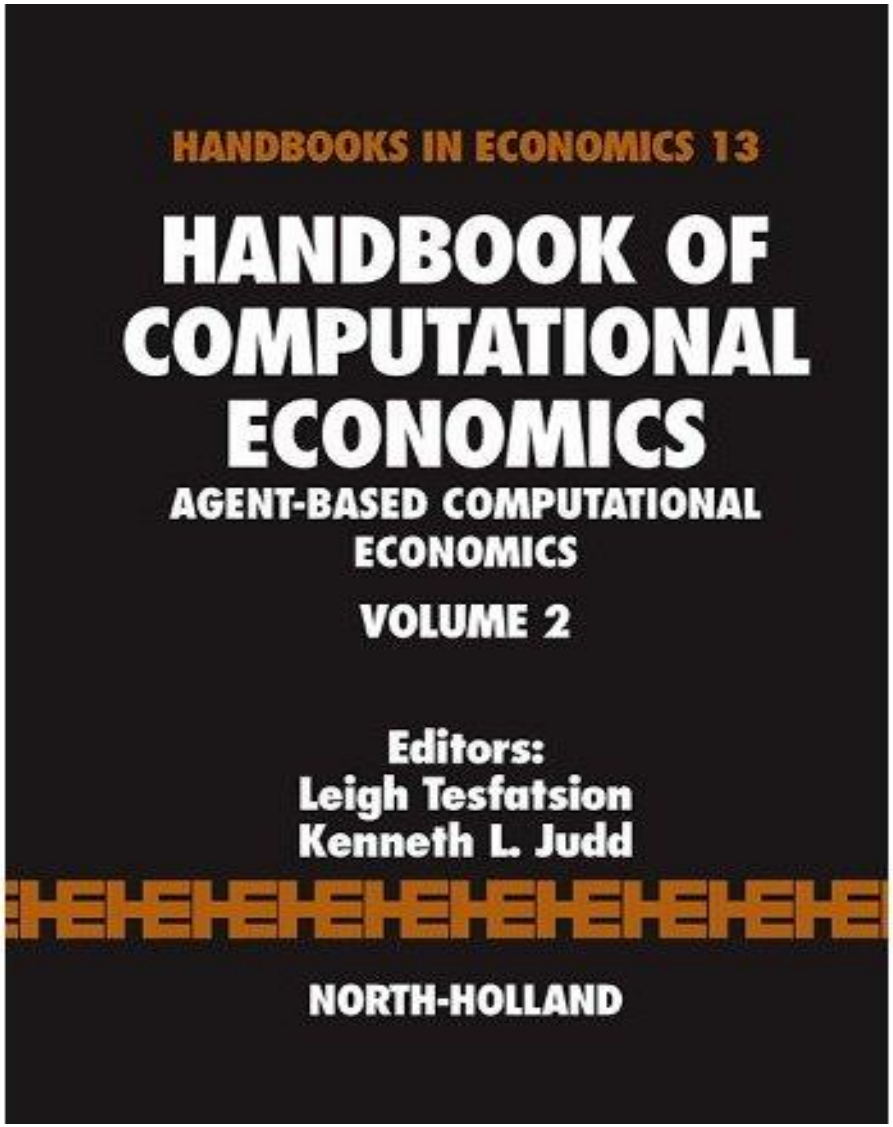
ACE Resources

- **ACE Website**

  https://www2.econ.iastate.edu/tesfatsi/ace.htm

- **ACE Handbook** (Tesfatsion & Judd, Handbooks in Economics Series, North-Holland, 2006, 904pp)

  https://www2.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

(https://www2.econ.iastate.edu/tesfatsi/aapplic.htm)

- Learning and embodied cognition
- Network formation
- Evolution of norms
- Real-world market studies (labor, energy, finance…)
- Industrial organisation
- Technological change and growth
- Macroeconomics
- Business and Management
- 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***

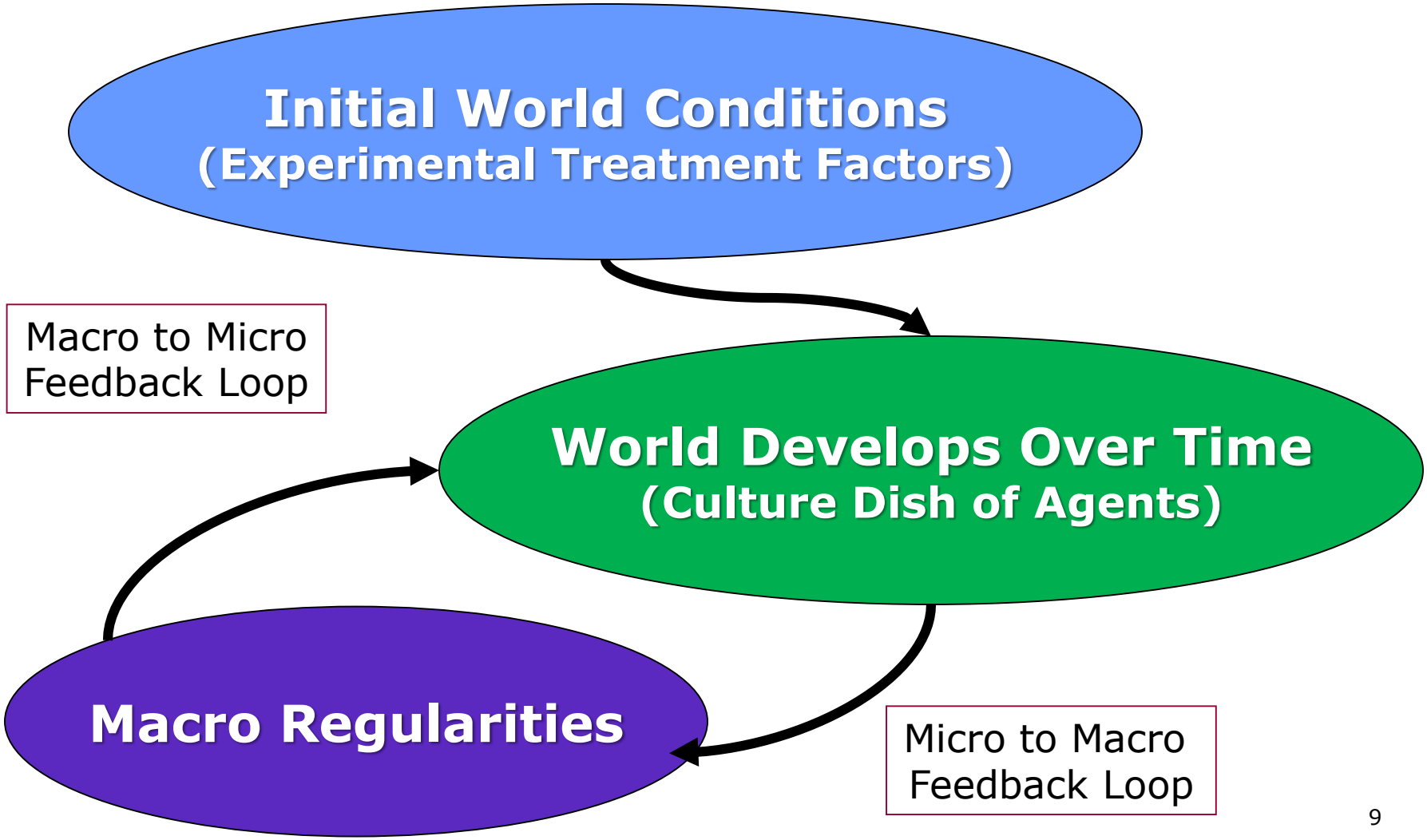
What is Agent-Based Computational Economics (ACE)?

- Computational modeling of economic processes (including whole economies) as open-ended dynamic systems of interacting agents
- **Culture-dish approach** to the study of decentralized market processes

ACE Modeling: Culture Dish Analogy

- Modeler constructs a **virtual economic world** populated by various agent types (economic, institutional, 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 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 anticipatory 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 https://www2.econ.iastate.edu/tesfatsi/afinance.htm

ACE and Institutional Design

Key Issue: Does an actual/proposed policy or institutional design ensure efficient, fair, and orderly outcomes over time despite attempts by participants to "game" the design for their personal advantage?

ACE Approach:

- Construct an agent-based world capturing salient aspects of the policy or institutional design.
- Introduce decision-making agents with learning capabilities and let the world evolve.
- Observe and evaluate the resulting 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 and let the world evolve. Observe the degree of coordination that results over time.

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)

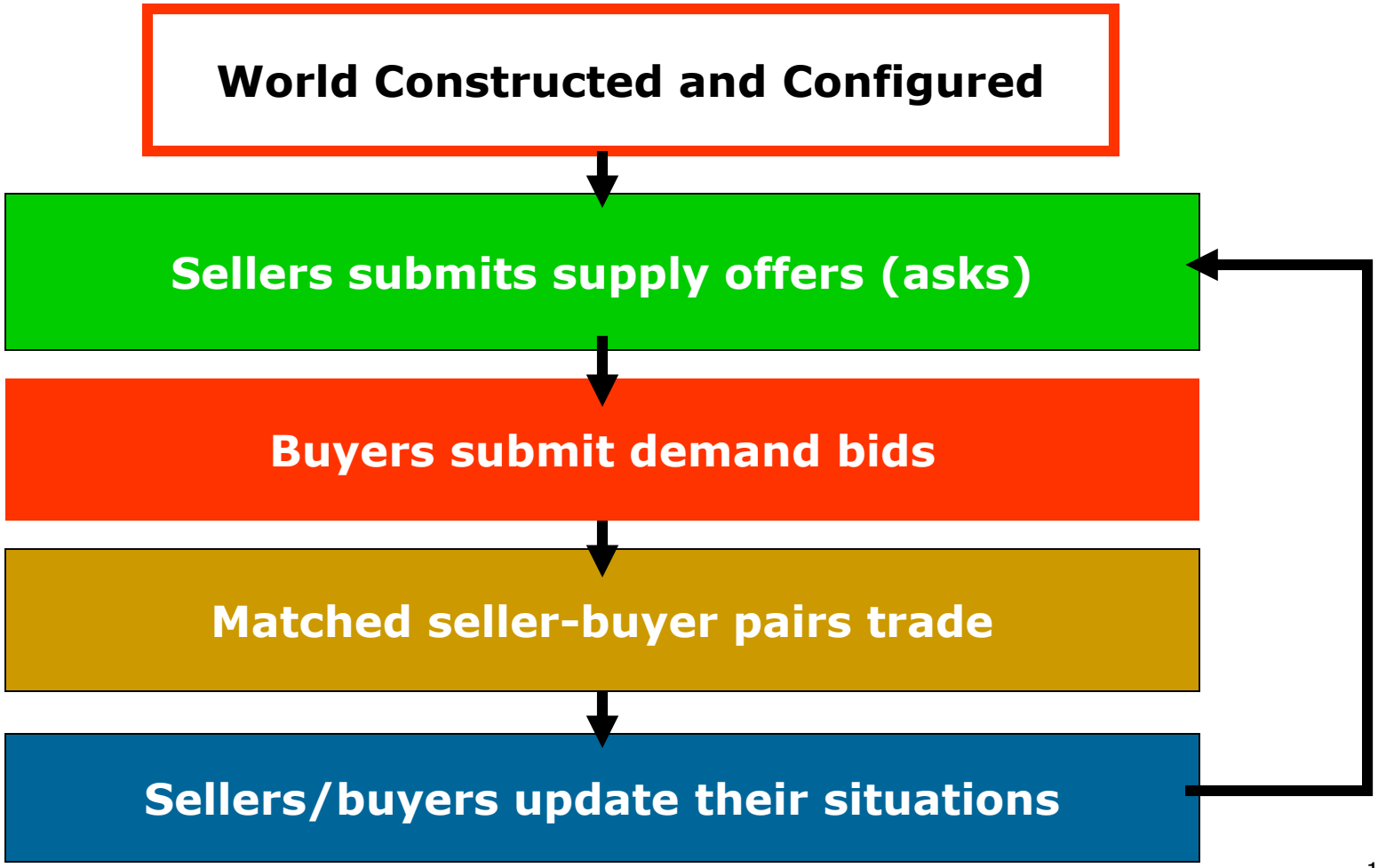
  https://www2.econ.iastate.edu/tesfatsi/mpeieee.pdf

- **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

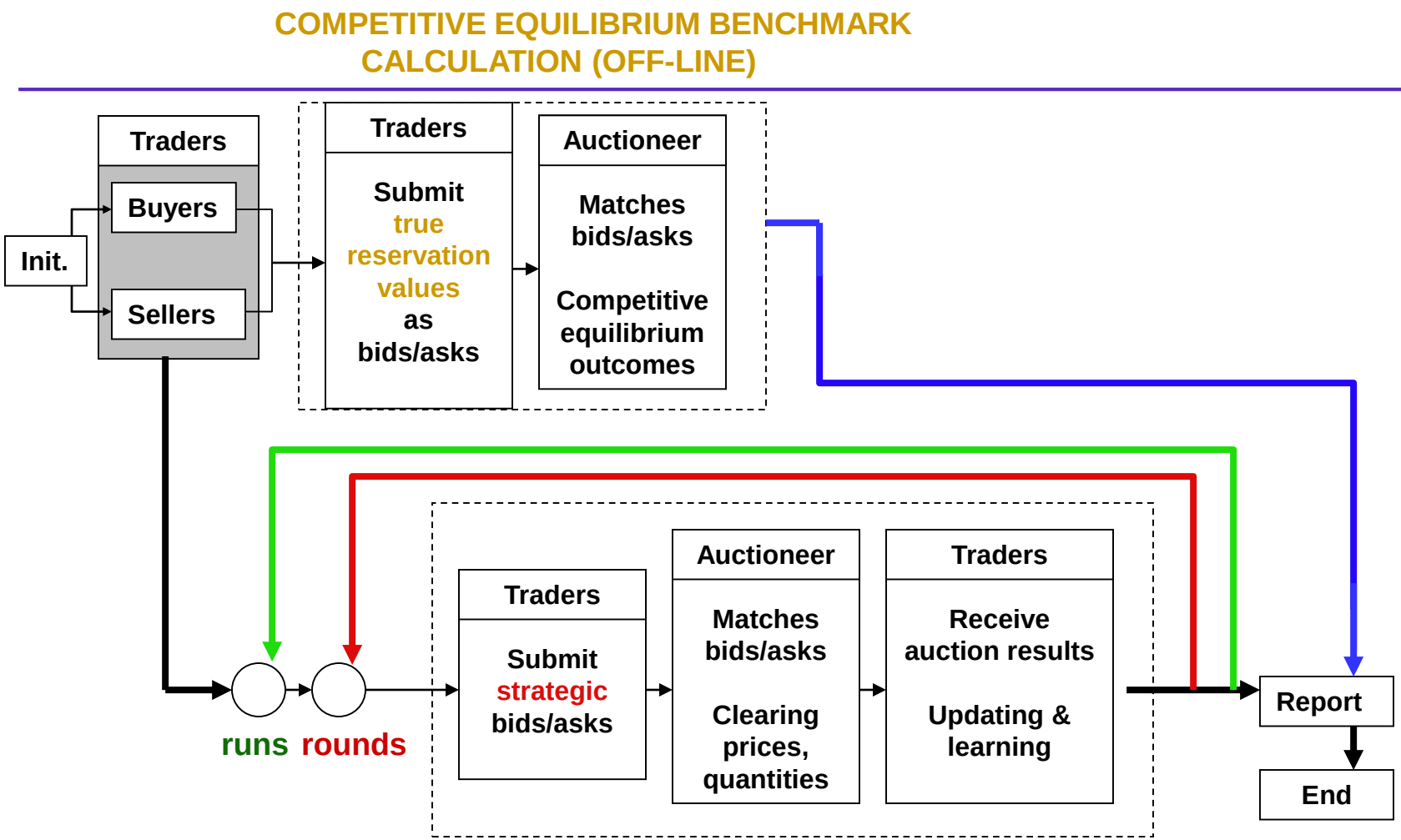
  RCAP = Relative demand/supply capacity

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

Market Efficiency, Market Power, and Market Concentration

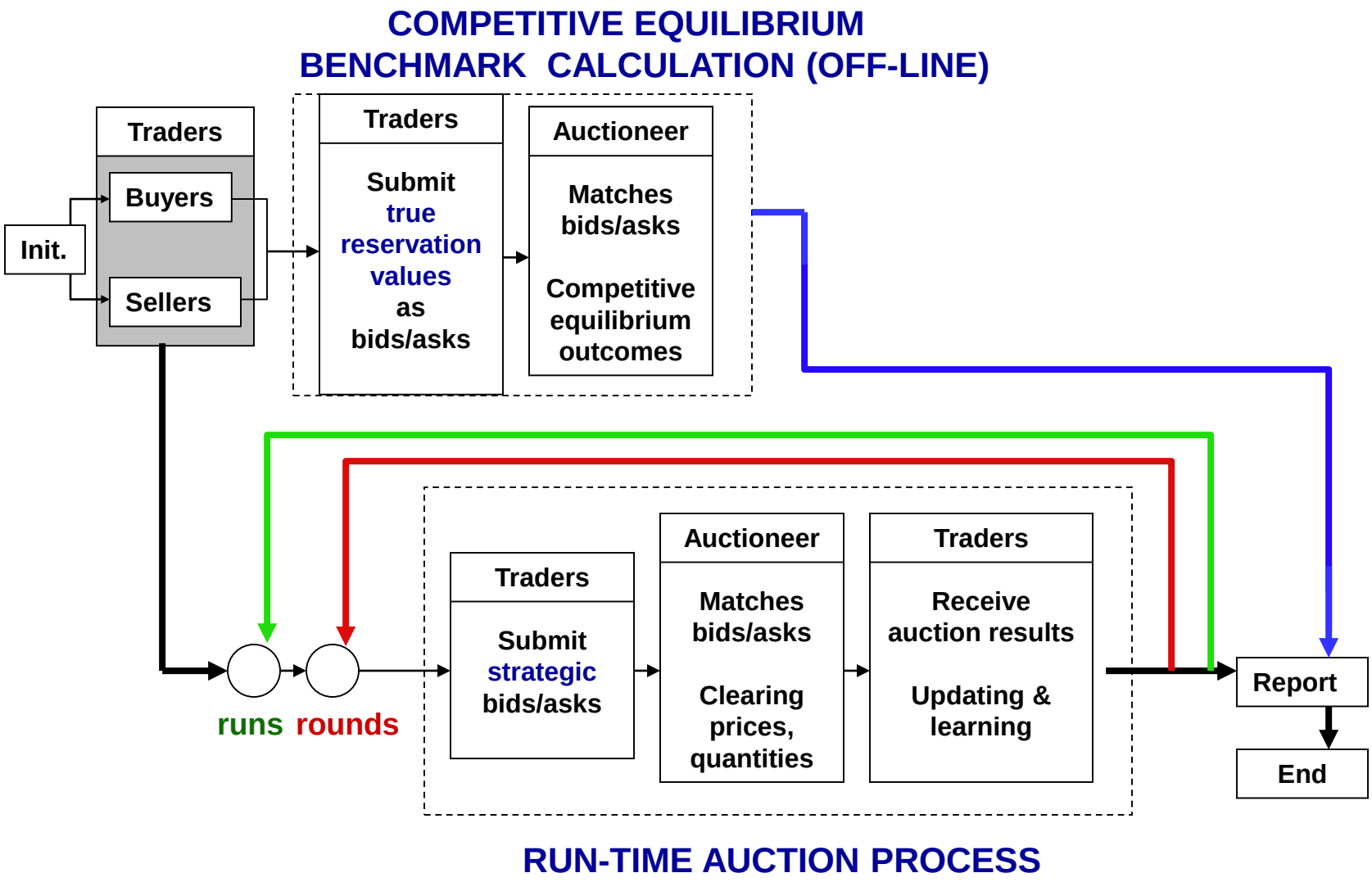
- ***Market Efficiency:*** *the degree to which market participants succeed in extracting maximum total net benefits from the market.*
- ***Market power:*** the degree to which a market participant can profitably influence prices away from competitive levels.
- ***Market concentration:*** the degree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

Activity Flow for the Double Auction (DA)



ACTUAL DOUBLE-AUCTION PROCESS
(DISCRIMINATORY-PRICE DOUBLE AUCTION WITH STRATEGIC BIDS/ASKS)

Activity Flow for the Double Auction (DA)



World Agent

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.

DA Market Agent (Auctioneer)

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).

DA Trader Agent

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:

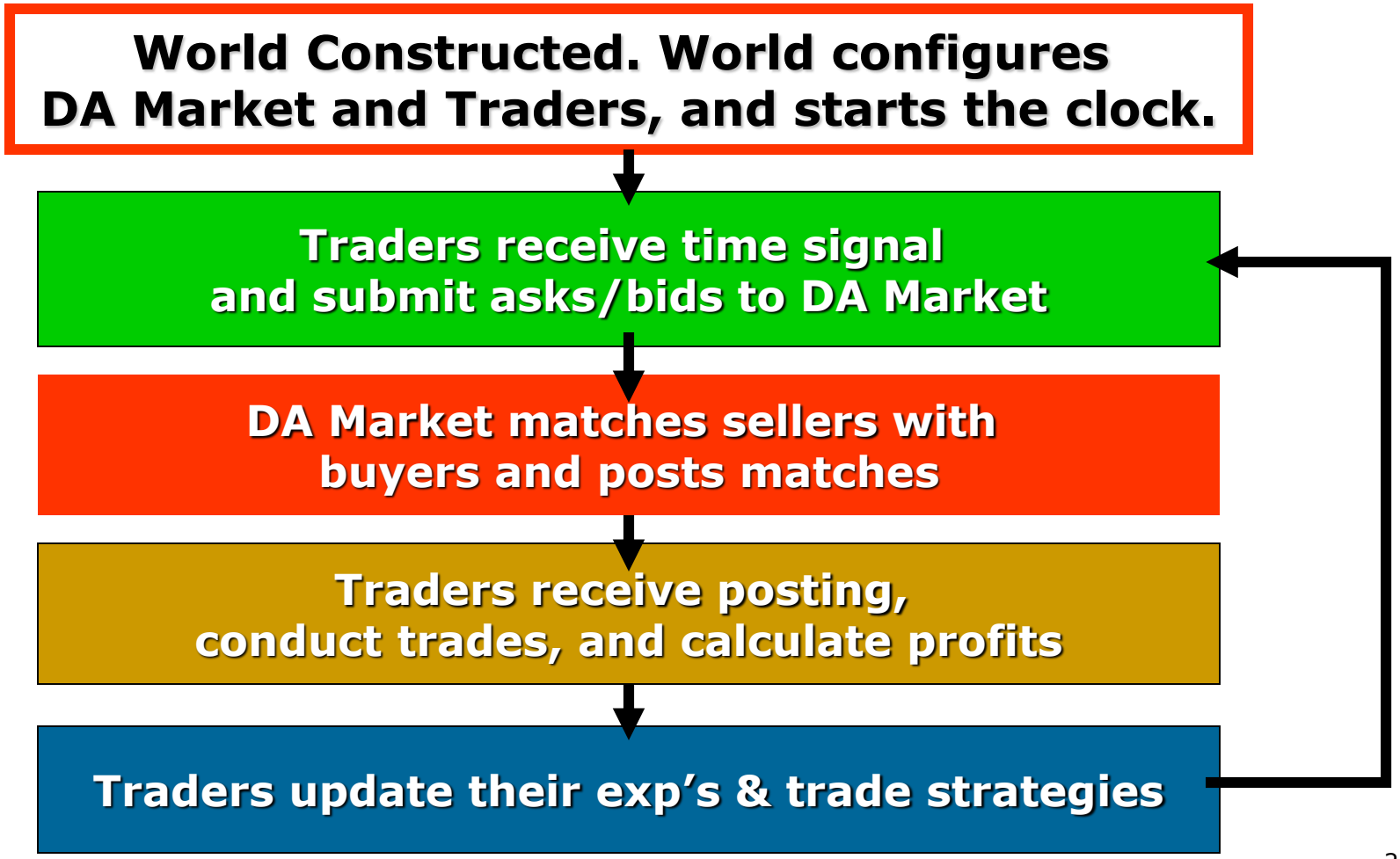
// **Private Methods**

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

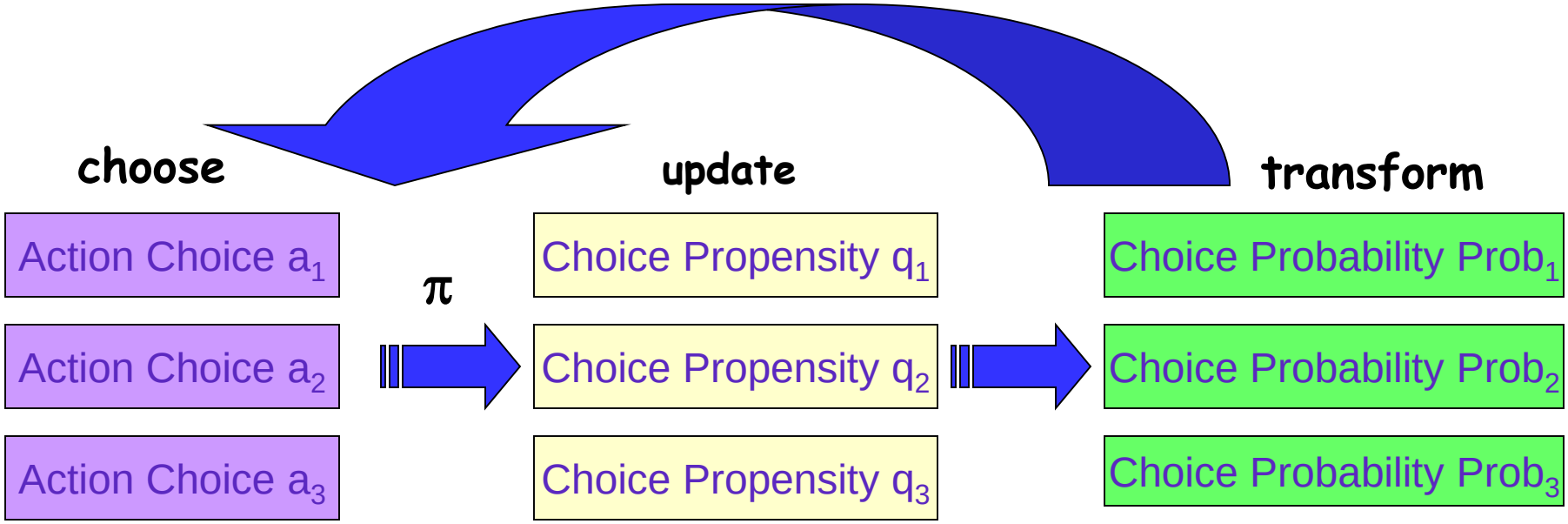
// **Private Data**

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

Dynamic Flow of DA Market



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

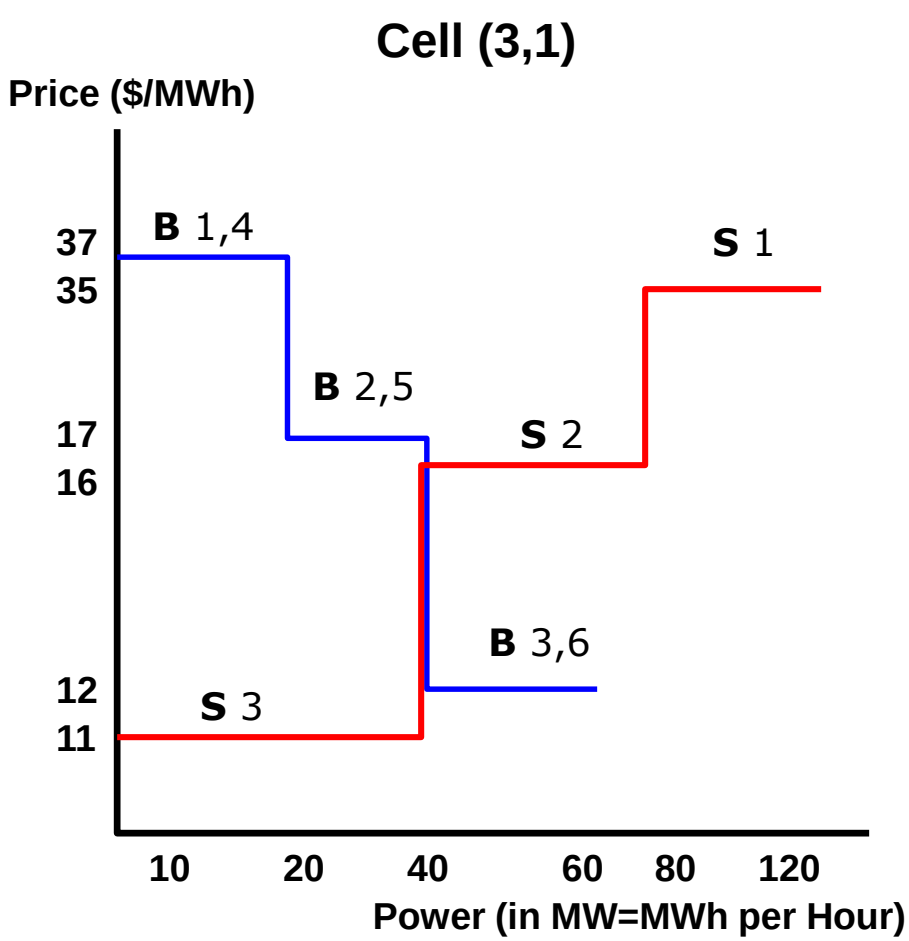
1. **Initialize** action propensities to an initial propensity value.
2. **Generate** choice probabilities for all actions using current propensities.
3. **Choose** an action according to the current choice probability distribution.
4. **Update** propensities for all actions using the reward (profits)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

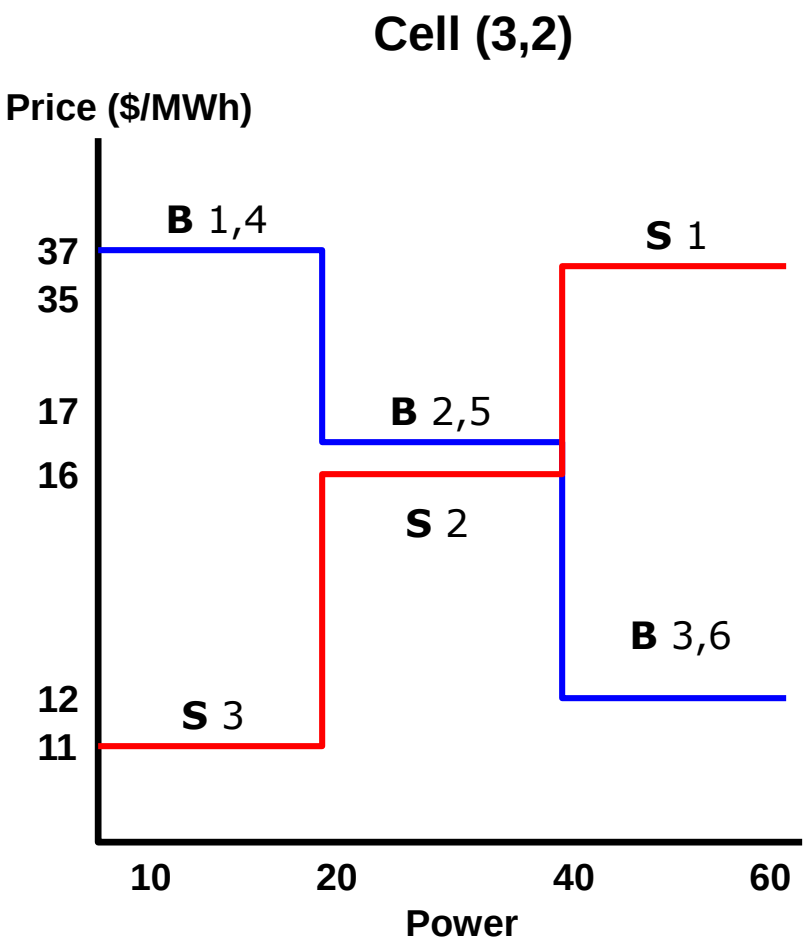
Structural Treatment Factor Values
(Tested for Each Learning Treatment)

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
	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
	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

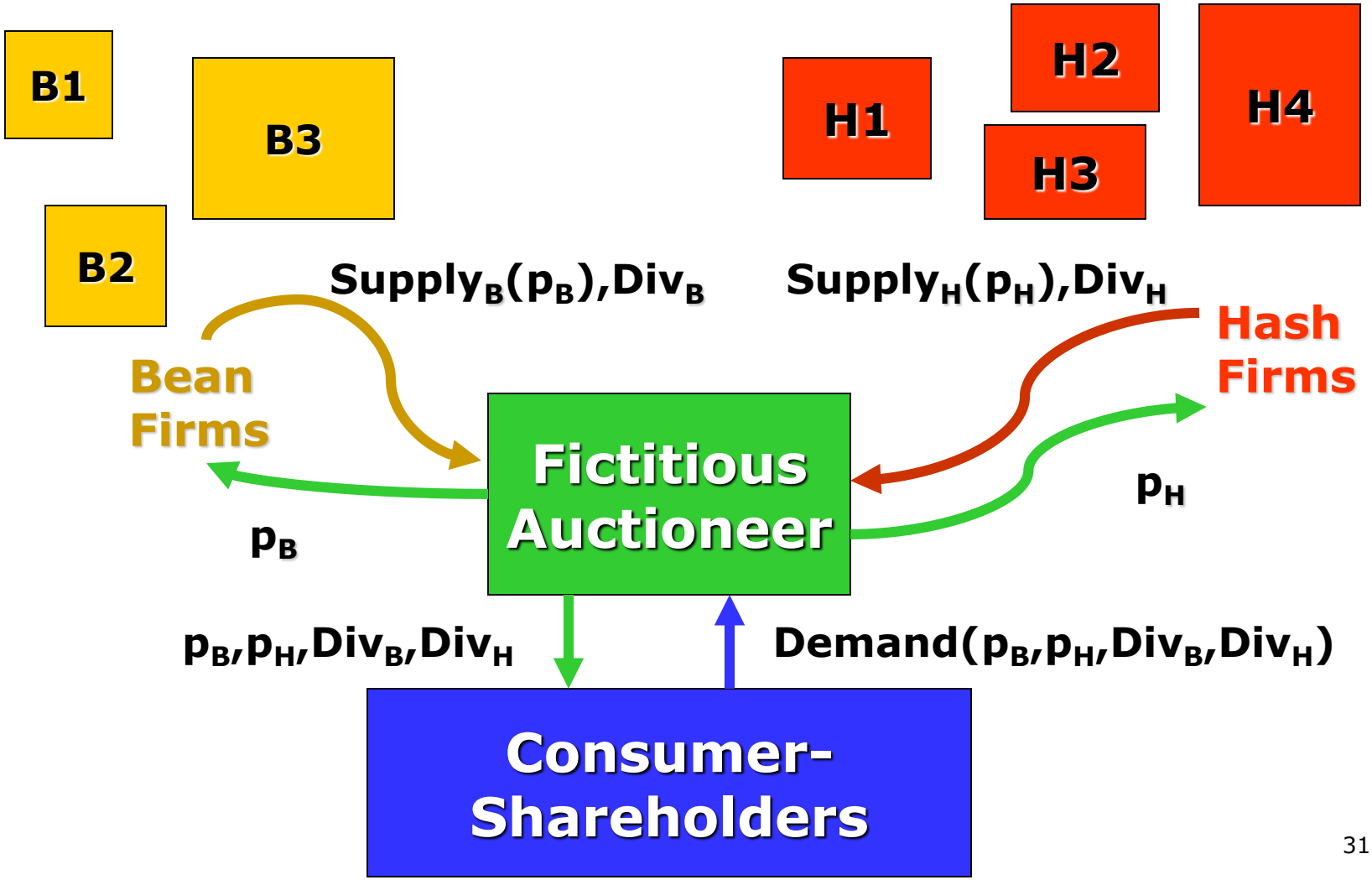
Starting Point:

Two-Sector General Equilibrium (GE) Economy

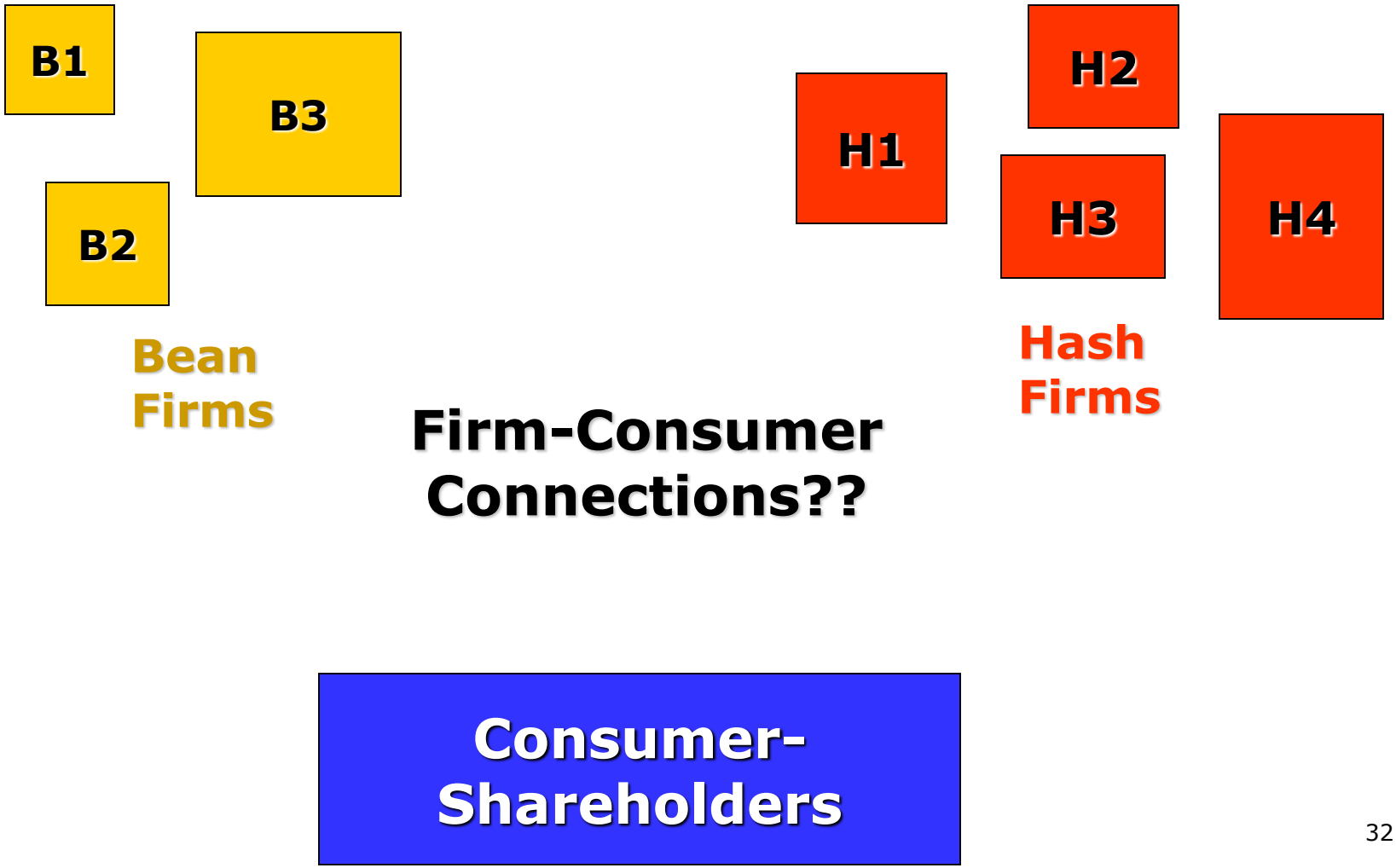
Exercise:

- **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

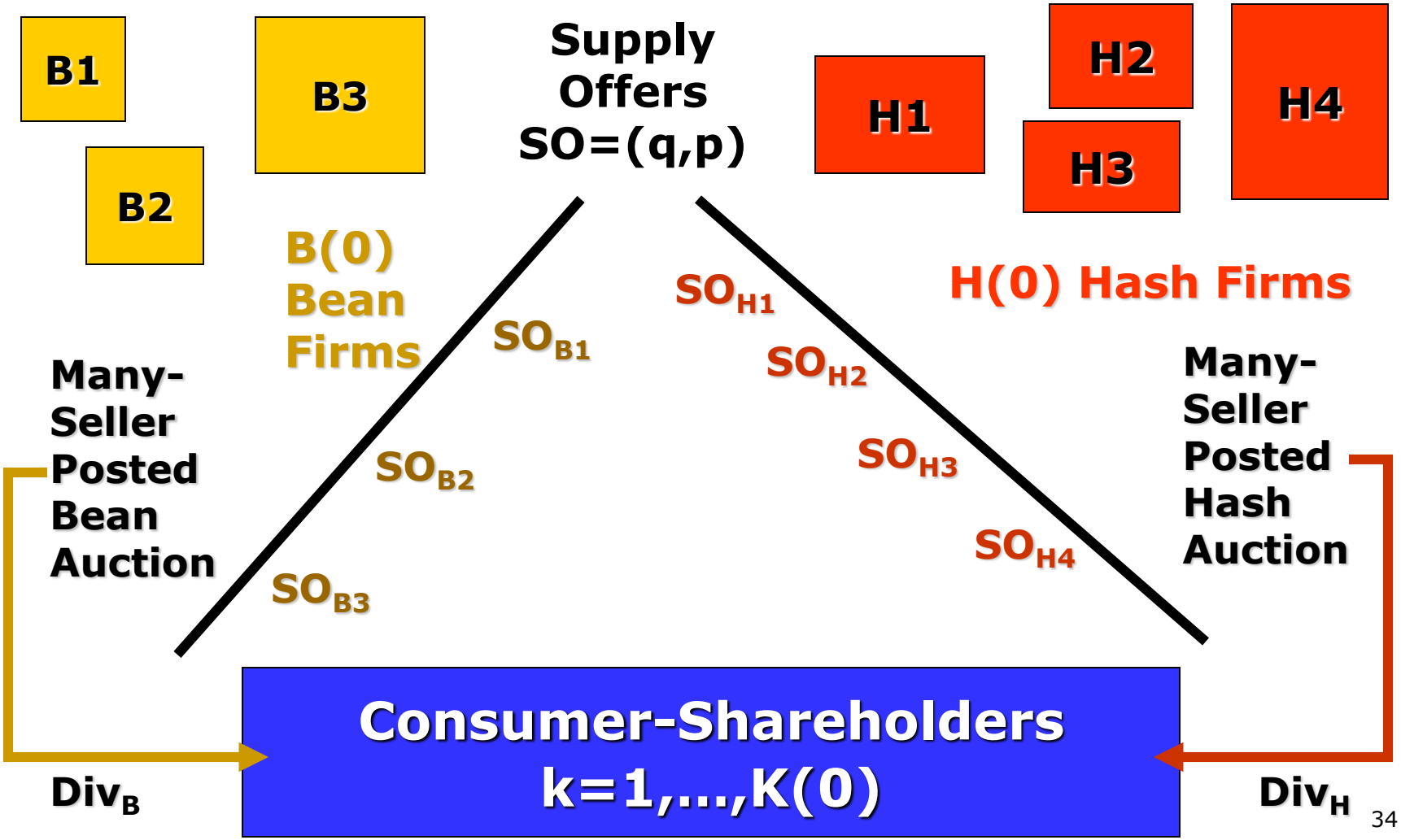


Plucking Out the Fictitious Auctioneer

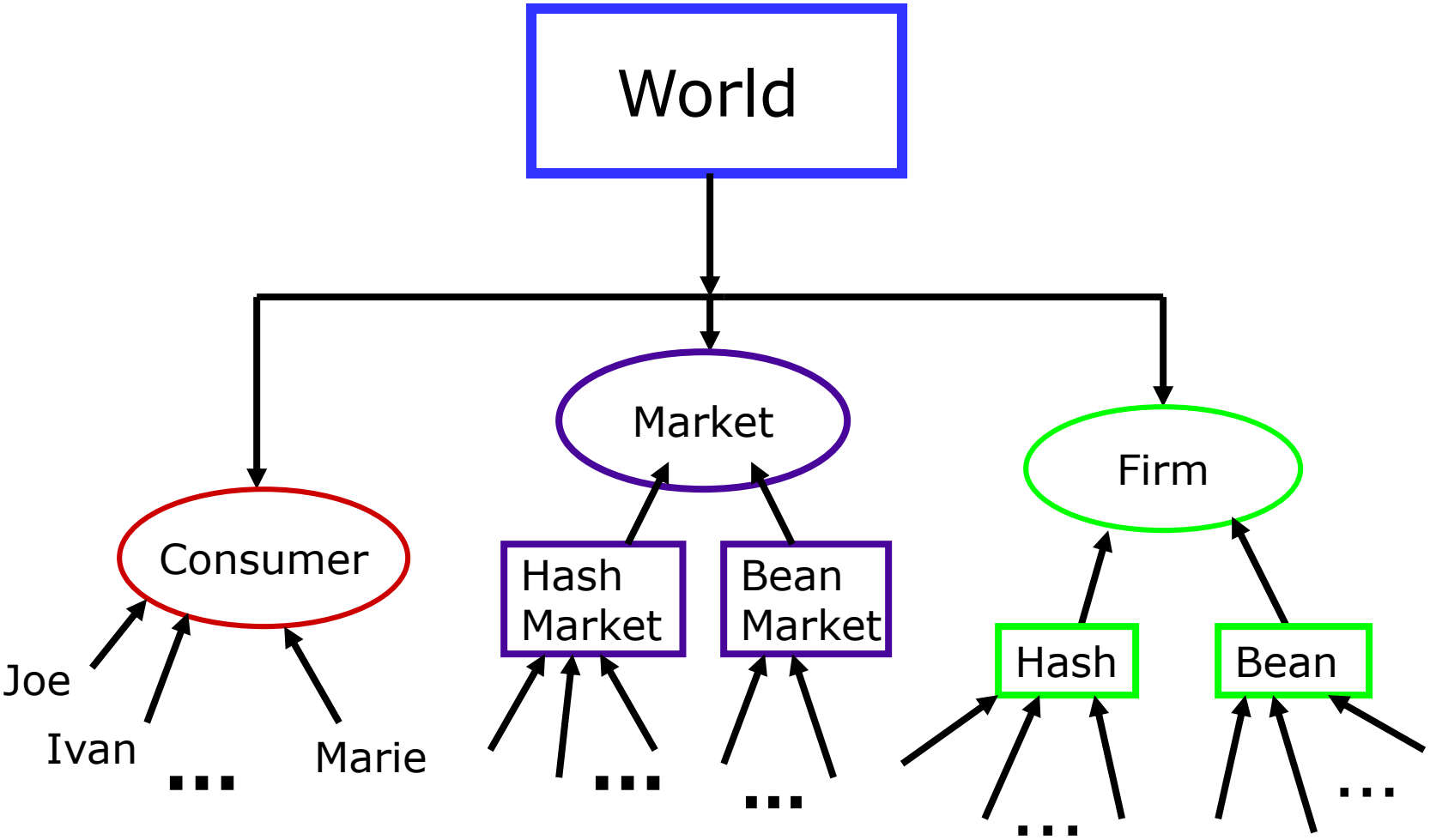
Focus must now be procurement processes

- ***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

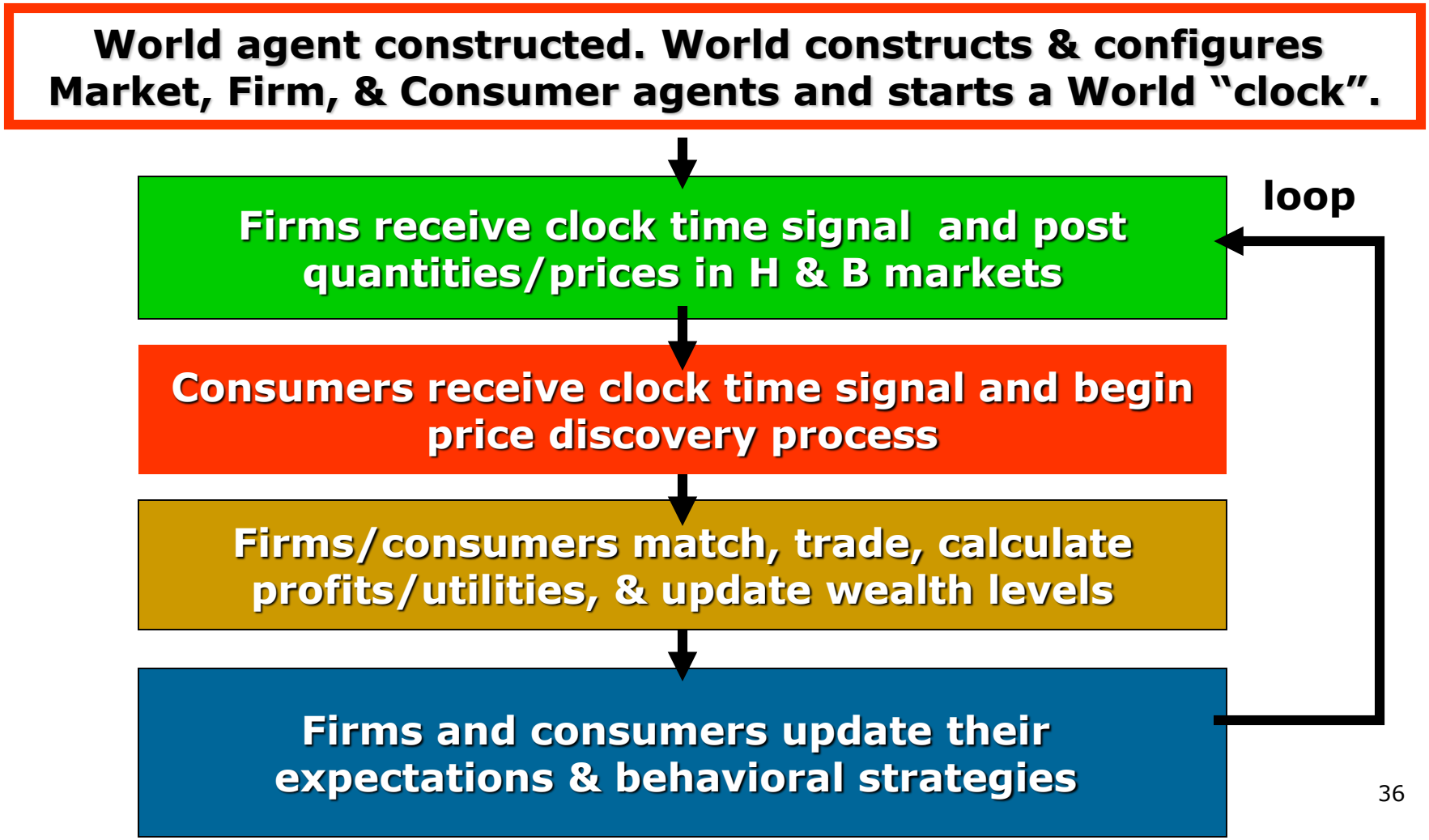
Illustration:
ACE Hash-and-Beans (H&B) Economy



ACE H&B Economy: Agent hierarchy



Overview of Activity Flow in the ACE H&B Economy



Activity Flow for 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 sunk cost $SC_f(T)$** for $T \geq 0$ is proportional to its current capacity $Cap_f(T)$
- At beginning of each $T \geq 0$, firm f **selects 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, & dividend payments.

Activity Flow for Consumer-Shareholders

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

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

- In each $T \geq 0$, consumer k's **utility** is measured by $U_k(T)=(\text{hash}(T) - h_k^*)^{\alpha_k} \bullet (\text{beans}(T) - b_k^*)^{[1-\alpha_k]}$
- In each $T \geq 0$, consumer k seeks to secure maximum utility by **searching** for beans and hash to buy at **lowest possible prices**.
- At end of each $T \geq 0$, whether consumer k **lives or dies** depends on whether or not he secures at least his **subsistence needs** (b_k^*, h_k^*).

Experimental Design Treatment Factors

- **Initial number of consumers** [K(0)]
- **Initial number/size of firms** [H(0), B(0), $Cap_f(0)$]
- **Firm learning** (supply offers & profit allocations)
- **Firm cost functions**
- **Firm initial money holdings** [$M_f(0)$]
- **Firm rationing protocols** (for excess demand)
- **Consumer learning** (price discovery & demand bids)
- **Consumer money endowment profiles** (rich, poor, ↗ , ↘ , life cycle u-shape)
- **Consumer preferences** (θ values)
- **Consumer subsistence needs** (b*,h*)

World Agent

Public Access:

// **Public Methods**

The ***World Event Schedule,*** i.e., a system clock that permits inhabitants to time and synchronize activities (e.g., opening/closing of H & B markets);

Protocols governing firm collusion;

Protocols governing firm 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 (H & B markets, firms, consumers);

World inhabitants' methods and data.

Market Agent

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
Protocols governing the public posting of supply offers;
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 firms (e.g., supplies, sales);
Data recorded about consumers (e.g., demands, purchases);
Address book (communication links).

Consumer Agent

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
getWorldProtocols (stock share ownership);
getMarketProtocols (price discovery process, trade process);
Methods for receiving data;
Methods for retrieving stored Consumer data.

Private Access:

// **Private Methods**

Methods for gathering, storing, and sending data;
Method for determining own budget constraint;
Method for searching for lowest prices (**LEARNING**);
Methods for changing my methods (**LEARNING TO LEARN**).

// **Private Data**

Data about self (history, utility function, current wealth,…);
Data about external world (posted supply offers, …);
Address book (communication links).

Firm Agent

Public Access:

// **Public Methods**

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

Private Access:

// **Private Methods**

Methods for gathering, storing, and sending data;
Methods for calculating own expected/actual profit outcomes;
Method for allocating own profits to shareholders;
Method for updating own supply offers (**LEARNING**);
Methods for changing my methods (**LEARNING TO LEARN**).

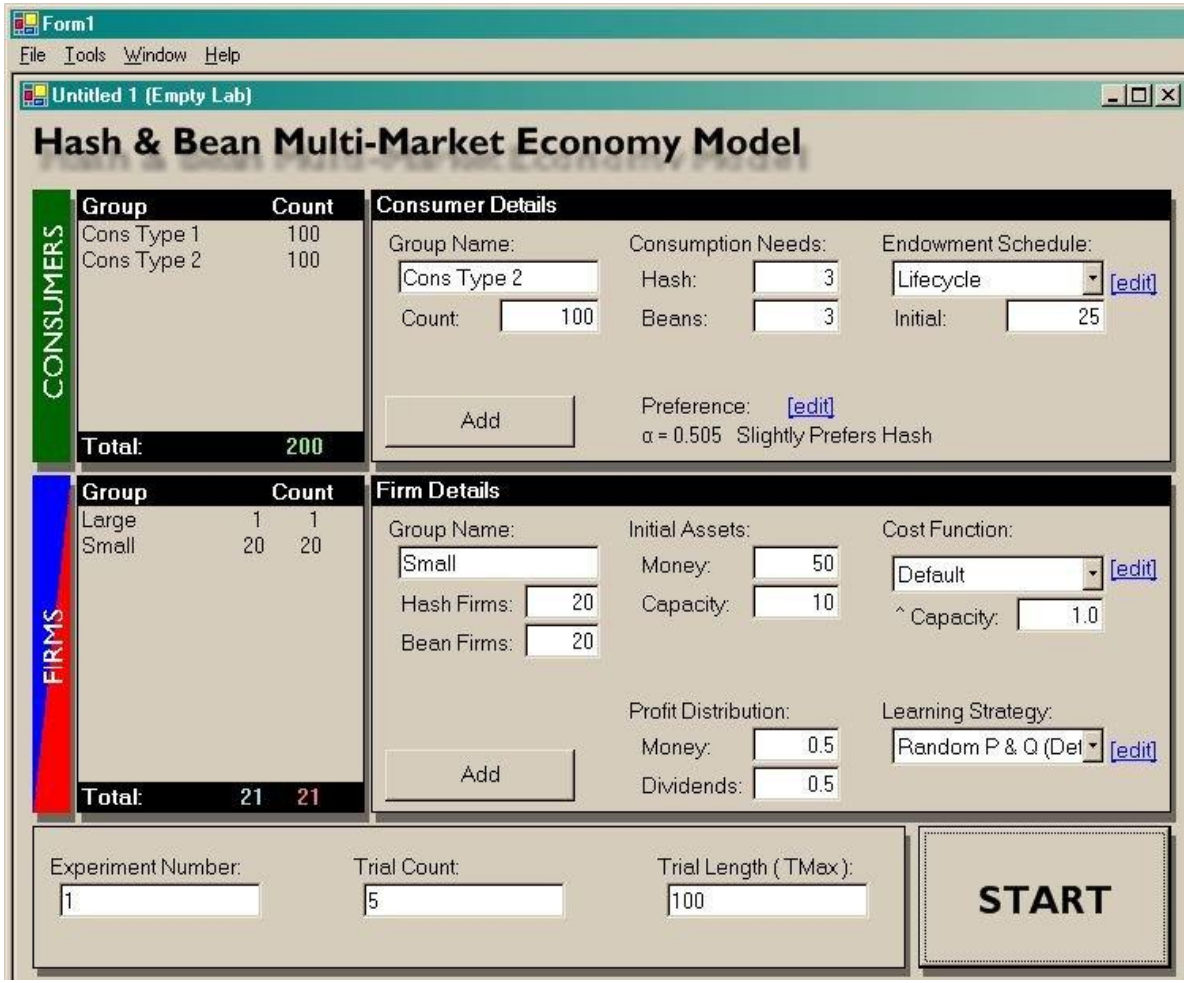
// **Private Data**

Data about self (history, profit function, current wealth,…);
Data about external world (rivals' supply offers, demands,…);
Address book (communication links).

Interesting Issues for Exploration

- Initial conditions → **carrying capacity?**
  (How many firms/consumers survive over long run?)
- Initial conditions → **market clearing?**
  (Supplies adequate to meet demands?)
- Initial conditions → **market efficiency?**
  (No wastage of physical resources or utility?)
- Standard firm concentration measures at T=0 → **good predictors of long-run firm market power?**
- Importance for market performance of **learning vs. market structure ?** *(Gode/Sunder, JPE, 1993)*

ACE Hash-and-Beans Economy Implementation
(C. Cook, 2005, C#/.Net, Incomplete Project)



An Extended ACE Hash & Beans Economy

Marc Oeffner's implementation of Agent Island

(Thesis, 2008, Julius-Maximilians-Universitat Wurzburg)

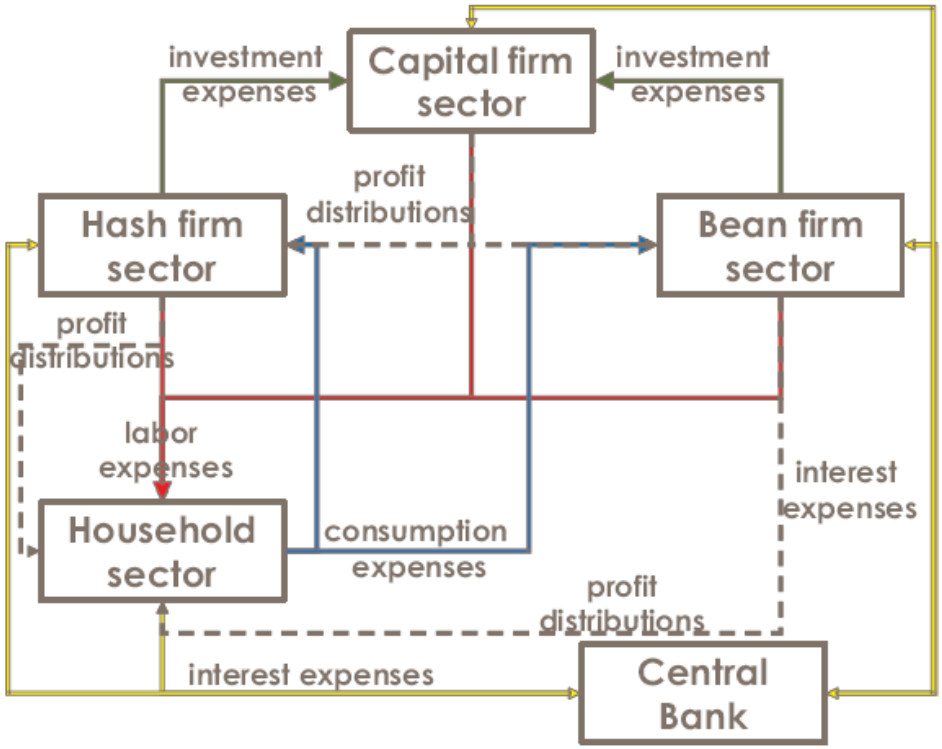


Figure 2.1: Markets and transactions on Agent Island

Thesis/Code (SeSAm) Available At:

https://www2.iastate.edu/tesfatsi/amulmark.htm

Equity and Loan Financing in Agent Island

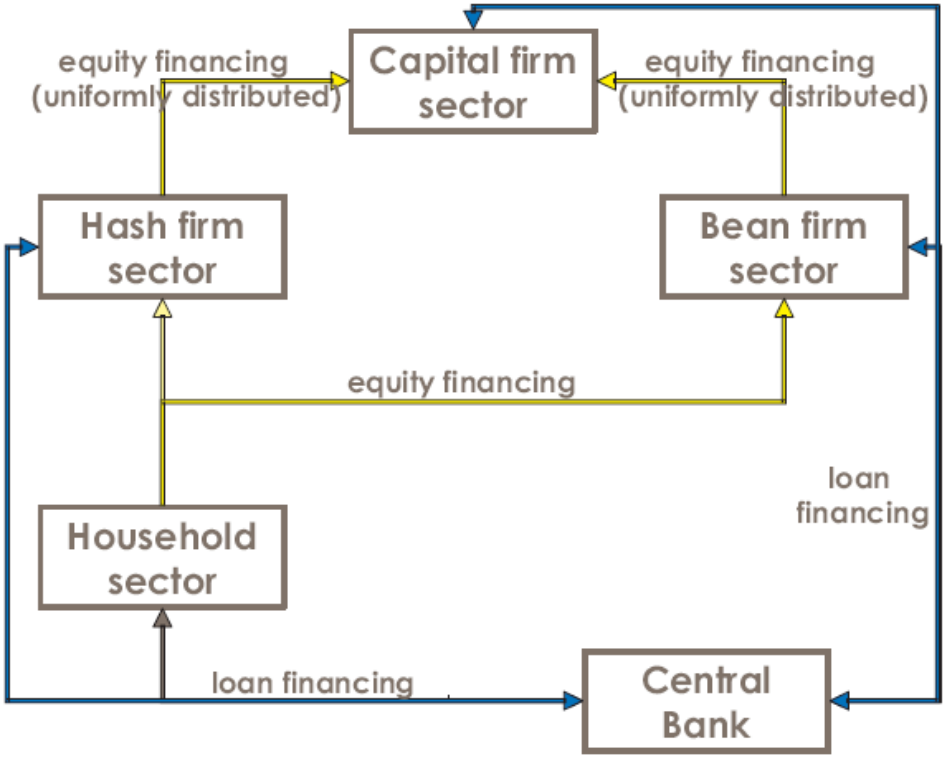


Figure 2.2: Financing contracts on Agent Island

Direct Finance:
Purchase of initial public offerings of securities, e.g., stocks (equities), bonds,…

Indirect Finance:
Loans obtained through a financial intermediary, such as a bank

Daily Activity Flow in Agent Island

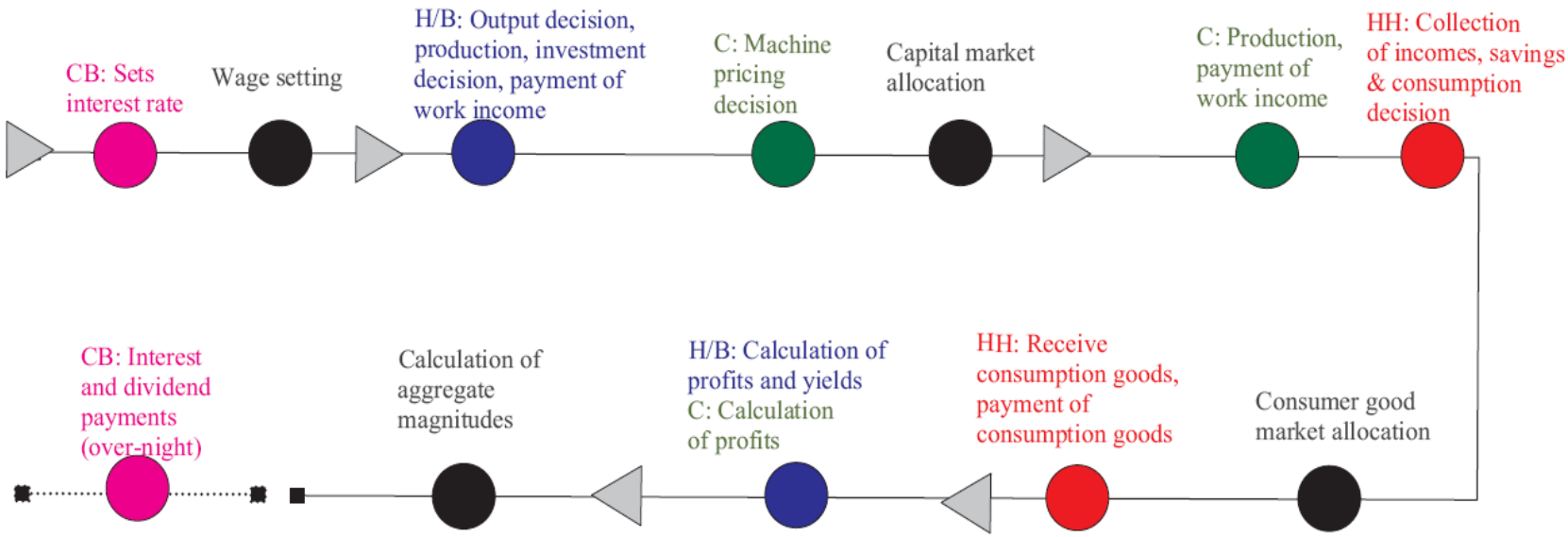


Figure 2.3: Intra-period sequence of decisions and actions

Sample Outcomes for Agent Island

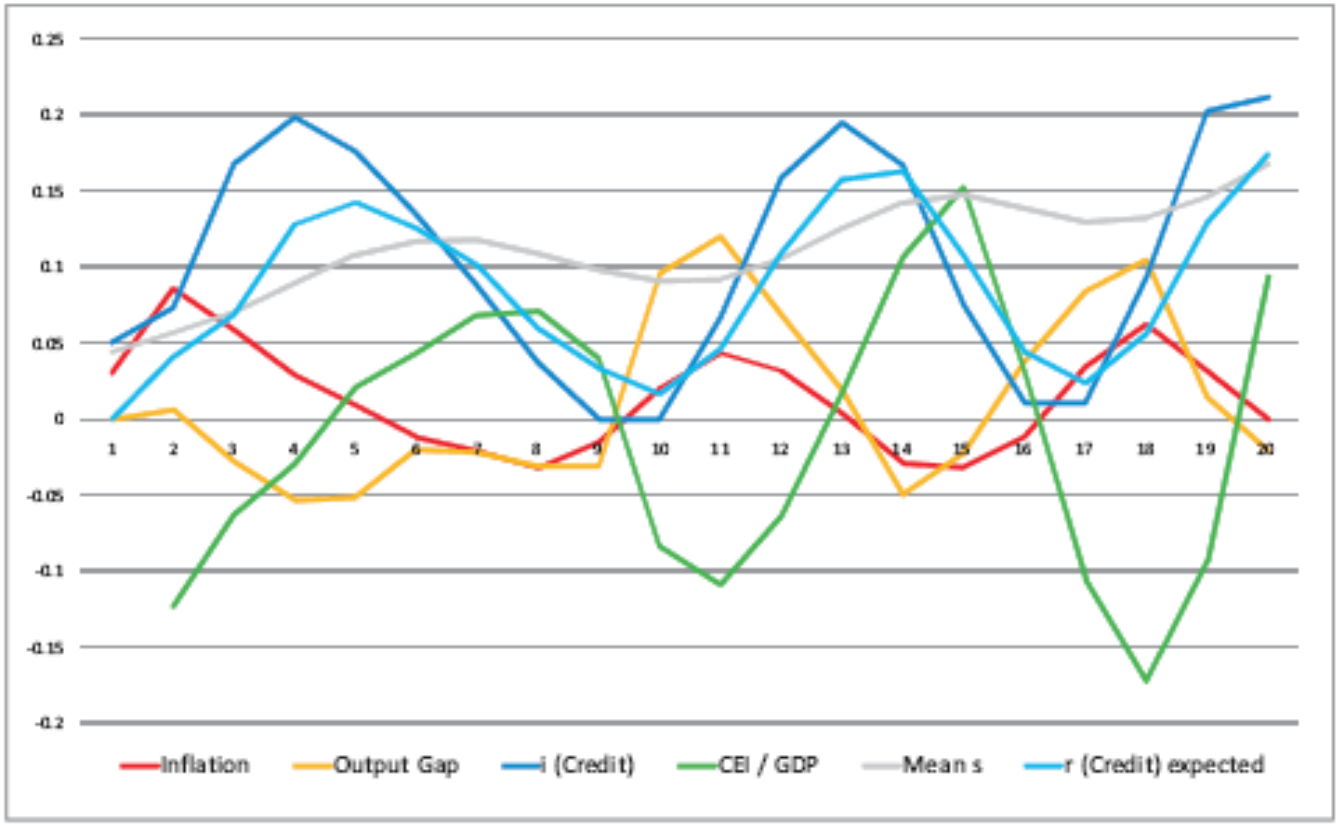


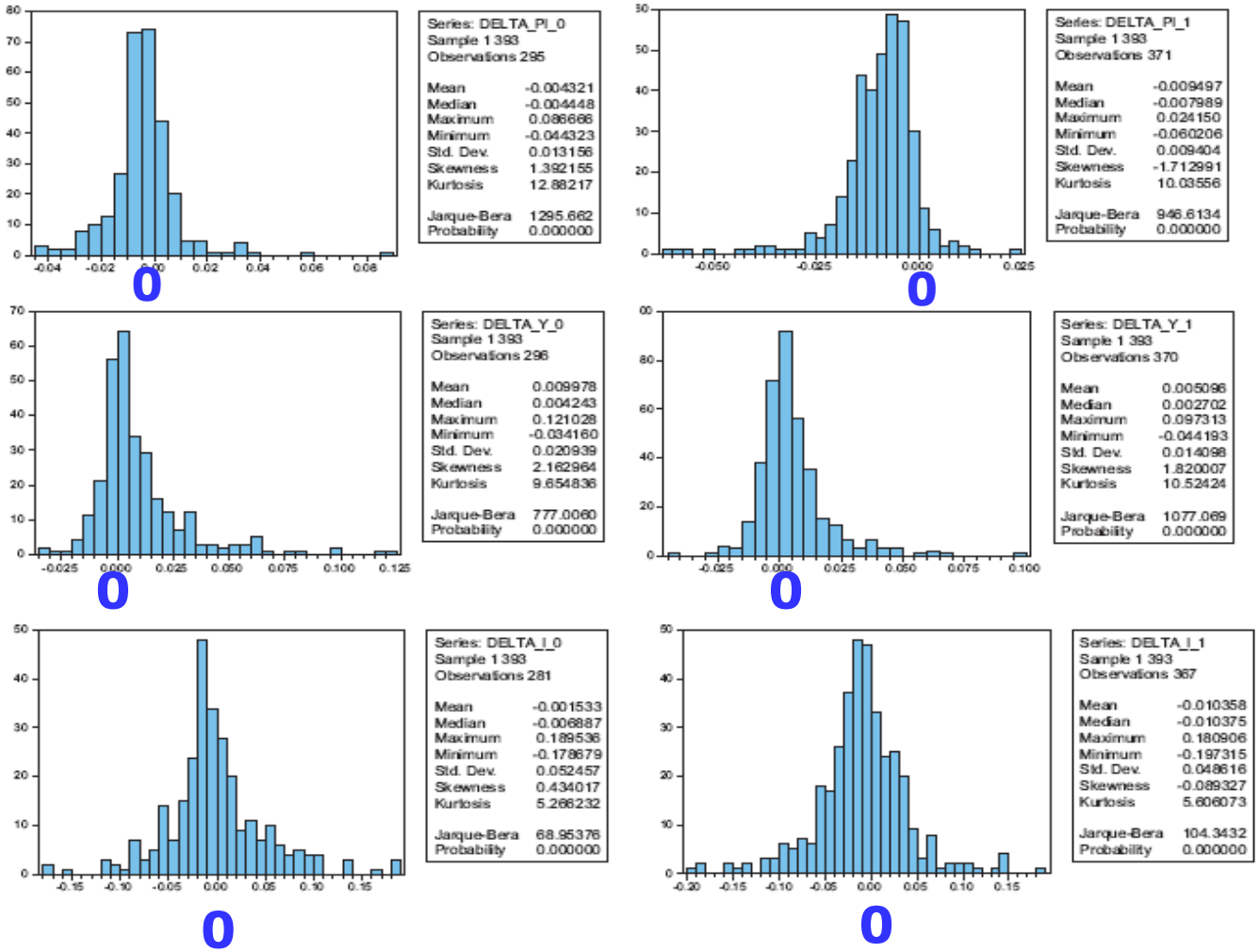
Figure 3.33: Stylized facts of the second rerun in the baseline case

Period 1 (Shock Time) Period 2 (After Shock Time)

inflation

Real GDP

Investment demand



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)

Sample PDFs for outcome changes due to a 1% increase in the credit interest rate occurring in period 1 and maintained in future periods

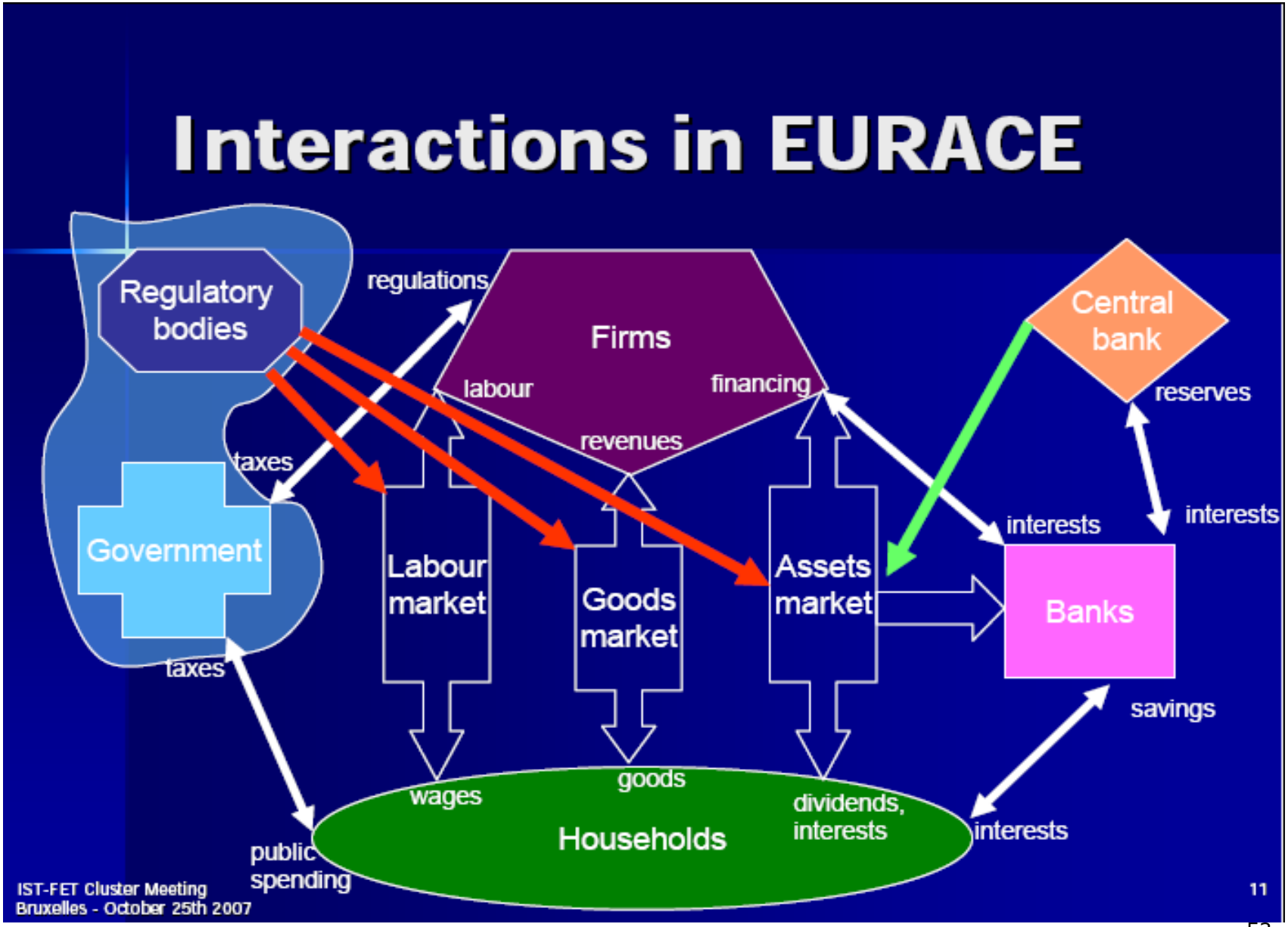
Example 3: EURACE -- Large-Scale ACE Model of the EU

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
Labour market
Goods market
Assets market
interests
interests
Banks
taxes
savings
wages
goods
dividends, interests
Households
interests
public spending
IST-FET Cluster Meeting
Bruxelles - October 25th 2007
11

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

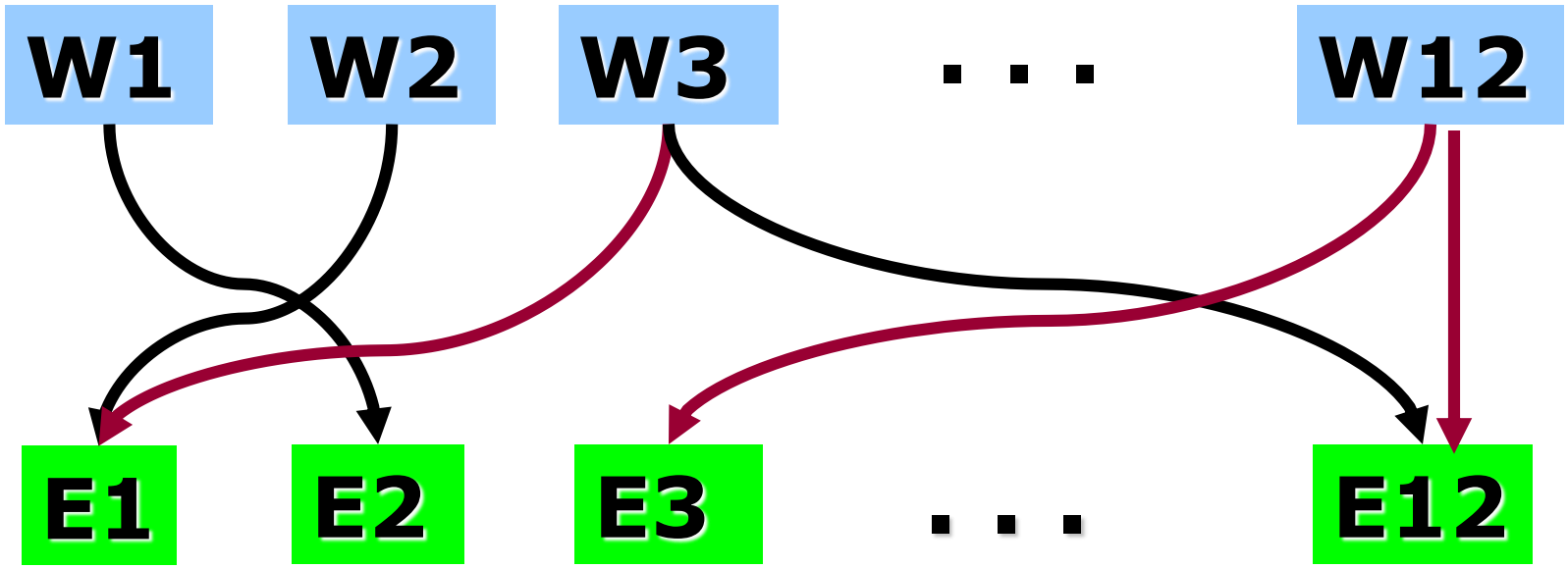
  M. Pingle and L. Tesfatsion, "Evolution of Worker-Employer Networks and Behaviors under Alternative Non-Employment Benefits: An Agent-Based Computational Economics Study"

- Pre-print available at

  https://www2.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

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]**

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]**;

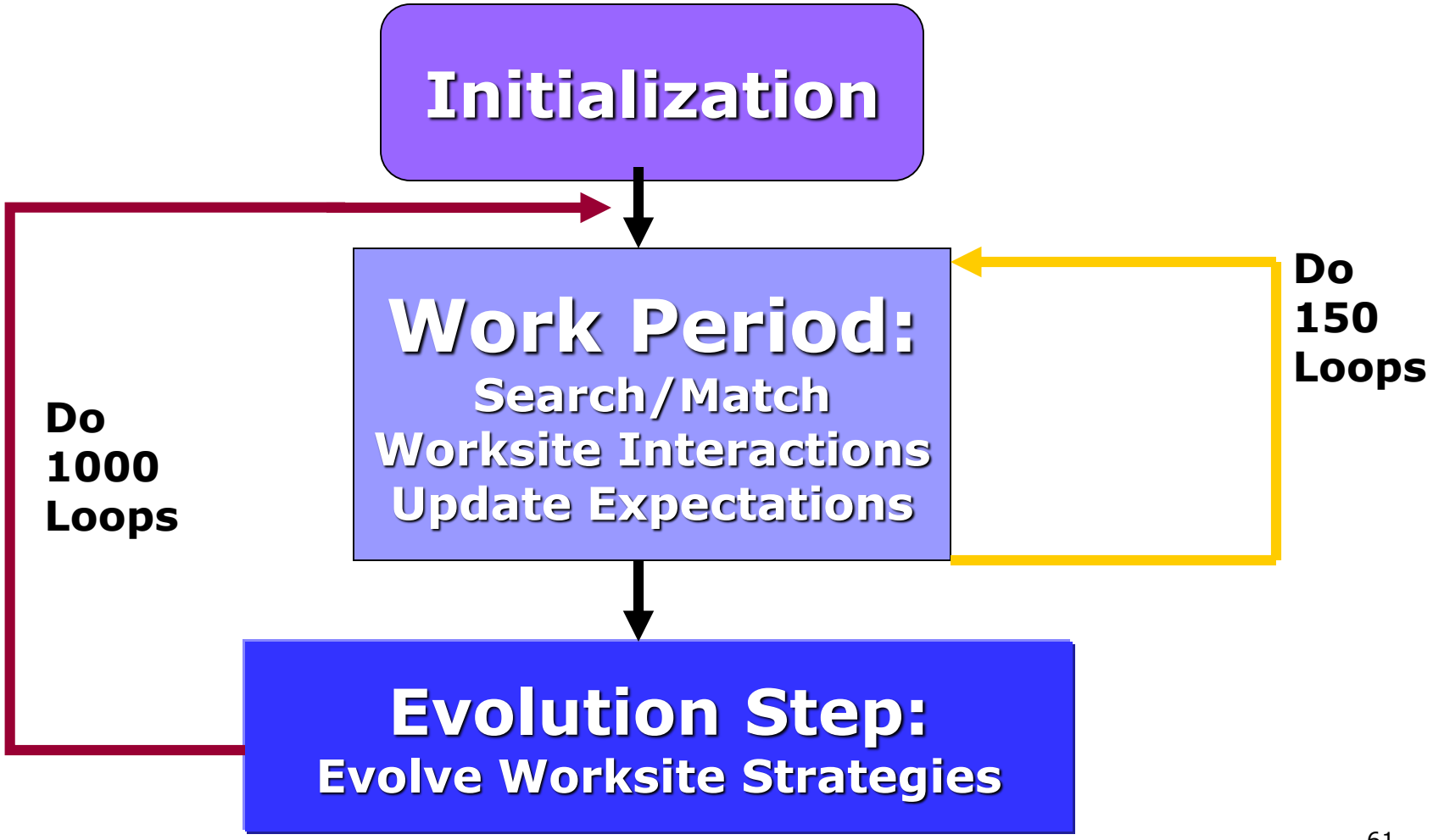
// **Private Data**

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	
		C	D
Worker	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

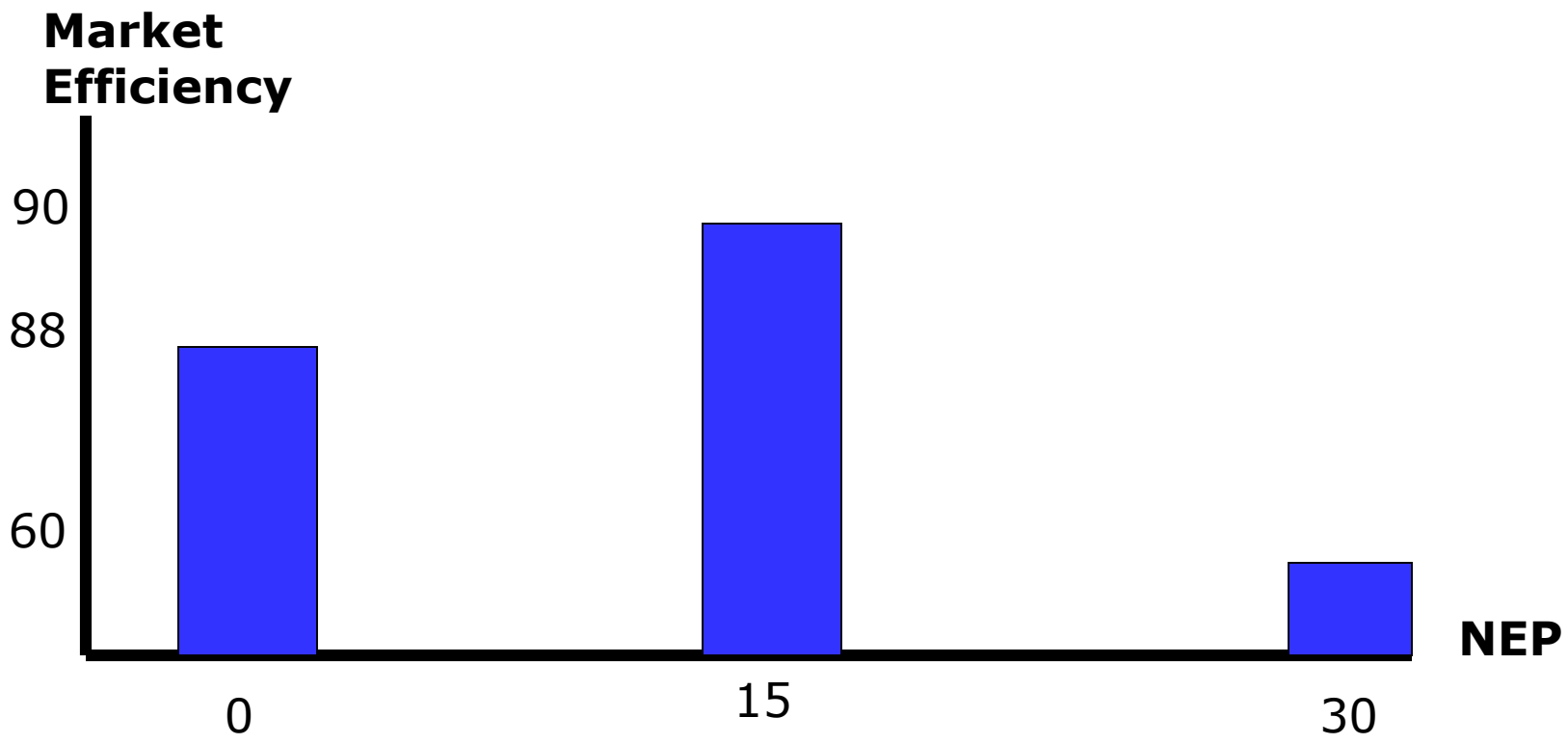
As NEP level **increases** from 0 to 30…

- ***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…Continued

- 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…

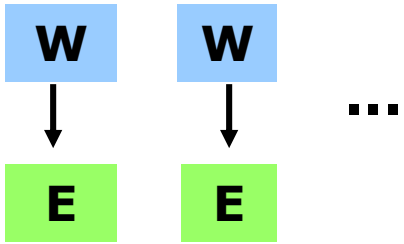
- **NEP=0 and NEP=15:**
  - First Attractor = Latched network supporting ***mutual cooperation***;
  - Second Attractor = Latched network supporting ***intermittent defection***
- **NEP=30:**
  - First Attractor = Latched network supporting ***mutual cooperation***
  - Second Attractor = Disconnected 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

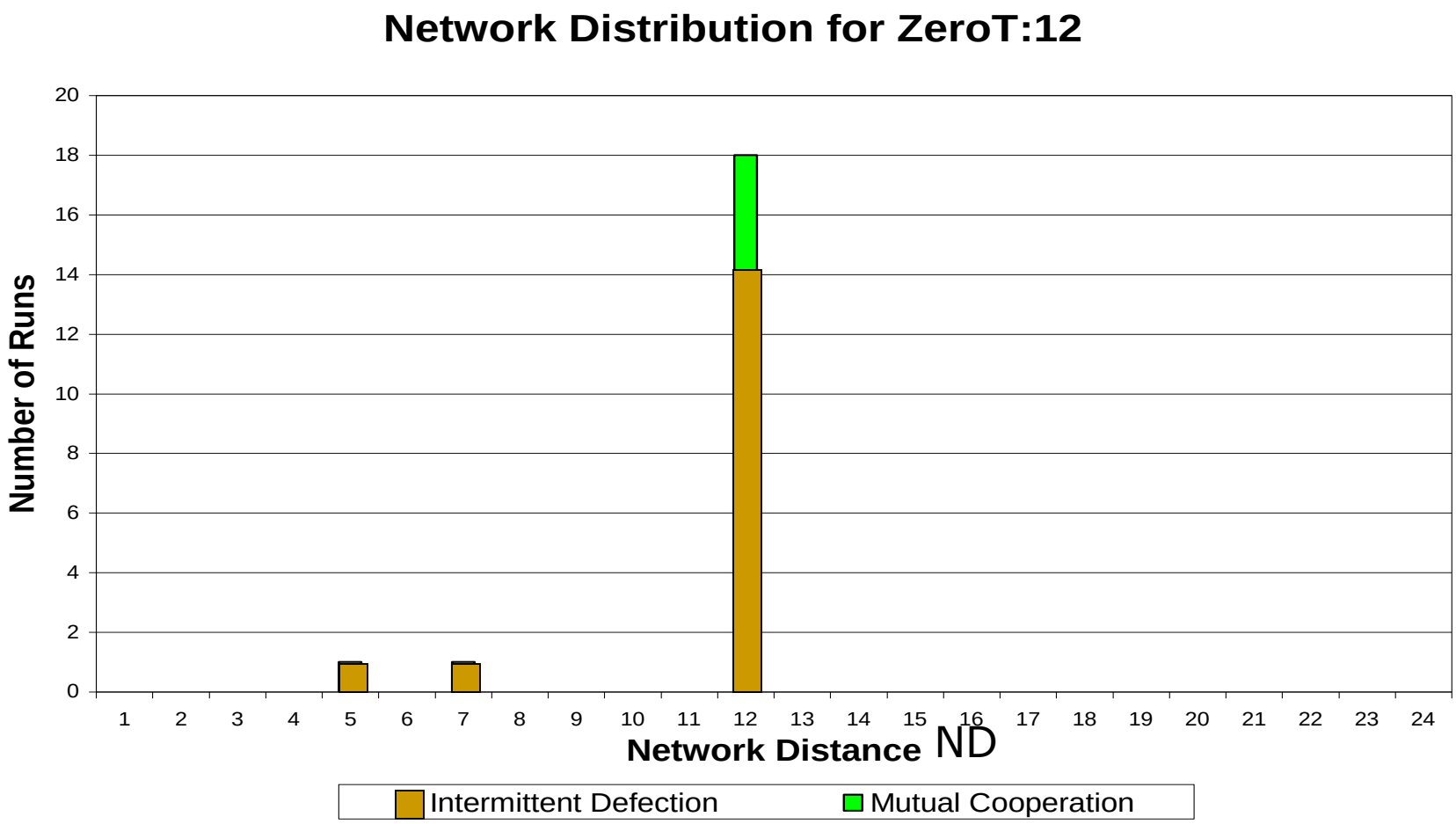
ND=12: Latched in pairs



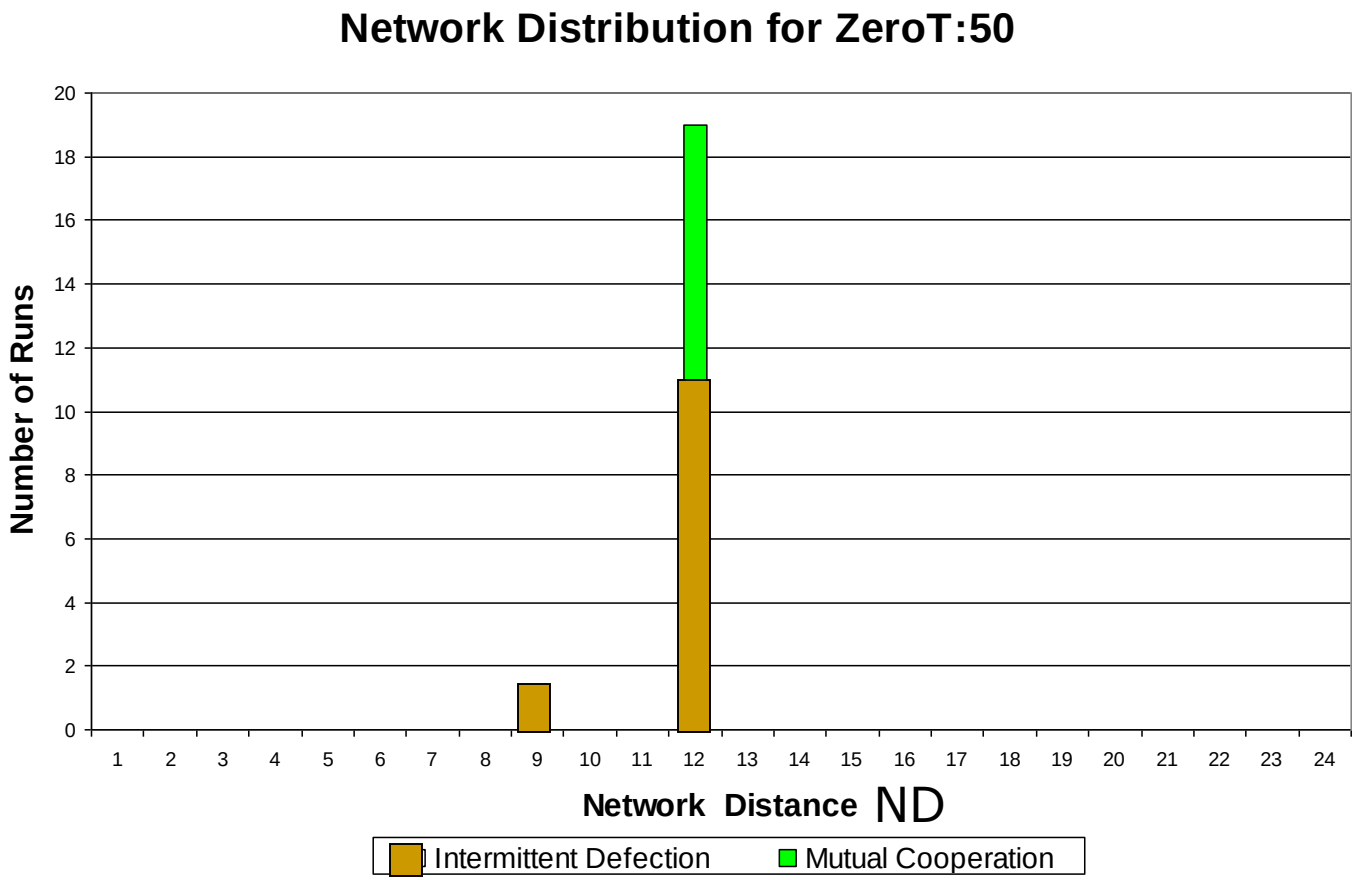
ND=24: Completely disconnected

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

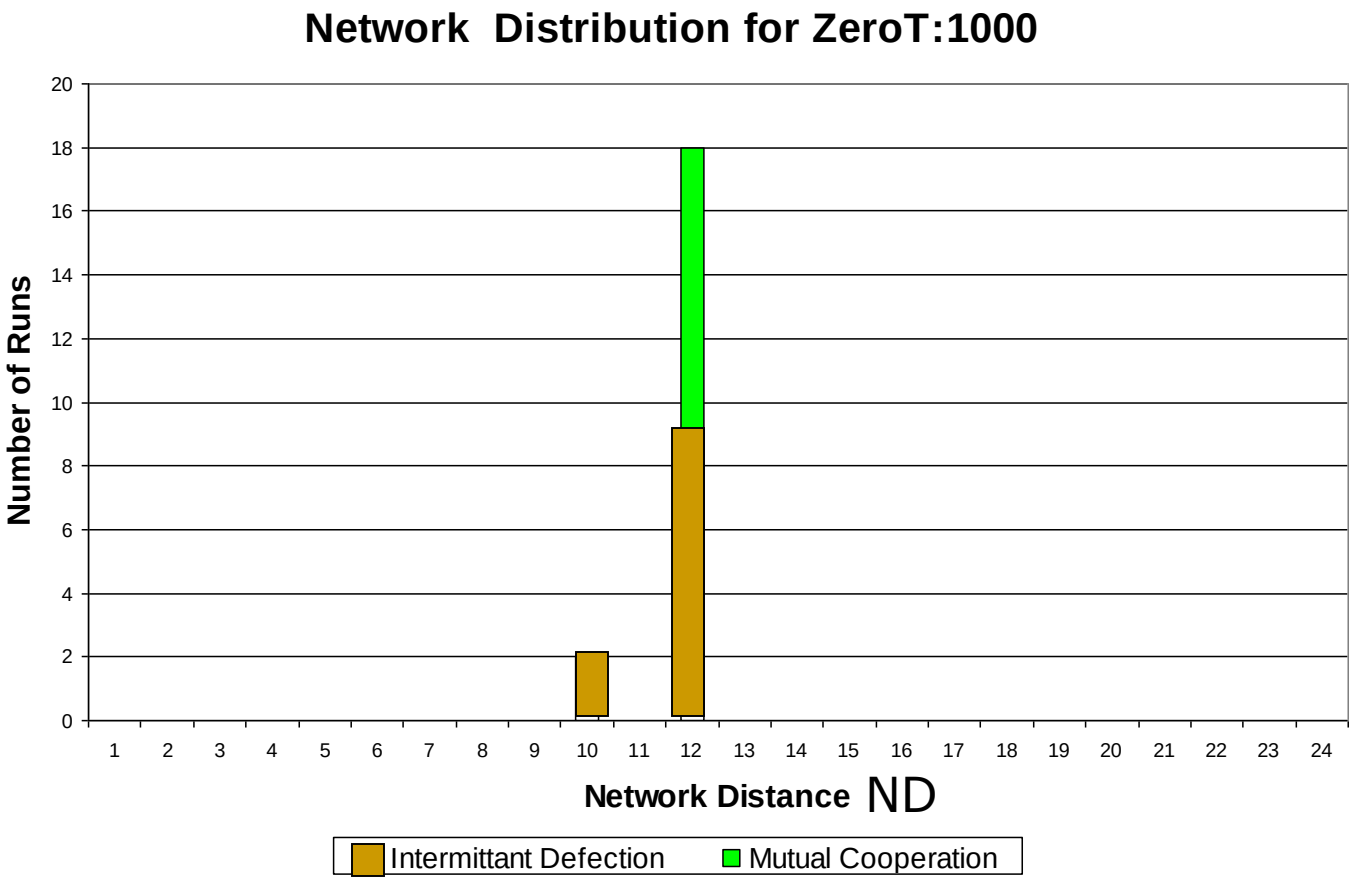
Network Distribution for **NEP=0** Sampled at End of **Generation 12**



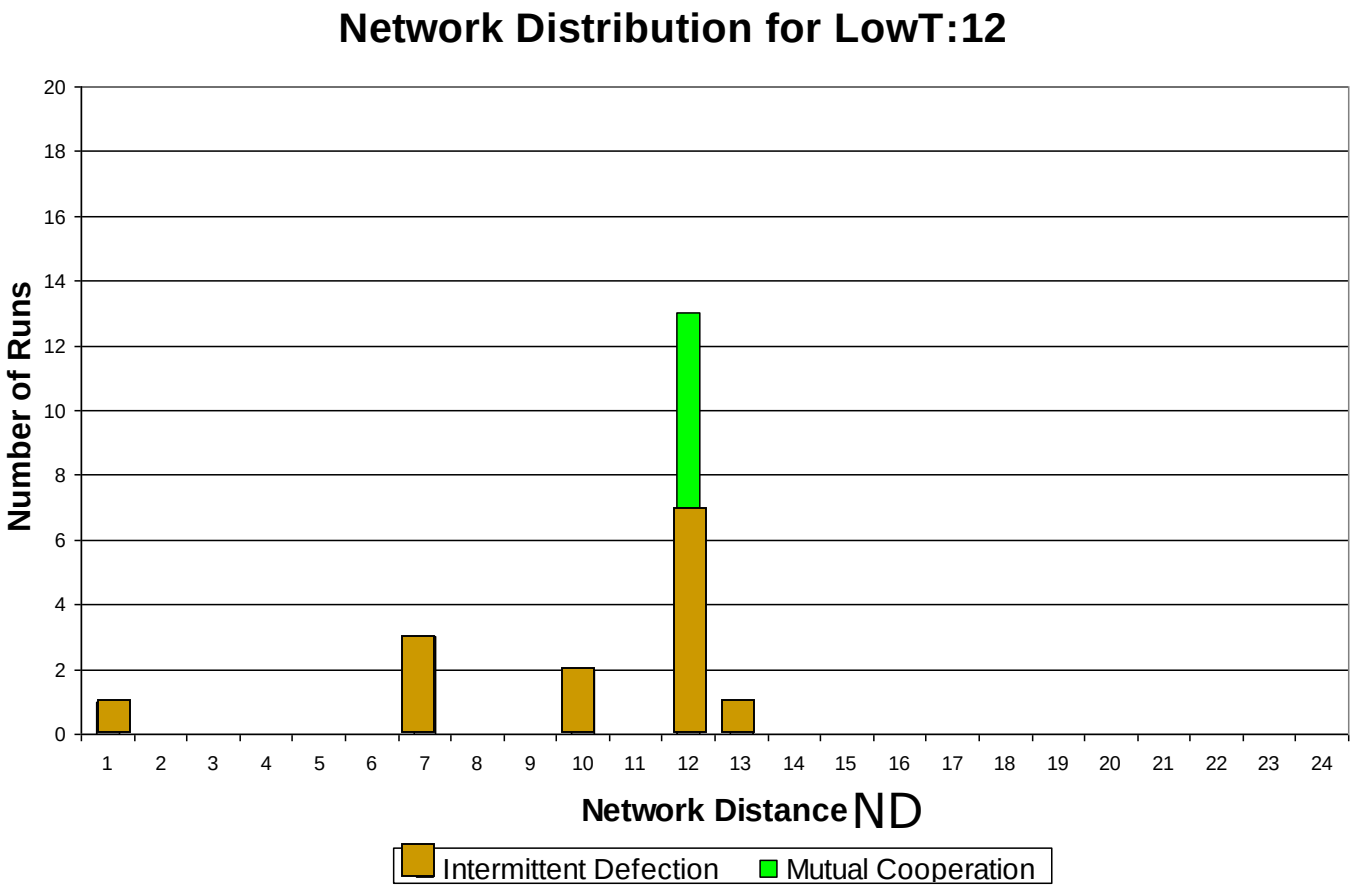
Network Distribution for **NEP=0** Sampled at End of **Generation 50**



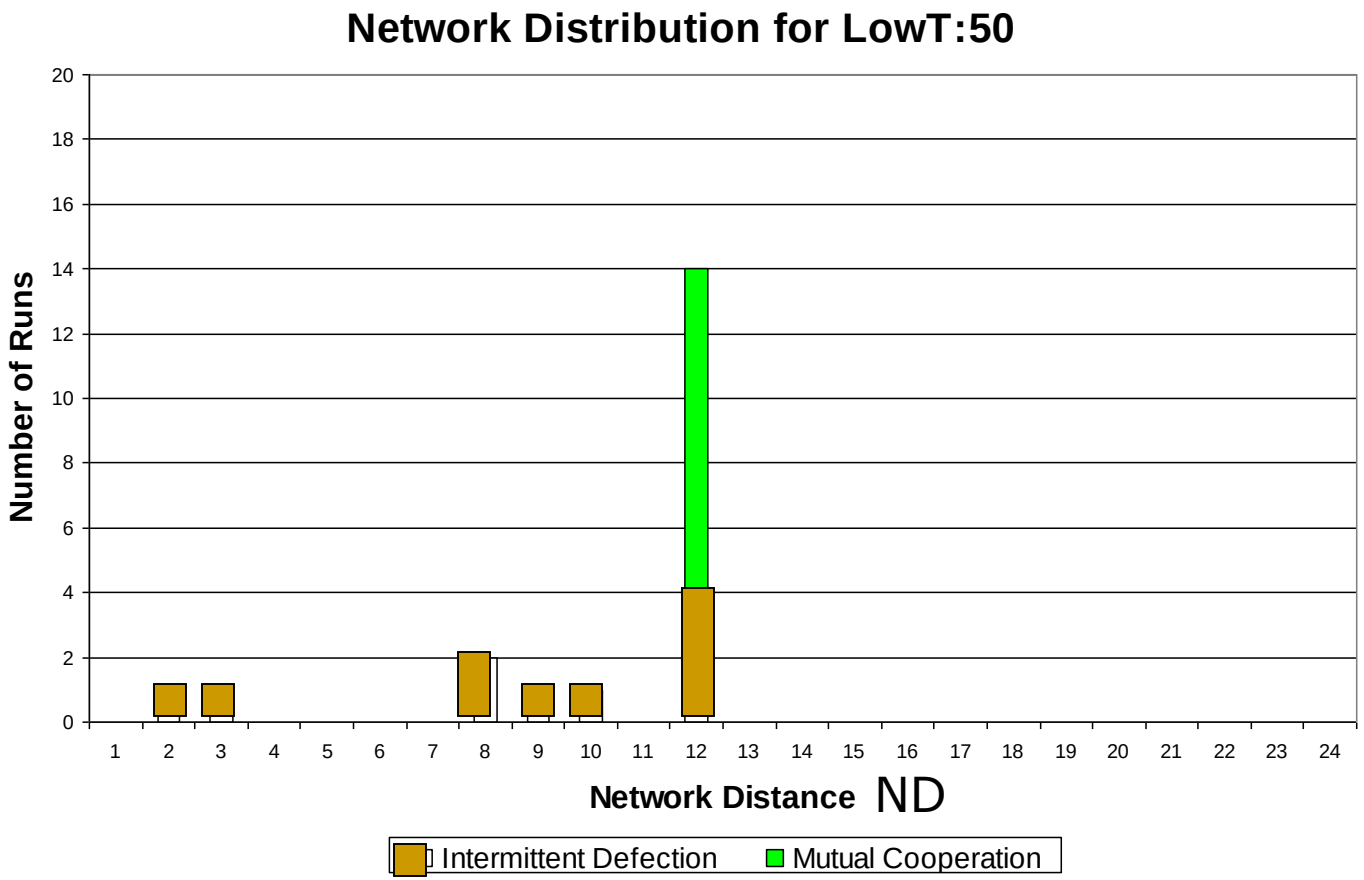
Network Distribution for **NEP=0** Sampled at End of **Generation 1000**



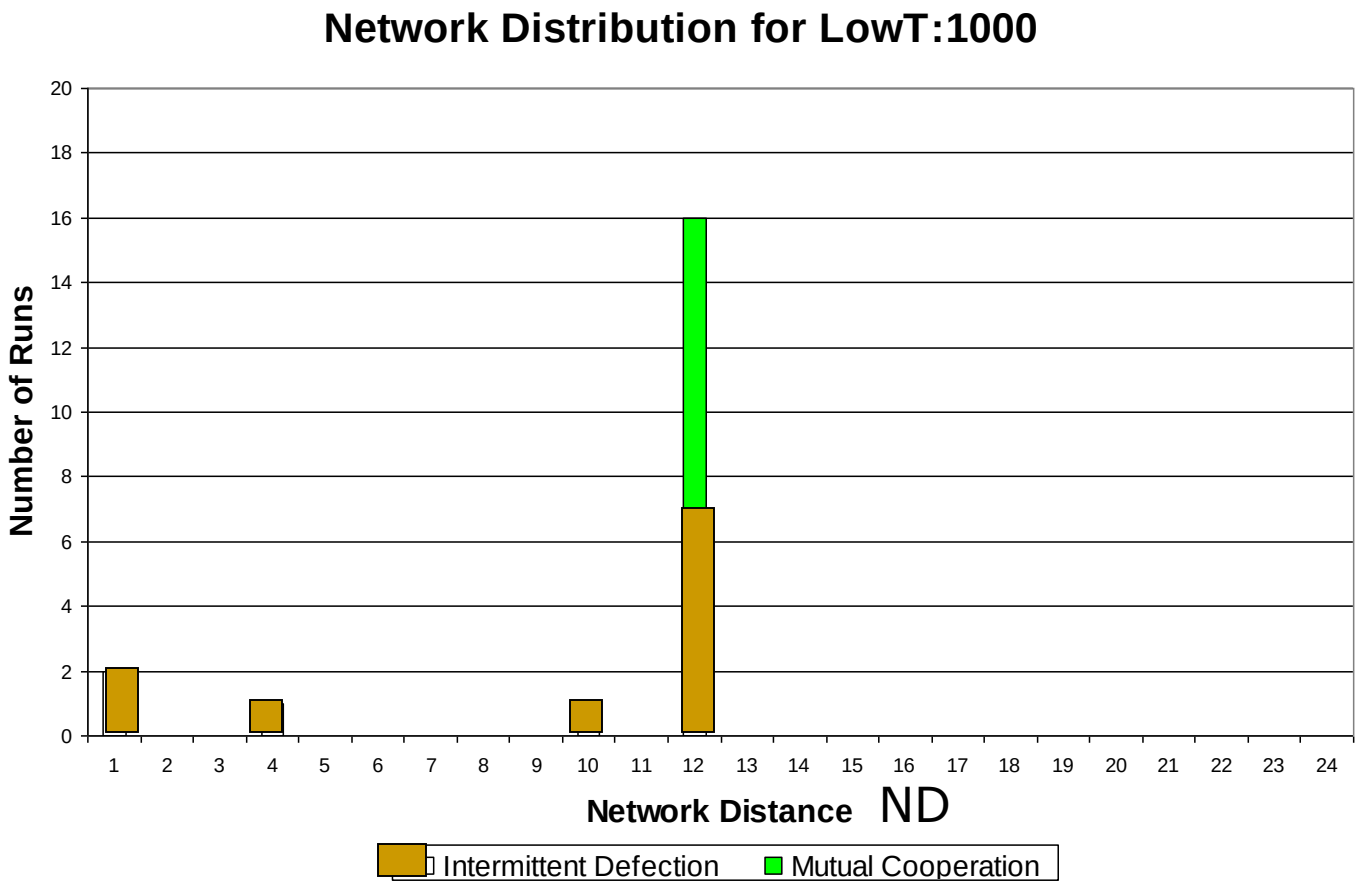
Network Distribution for **NEP=15** Sampled at End of **Generation 12**



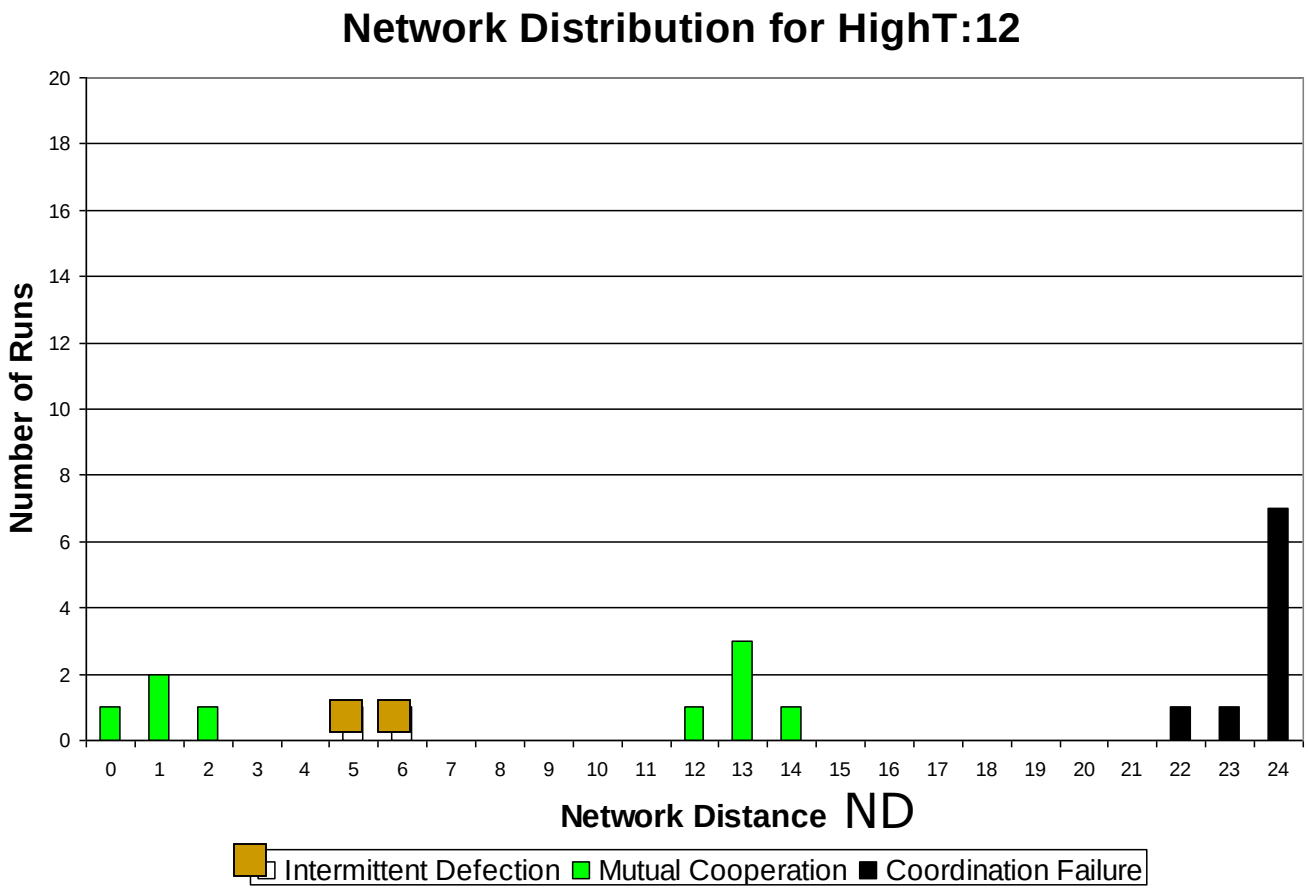
Network Distribution for **NEP=15** Sampled at End of **Generation 50**



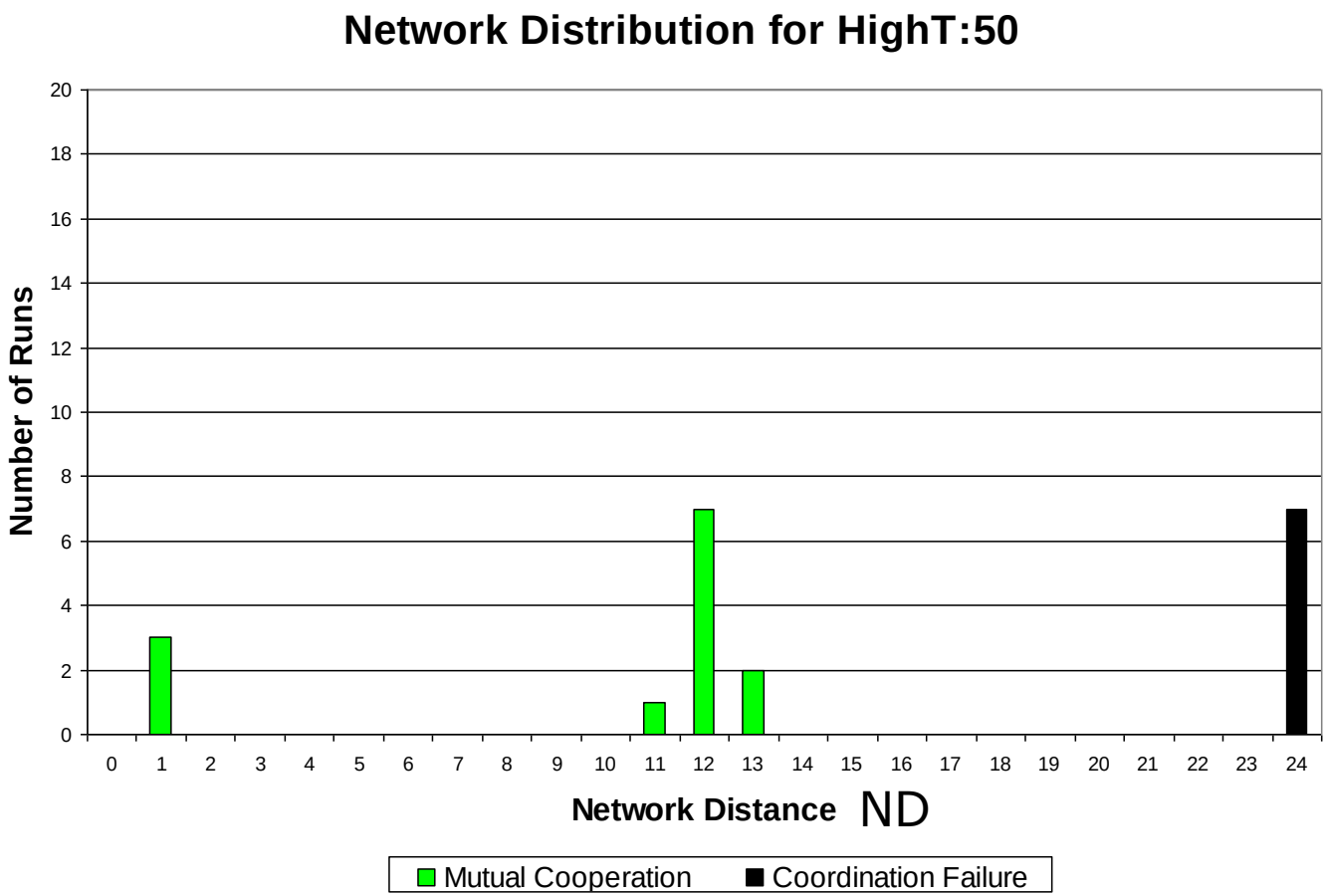
Network Distribution for **NEP=15** Sampled at End of **Generation 1000**



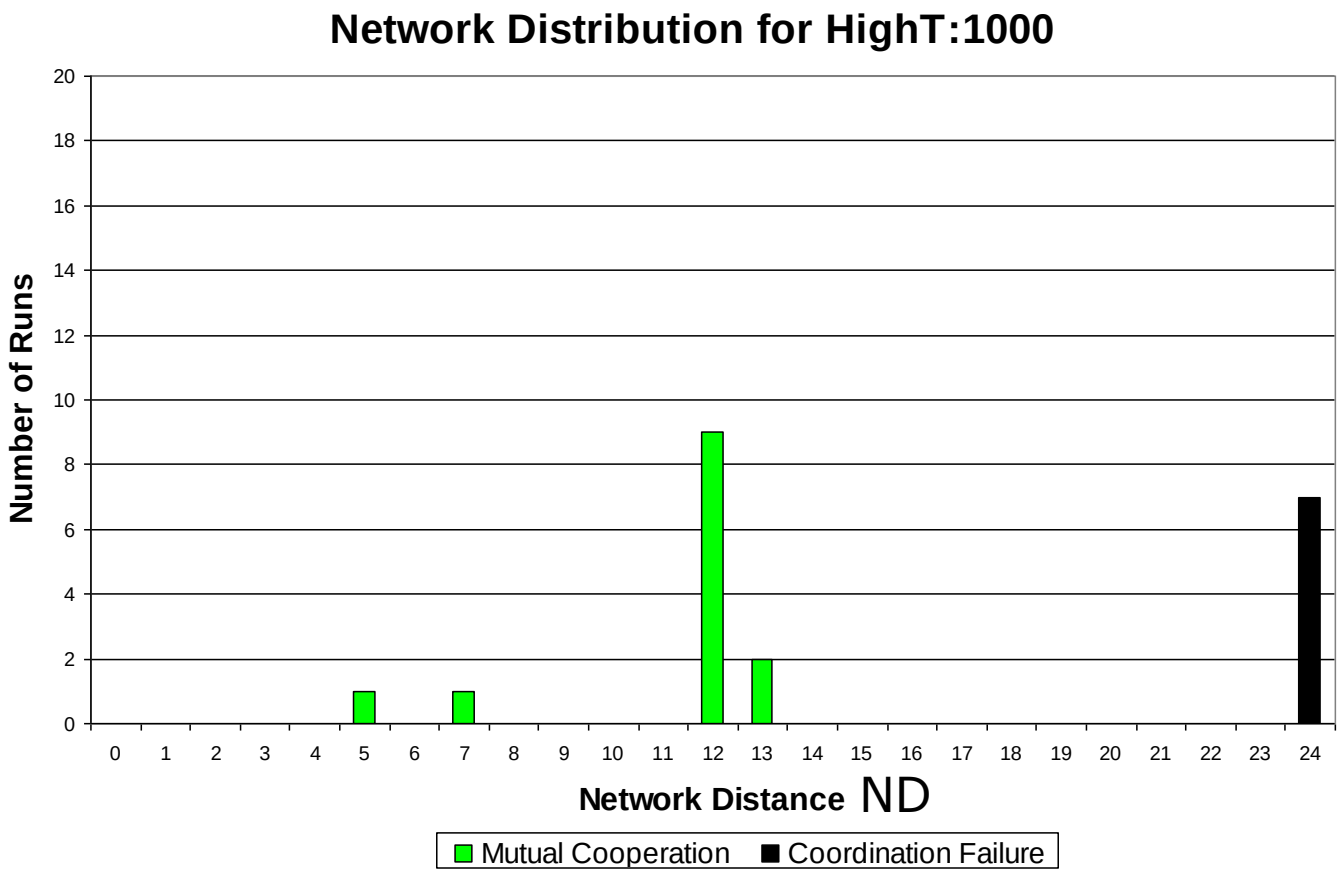
Network Distribution for **NEP=30** Sampled at End of **Generation 12**



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 have ***systematic effects*** on 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

Ex. 5: Trade Network Game (TNG)

https://www2.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 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

Genetic Algorithm

Generations	50
Trade Cycles	150
Seed	19
Mutation Rate	0.005

Payoffs

Initial Expected	1.4	Both Co-op	1.4
Refusal	-0.5	Both Defect	-0.6
Inactive	0	Temptation	3.4
Experience Gain	0	Sucker	-1.6

FSM

States	16
Memory	1

Trade Network Game

Buyer	12	% Elite	0.67	Quotas:	
Seller	12	% Elite	0.67	Buyer	1
Dealer	0	% Elite	0.67	Seller	1

TNG Results Screen

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

File Edit View Help

50/50 gens

150/150 cycles

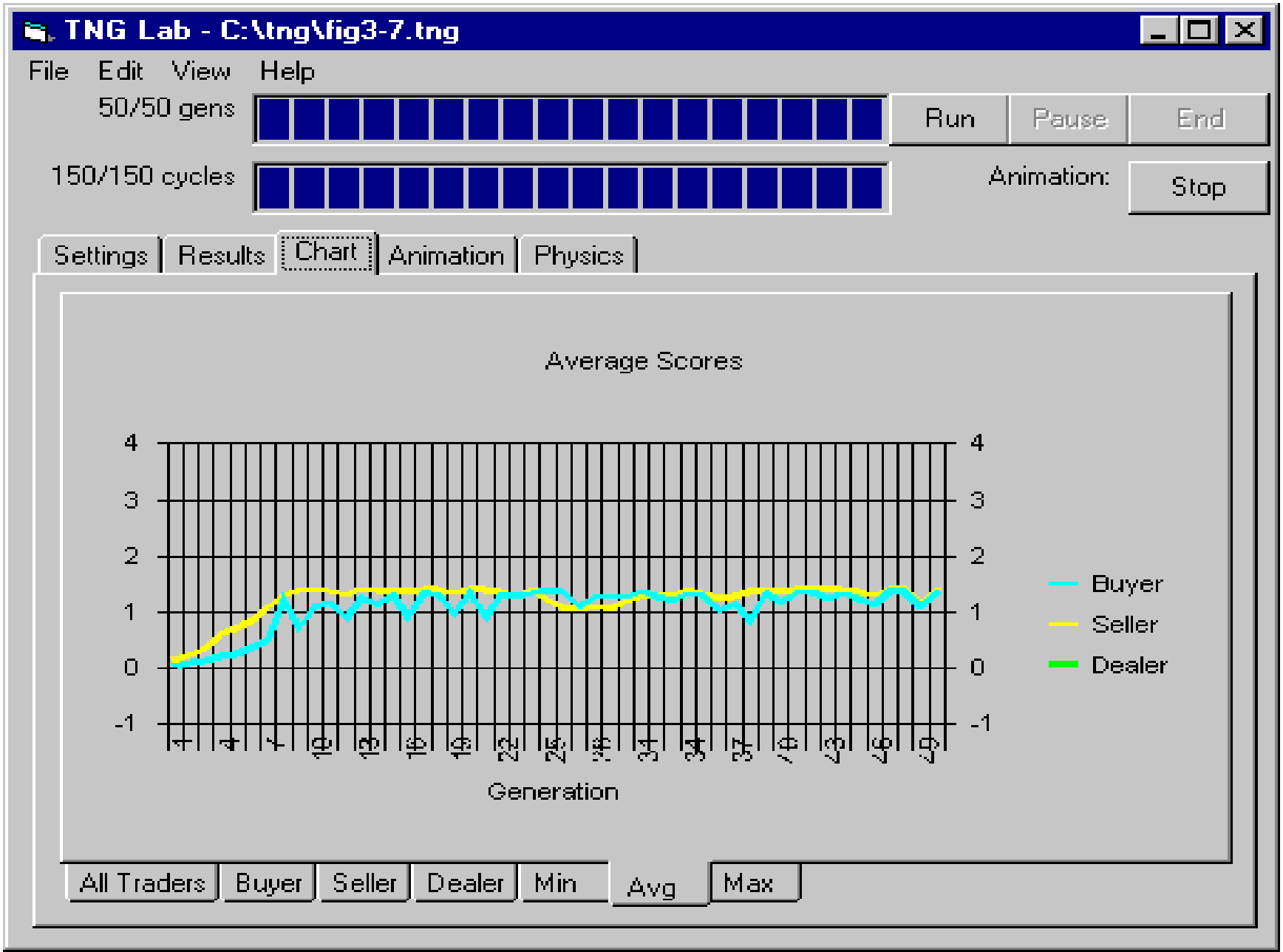
Run Pause End

Animation: Stop

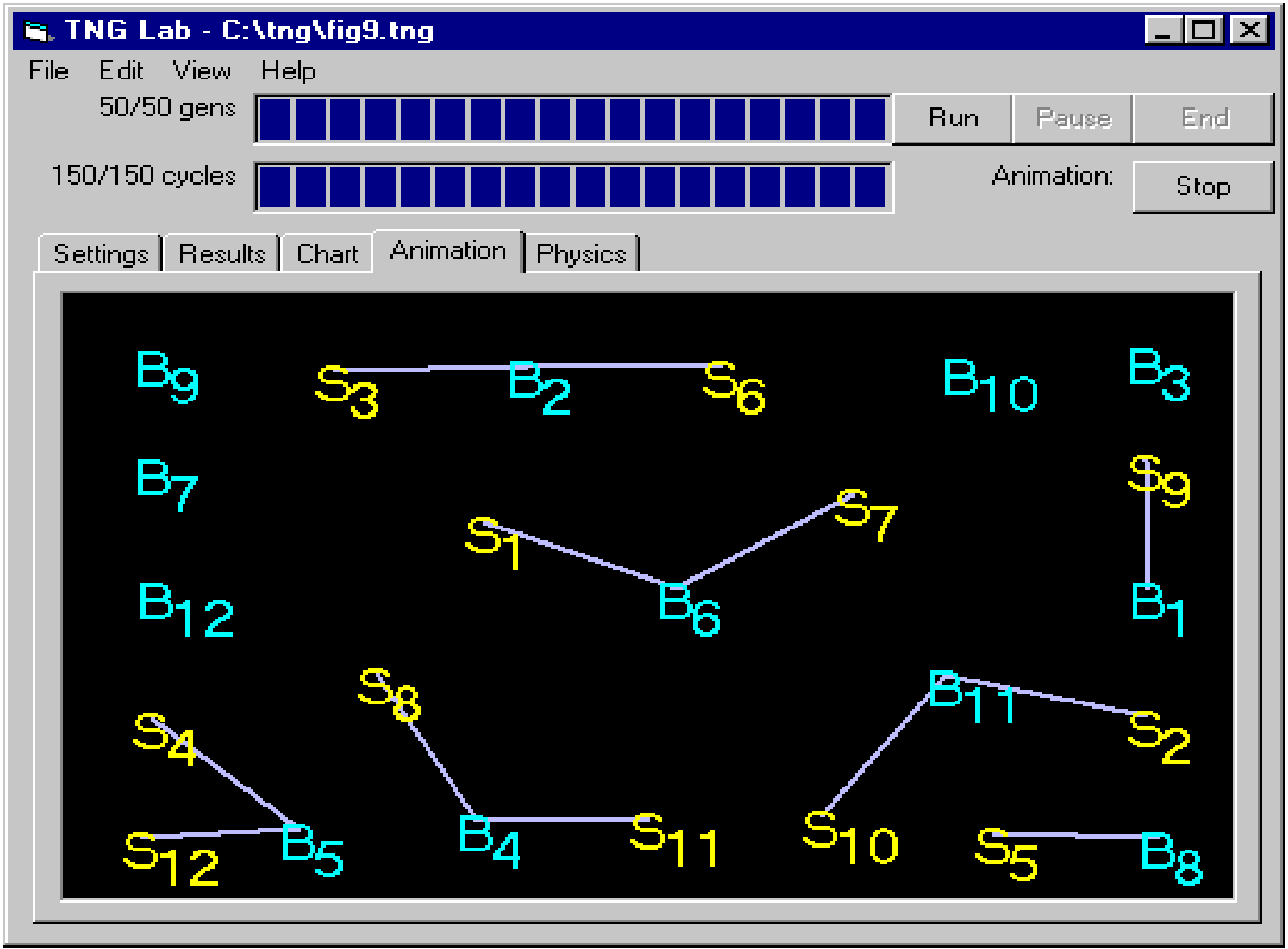
Settings | Results | Chart | Animation | Physics

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

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

Physics

Springs

	Length:	Strength:
Latched	150	200
Recurrent	250	100

Repulsion

Boundary	100
Trader	200

Friction 0.25

Network Settings

Frequency Threshold:

Latched	6
Transient	6

Reset

Example 6:
A Real-World Market Design Project

https://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

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

Project Director:

Leigh Tesfatsion

Professor of Econ, Courtesy Professor of Math & ECpE

Iowa State University

funded in part by

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

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

- Over 60% of electric power generating capacity in the U.S. is now operating under some version of the WPMP market design

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

AMES Wholesale Power Market Test Bed

(AMES = *A*gent-based *M*odeling of *E*lectricity *S*ystems)

- **Target Features of the AMES Test Bed**
  - Research/training grade model (2-500 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** (understanding)
  - **Industry stakeholders** (learn rules, test strategies)
  - **Policy makers** (efficient and reliable market design)

Basic Project Approach: Iterative Participatory Modeling

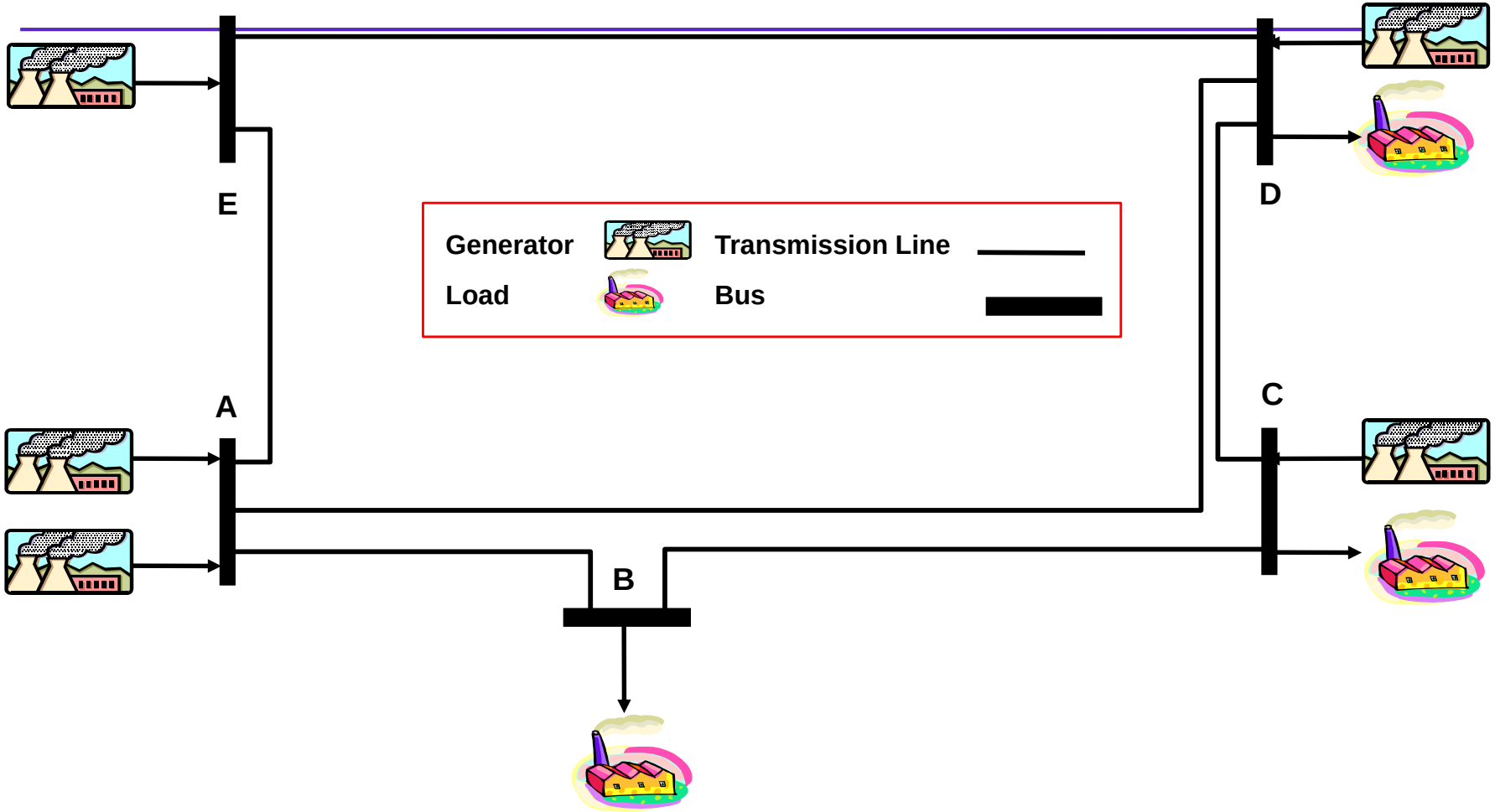
- See, e.g., Barreteau et al. (*JASSS* 2003)
- Stakeholders and researchers from multiple disciplines join together in a repeated looping through four stages of analysis:
  - Field work and data collection;
  - Role-playing games;
  - Agent-based model development (Java/RepastJ);
  - Intensive computational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

Key Components of AMES Test Bed

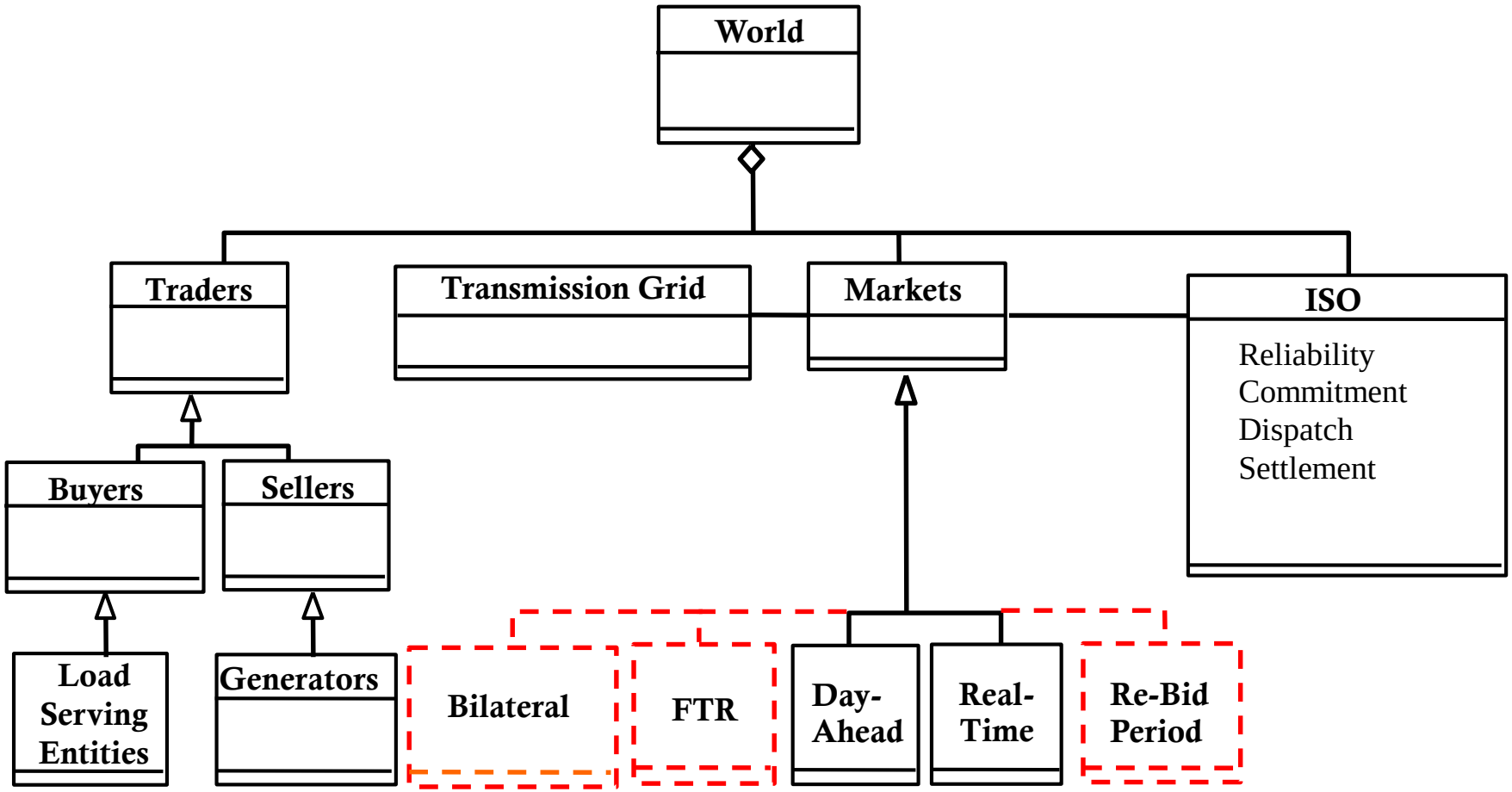
(Based on Business Practices Manuals for MISO/ISO-NE)

- **Traders**
  - Generators (Sellers)
  - LSEs (Buyers)
  - Follow market rules
  - **Learning abilities**
- **Independent System Operator**
  - System reliability assessments
  - Day-ahead bid/offer-based optimal power flow (OPF)
  - Real-time dispatch
- **Two-settlement system**
  - 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-Bus Transmission Grid



AMES Framework: Agent Hierarchy



Activities of AMES ISO During a Typical Day D-1

Real-Time Market (RTM) open for all 24 hours hours of day D-1

Real-time settlement

00:00

Day-Ahead Market (DAM) for day D

ISO collects energy bids & offers from LSEs & Generators

11:00

ISO solves SCED (bid/offer-based DC OPF) to determine dispatch set-points & LMP schedule for all 24 hours of day D.

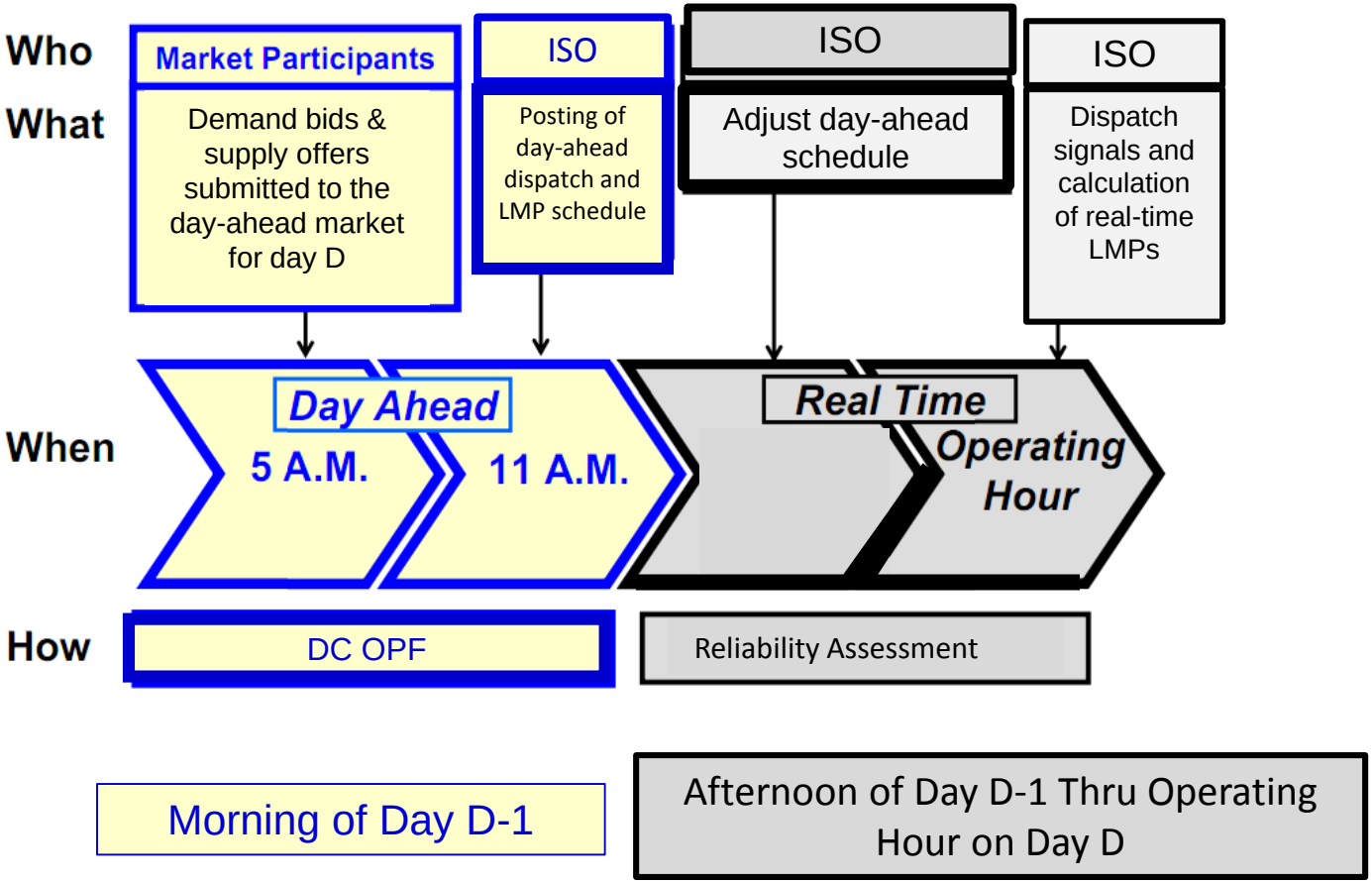
16:00

ISO posts dispatch set-points and LMP schedule for each hour of day D.

23:00

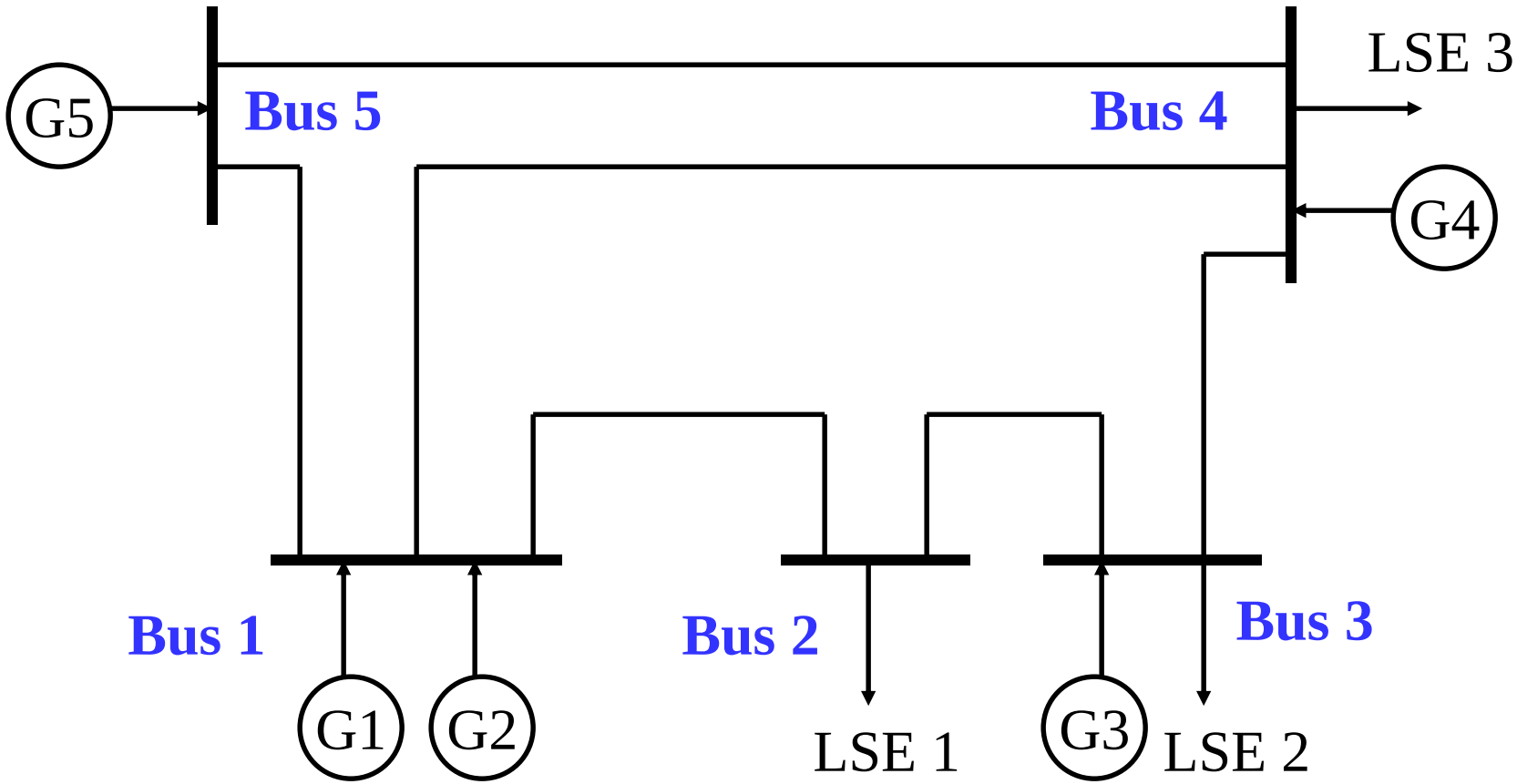
Day-ahead settlement

Activity of AMES ISO on Successive Days D-1 and D

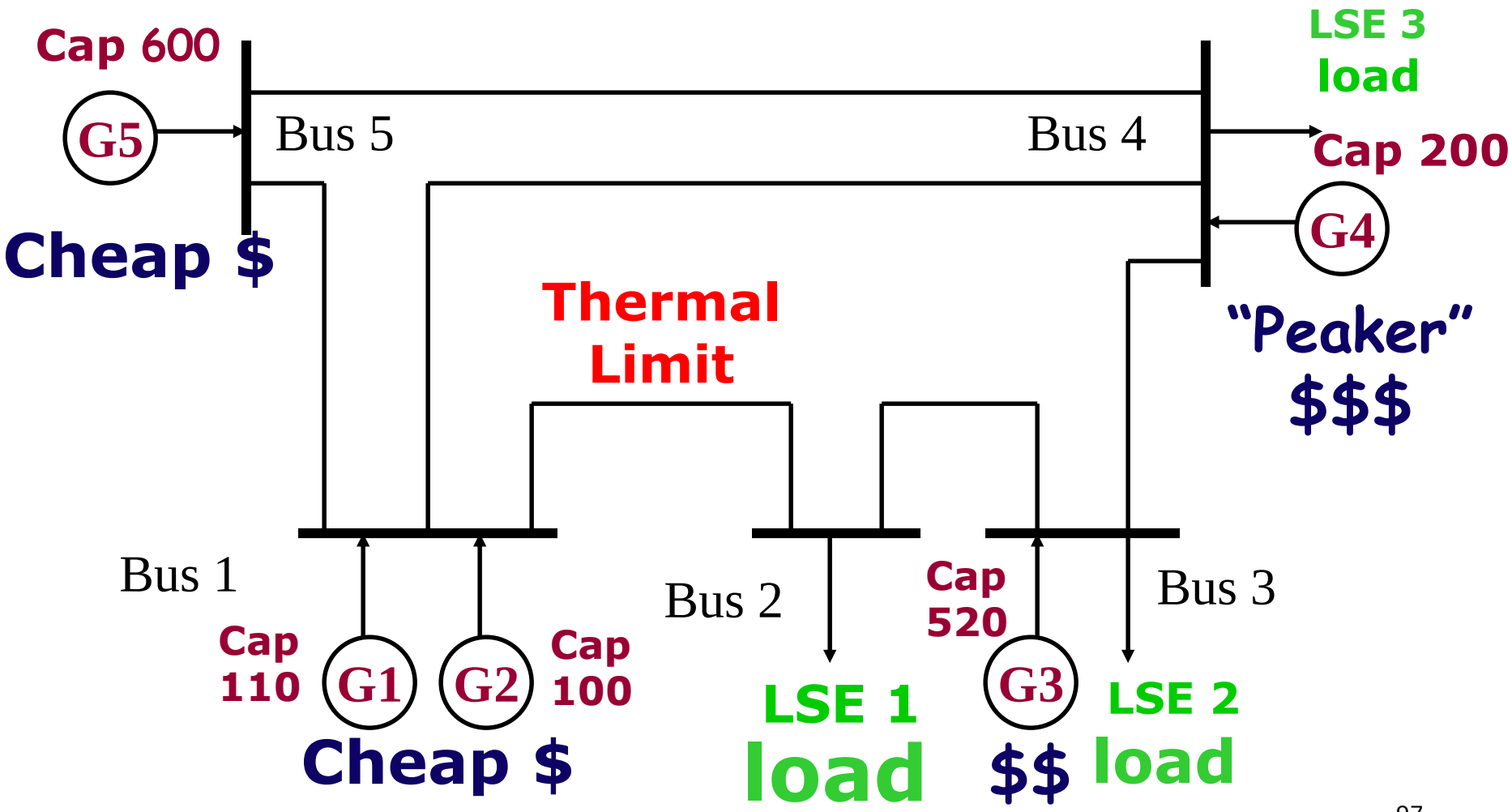


Illustrative 5-Bus Test Case

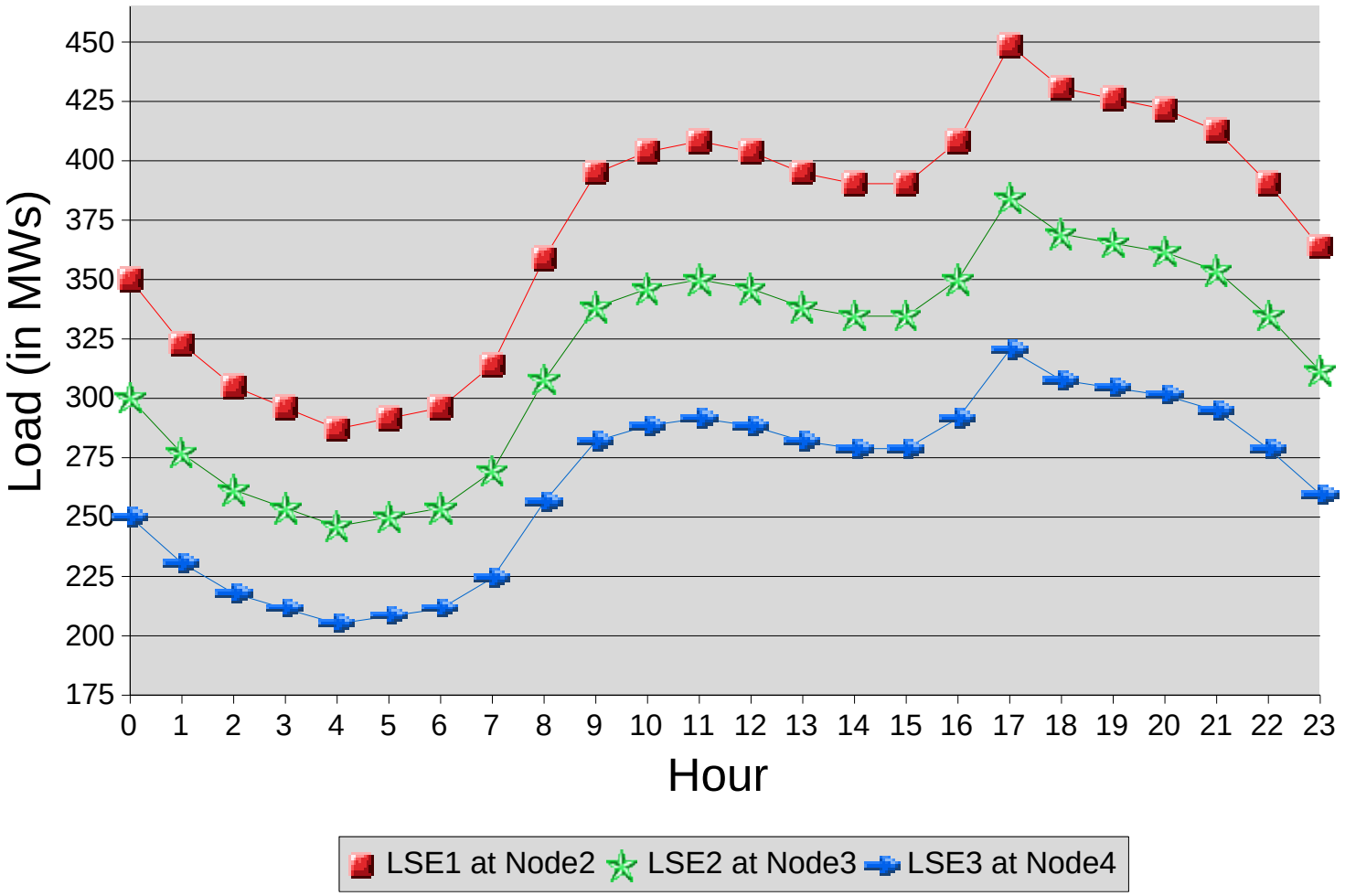
(Dynamic Extension of Static ISO-NE/MISO/PJM Training Example)



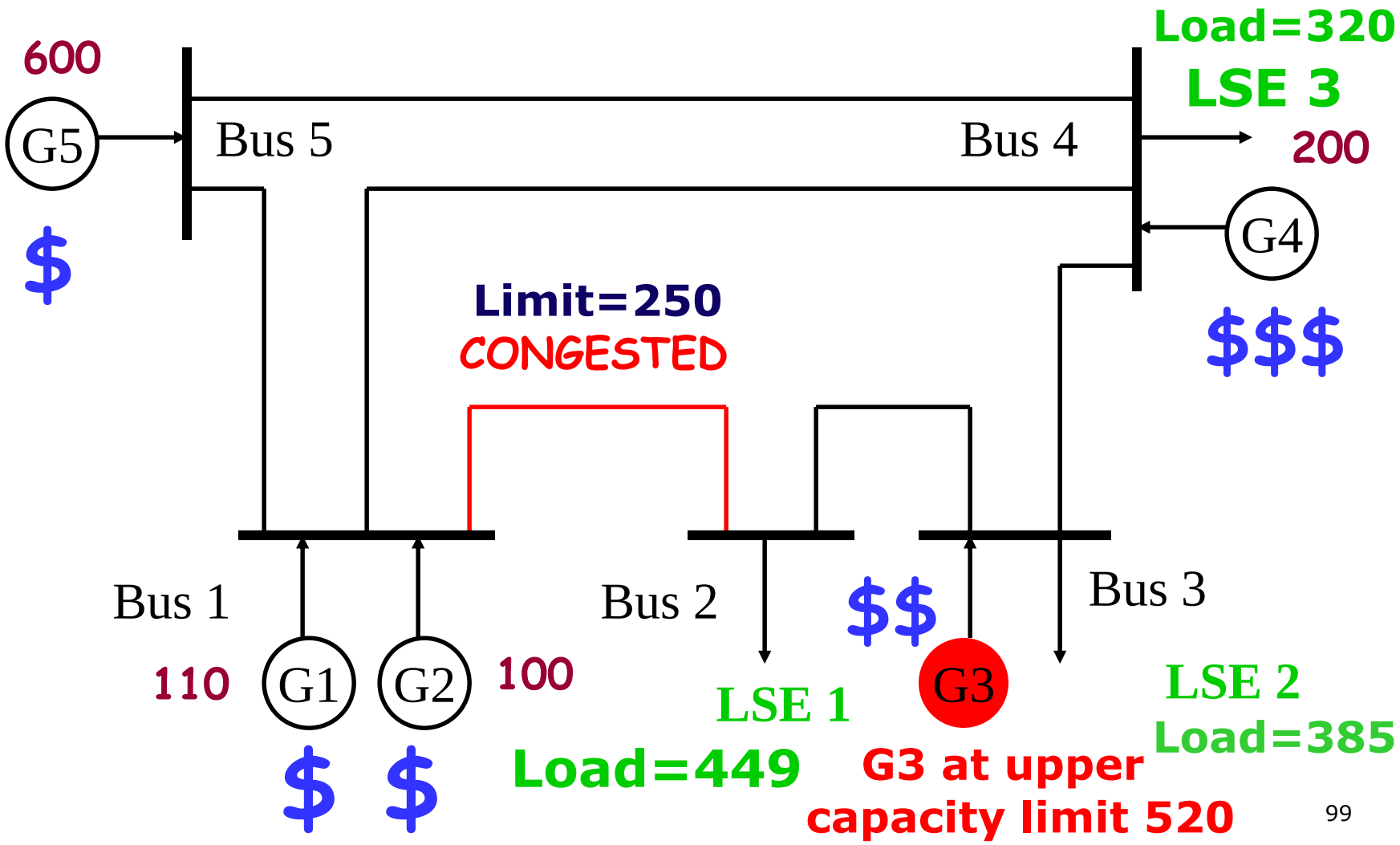
Illustrative 5-Bus Test Case…



Daily LSE Load Profiles for 5-Bus Test Case

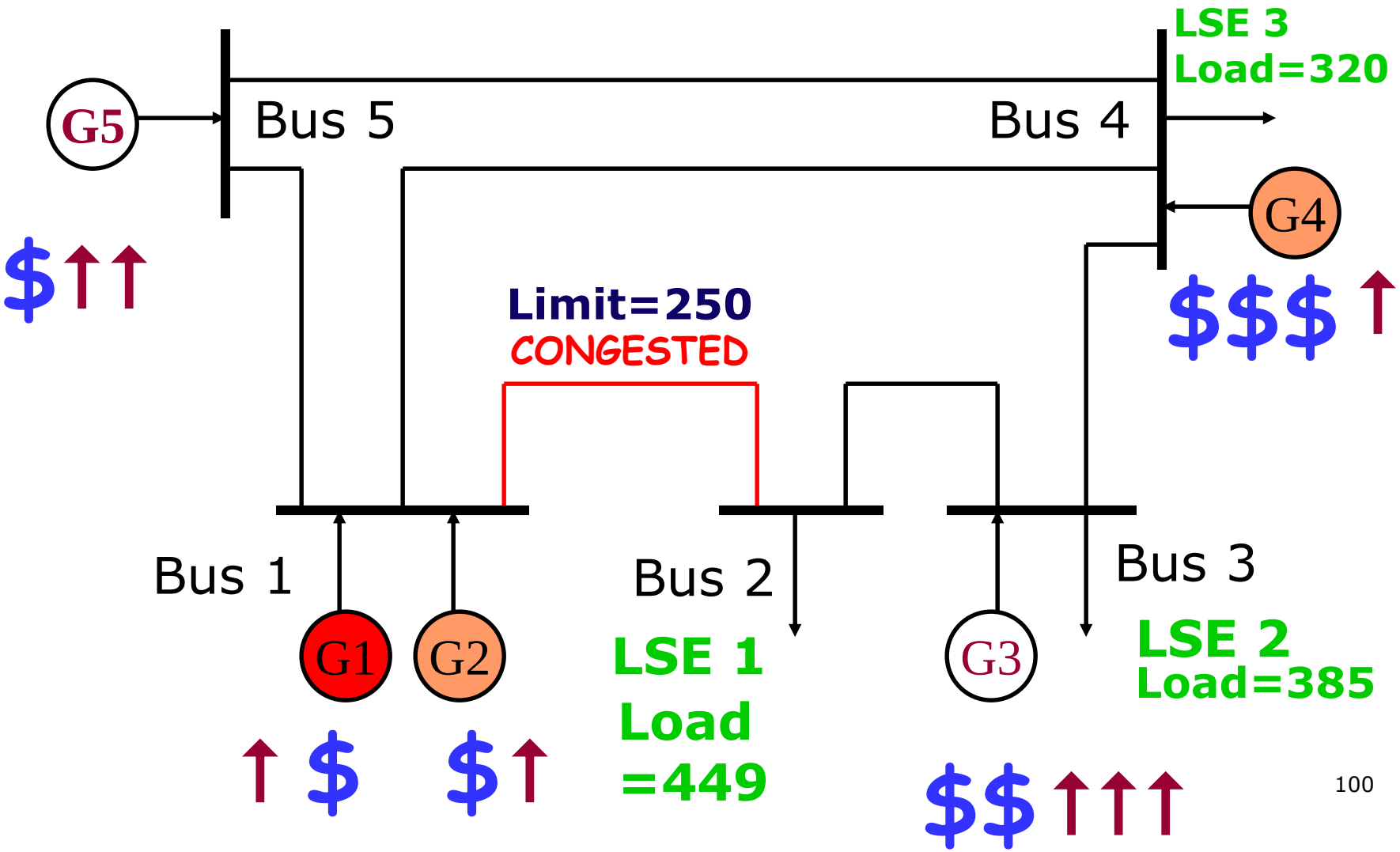


Hour 17 Outcomes With No Generator Learning (Generators report their true MC curves)



Day 422-Hour 17 Outcomes With Gen Learning

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

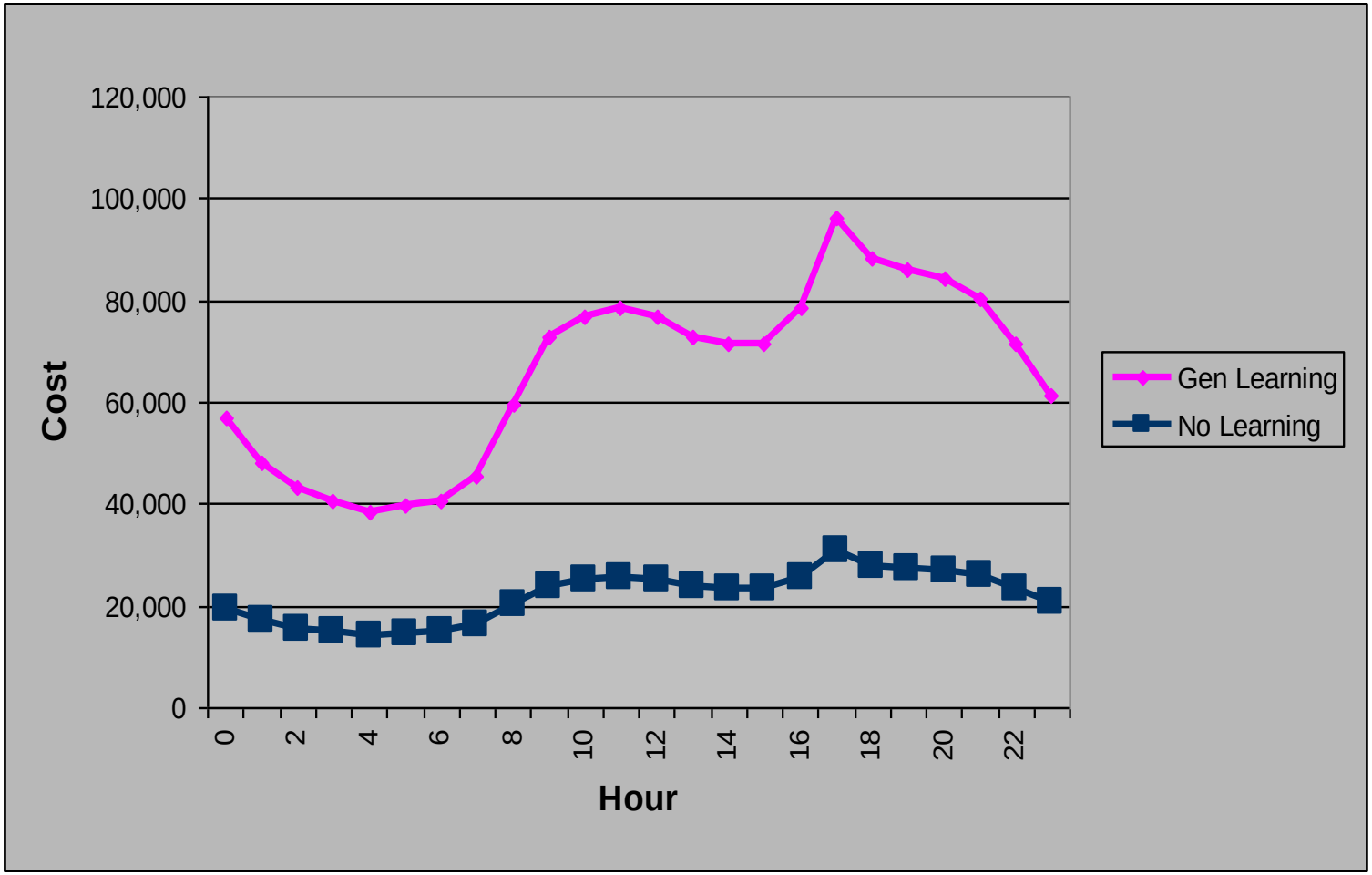


True Vs. Reported MC (Averaged)* on Day 422

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

*NOTE: Reported marginal costs (MCs) for learning generators are 20-run averages. Typical convergence time = 62 days, max time = 422 days. 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



Five-Bus Test Case …

BOTTOM LINE:

Learning Matters !

AMES Software Development to Date

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

- 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.