Agent-Based Computational Economics

Growing Economies from the Bottom Up

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Outline

- What is Agent-based Computational Economics (ACE) in a nutshell?
- Simple labor market illustration (implemented via the TNG Lab)
- Four strands of current ACE research
- Potential advantages and disadvantages of ACE for economic modeling

What is ACE?

- Computational study of economic processes as **dynamic systems of interacting agents**
- A **culture-dish approach** to the theoretical study of economic processes

ACE Culture-Dish Analogy

- Modeler constructs a virtual economic world populated by various **agent types**
- Modeler sets **initial world conditions**
- Modeler then steps back to observe how the **world develops over time** without intervention **(no imposed equilibrium, rational expectations, etc.)**
- World events are **driven by agent interactions**

ACE Agent Types

Agents = Encapsulated software programs representing **individual, social, biological and/or physical entities**

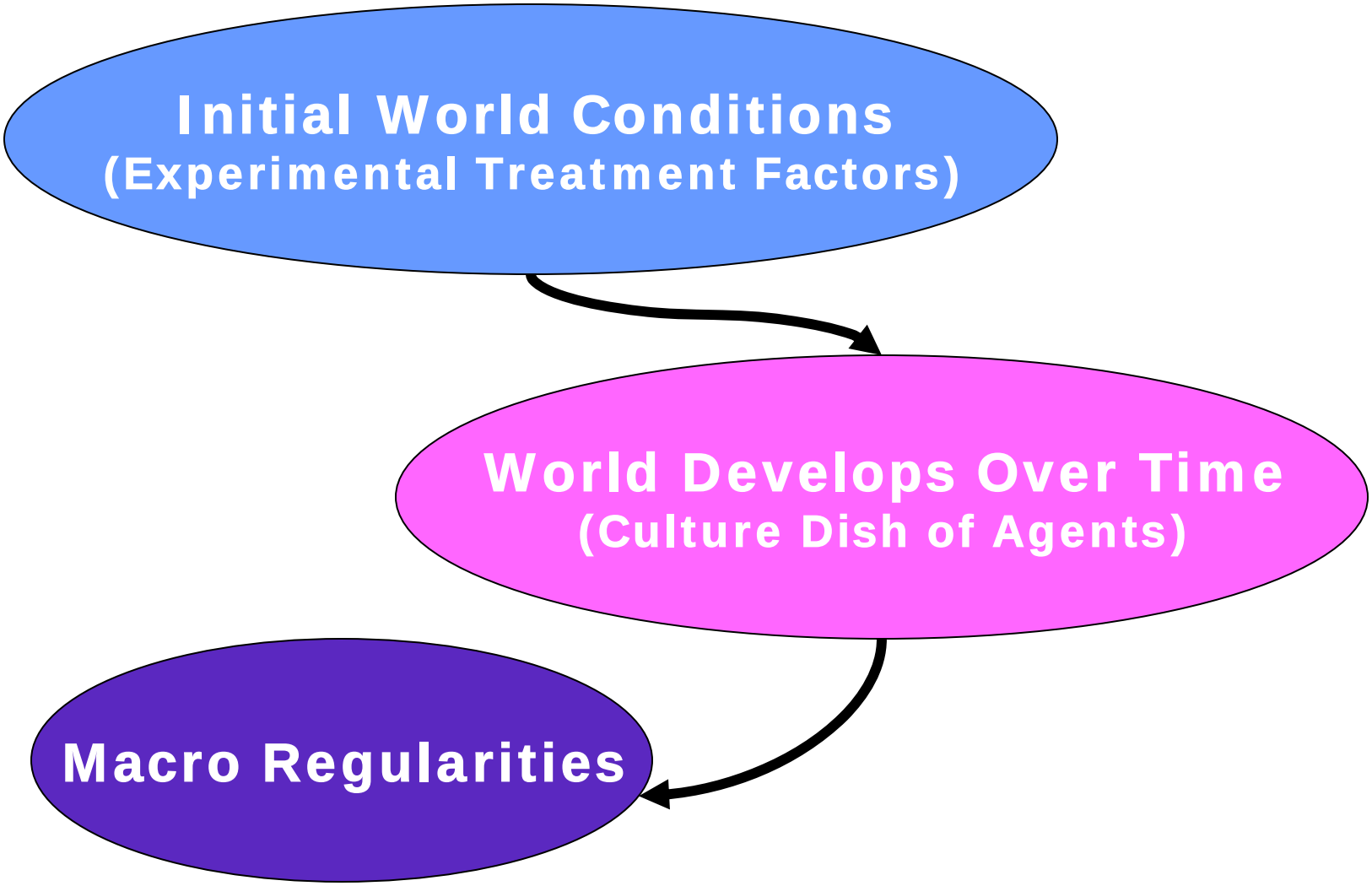
✱ Cognitive agents are capable (in various degrees) of

- **Behavioral adaptation**
- **Social communication**
- **Goal-directed learning**
- **Endogenous evolution of interaction networks**
- **"Autonomy"** (self-activation and self-determinism based on private internal processes)

Initial World Conditions
(Experimental Treatment Factors)

- Structural conditions
- Institutional arrangements
- Behavioral dispositions of agents

ACE Culture Dish Analogy…



Illustrative ACE Application Area: Labor Institutions and Market Performance

Some Key Issues:

- Labor contracts typically **incomplete**
- Supplemented by government programs with **numerous eligibility restrictions**
- **Difficult to test program effects** by means of conventional analytical and/or statistical tools

Example: U.S. State Programs Providing Unemployment Benefits (UB)

Typical Features of State Programs (e.g., Iowa):

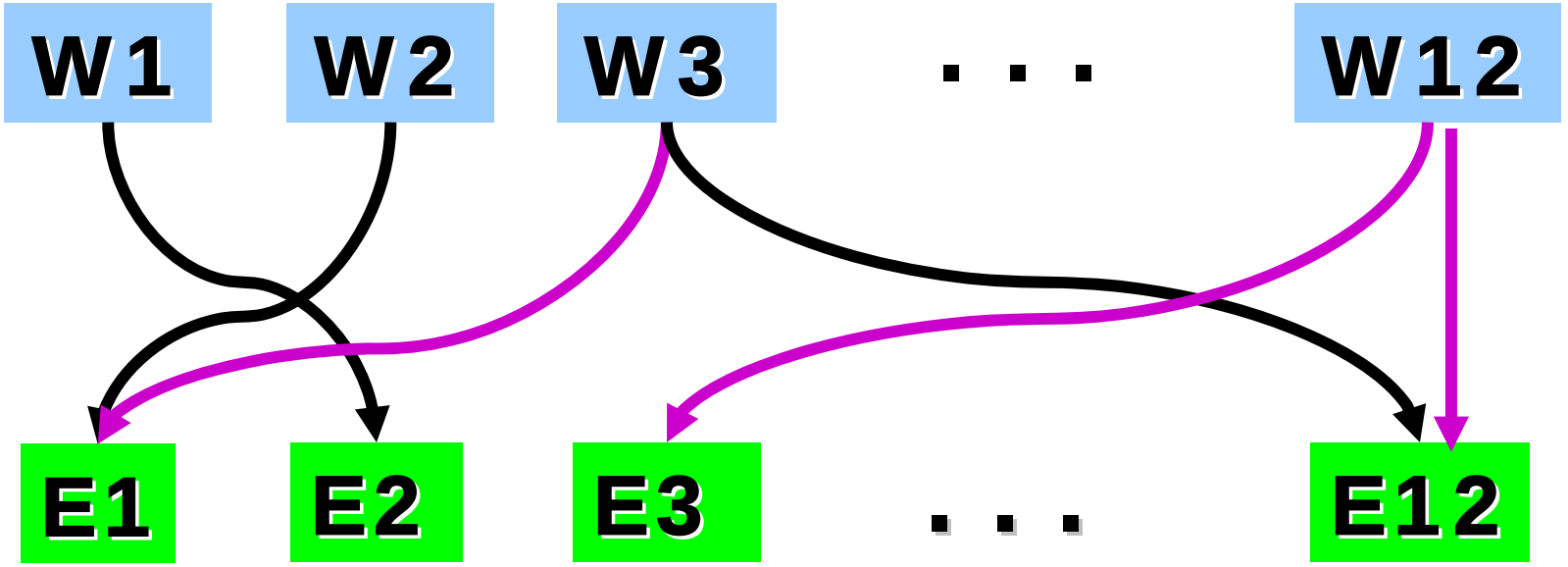
- UB only paid to "no fault of their own" unemployed
- UB recipients must continue to seek employment
- UB levels based on past earnings
- UB of limited duration
- UB financed by employer contributions at rates determined in part by each employer's "benefit ratio" = [UB paid out to former employees divided by the employer's taxable payroll]
- Additional UB often granted when unemployment rate is abnormally high for prolonged periods

➔ **Complicated Rules!!**

ACE Labor Market UB Study

Pingle/Tesfatsion 2003

(Experiments Implemented via TNG Lab)



Preferential job search (workers W ➔ employers E) with choice/refusal of partners:

Purple directed arrow = **Refused work offer**.

ACE Labor Market

- 12 workers with same **observable** structural attributes in initial period T=0
- 12 employers with same **observable** structural attributes in initial period T=0
- Only **observable** source of heterogeneity among workers and among employers is their expressed behaviors on the work-site

ACE Labor Market...

- 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
- Work-site strategies in initial period T=0 are **randomly determined and private information**

Each worker and employer has...

- ***Publicly available information*** about various market/policy protocols (e.g., unemployment benefit eligibility rules)
- ***Private behavioral methods*** that can evolve over time
- ***Privately stored data*** that can change over time

A Computational Worker

Public Access:

// **Public Methods**

Protocols governing job search
Protocols governing negotiations with potential employers
Protocols governing unemployment benefits program
Methods for receiving data
Methods for retrieving Worker data

Private Access:

// **Private Methods**

Method for calculating my expected utility assessments
Method for calculating my actual utility outcomes
Method for updating my worksite strategy (**learning**)

// **Private Data**

Data about myself (my history, utility fct., current wealth...)
Data recorded about external world (employer behaviors,...)
Addresses for potential employers (permits communication)

A Computational Employer

Public Access:

// **Public Methods**

Protocols governing search for workers
Protocols governing negotiations with potential workers
Protocols governing unemployment benefits program
Methods for receiving data
Methods for retrieving Employer data

Private Access Only:

// **Private Methods**

Method for calculating my expected profit assessments
Method for calculating my actual profit outcomes
Method for updating my work-site strategy (**learning**)

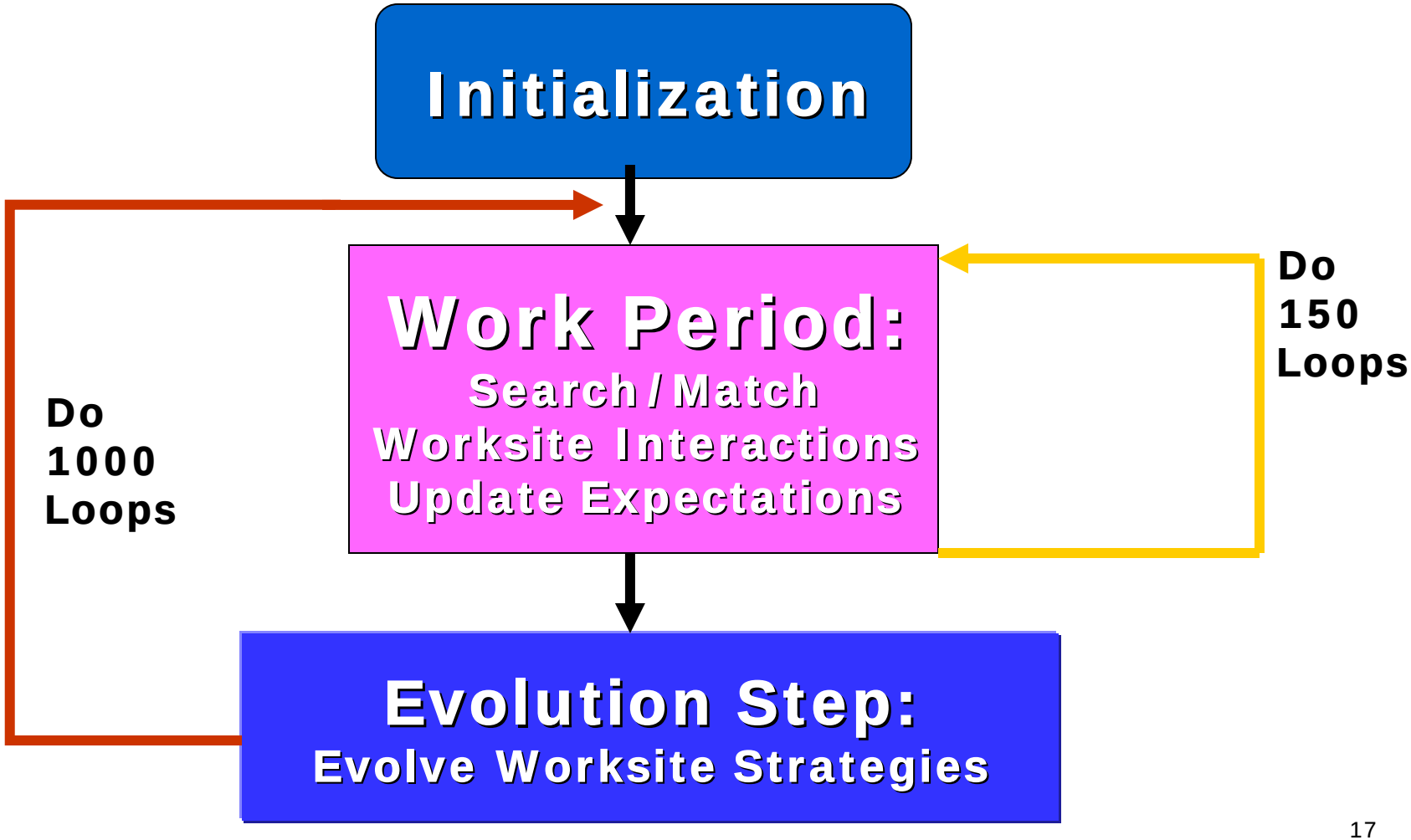
// **Private Data**

Data about myself (my history, profit fct., current wealth…)
Data recorded about external world (worker behaviors,…)
Addresses for potential workers (permits communication)

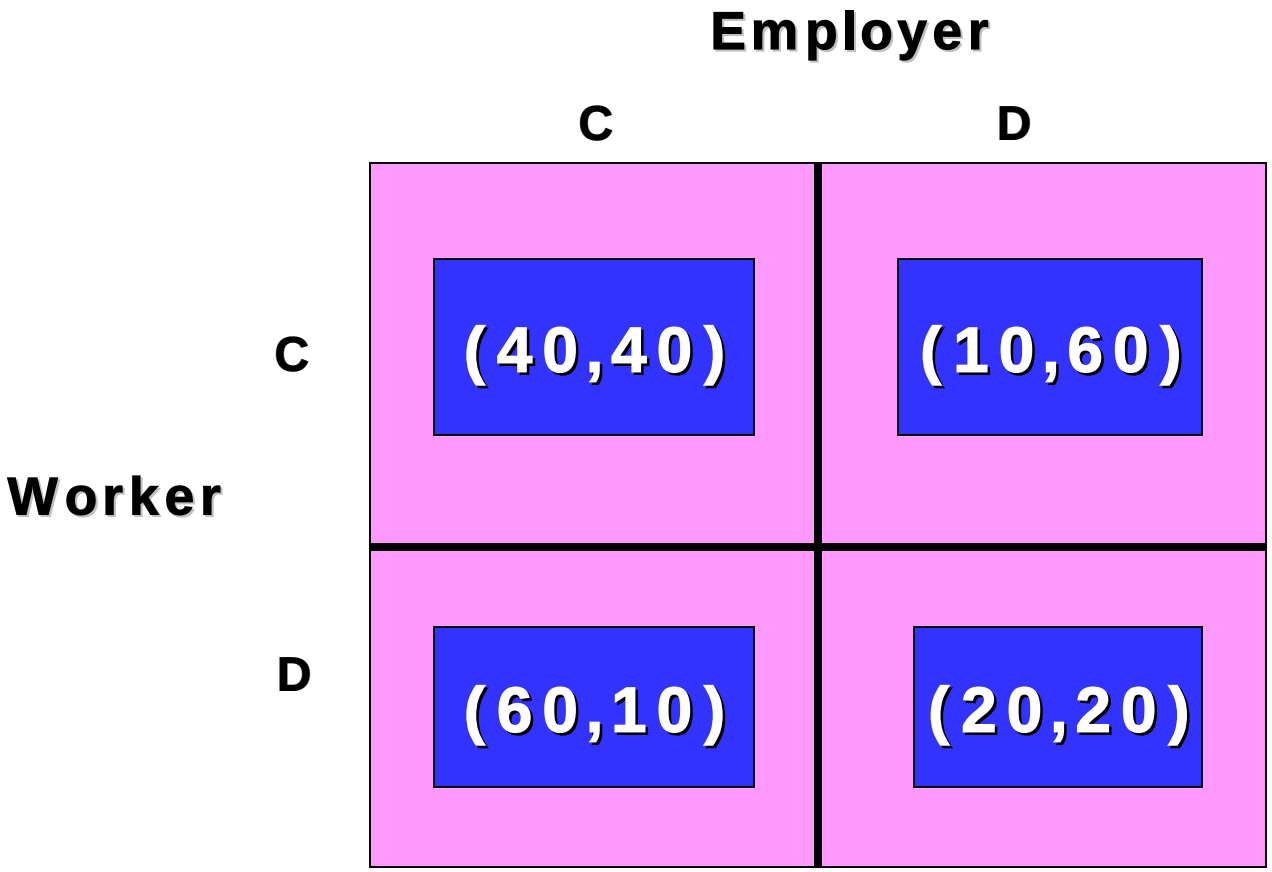
Flow of Activities in the ACE Labor Market

- 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 work-site interaction (**PD game - cooperate or defect**)
- Any unemployed (unmatched) worker or vacant (unmatched) employer receives a UB payment
- After 150 work periods, each worker and employer updates its work-site strategy

Flow of Activities in the ACE Labor Market



Worksite Interactions as Prisoner's Dilemma (PD) Games



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

Key Issues Addressed

How do **changes** in the level of the unemployment benefits (UB) payment 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 UB program costs, unemployment/vacancy rates,...)
- **Market Power** (distribution of total net surplus)

Experimental Design

- **Treatment Factor:**

  Unemployment Benefits Payment (UB)

- **Three Tested Treatment Levels:**

  UB=0, UB=15, UB=30

- **Runs per Treatment:**

  20 (1 Run = 1000 Generations; 1 Gen.=150 Work Periods)

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

Three UB Treatments in Relation to PD Payoffs

① **UB=0** < L=10

② L=10 < **UB=15** < D=20

③ D=20 < **UB=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

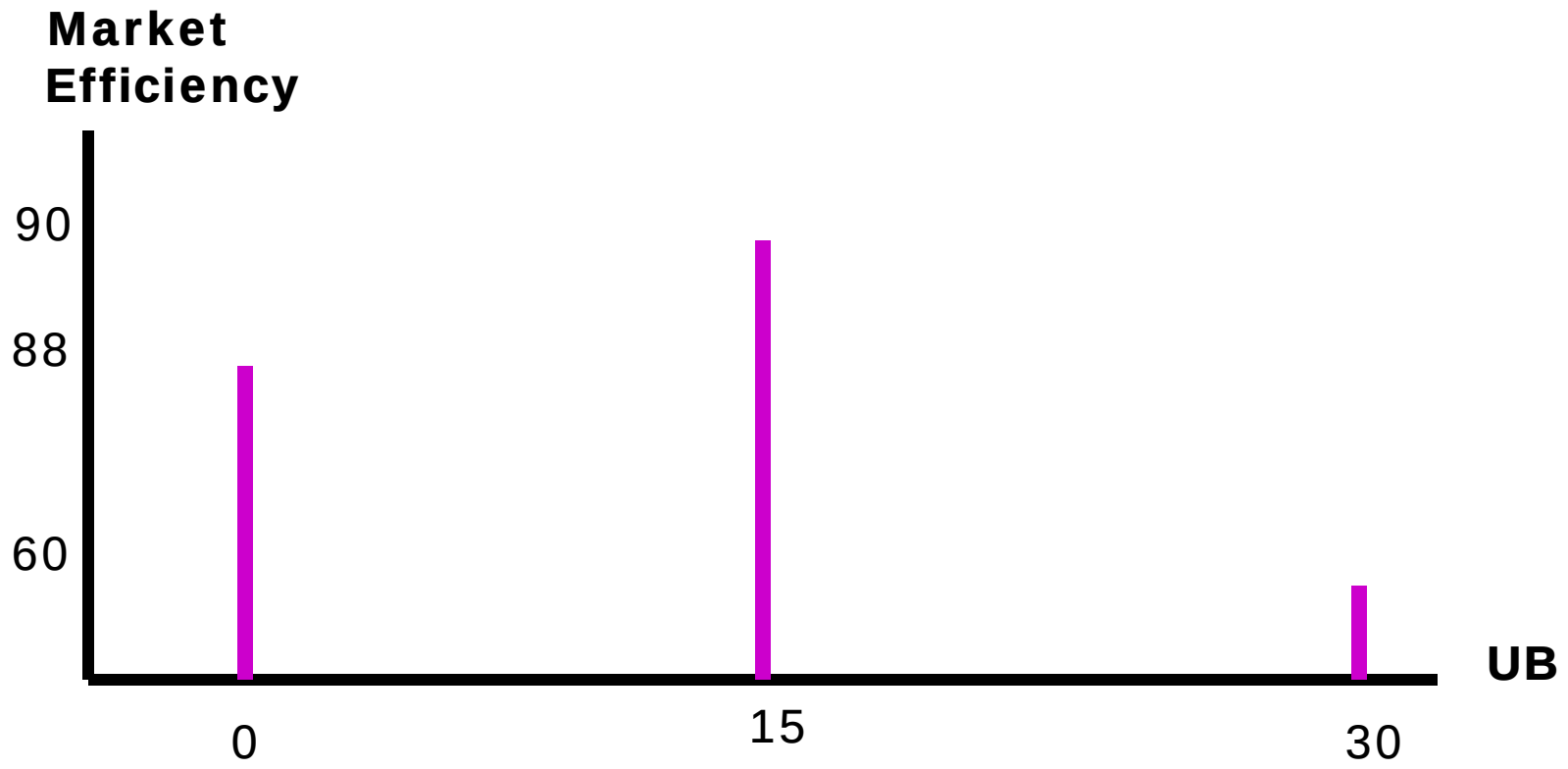
As UB level **increases** from 0 to 30…

- *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 UB Program Costs) Averaged Across Generations 12, 50, and 1000 for three different UB treatments



Efficiency Findings...

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

Multiple Attractors

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

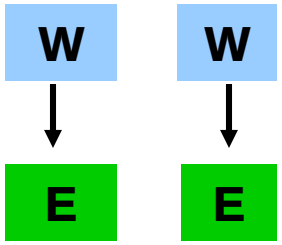
Multiple Network Attractors

- **Two distinct "attractors" observed for each UB treatment...**
  - **No UB (0) or Low UB (15) :**
    - ***First Attractor*** = Latched W-E network supporting ***mutual cooperation***;
    - ***Second Attractor*** = Latched W-E network supporting ***intermittent defection***
  - **High UB (30):**
    - ***First Attractor*** = Latched network supporting ***mutual cooperation***
    - ***Second Attractor*** = Completely disconnected network (***total coordination failure***)

The Following Diagrams Report...

① Two-sided (W-E) network distributions

0 = Stochastic fully connected network

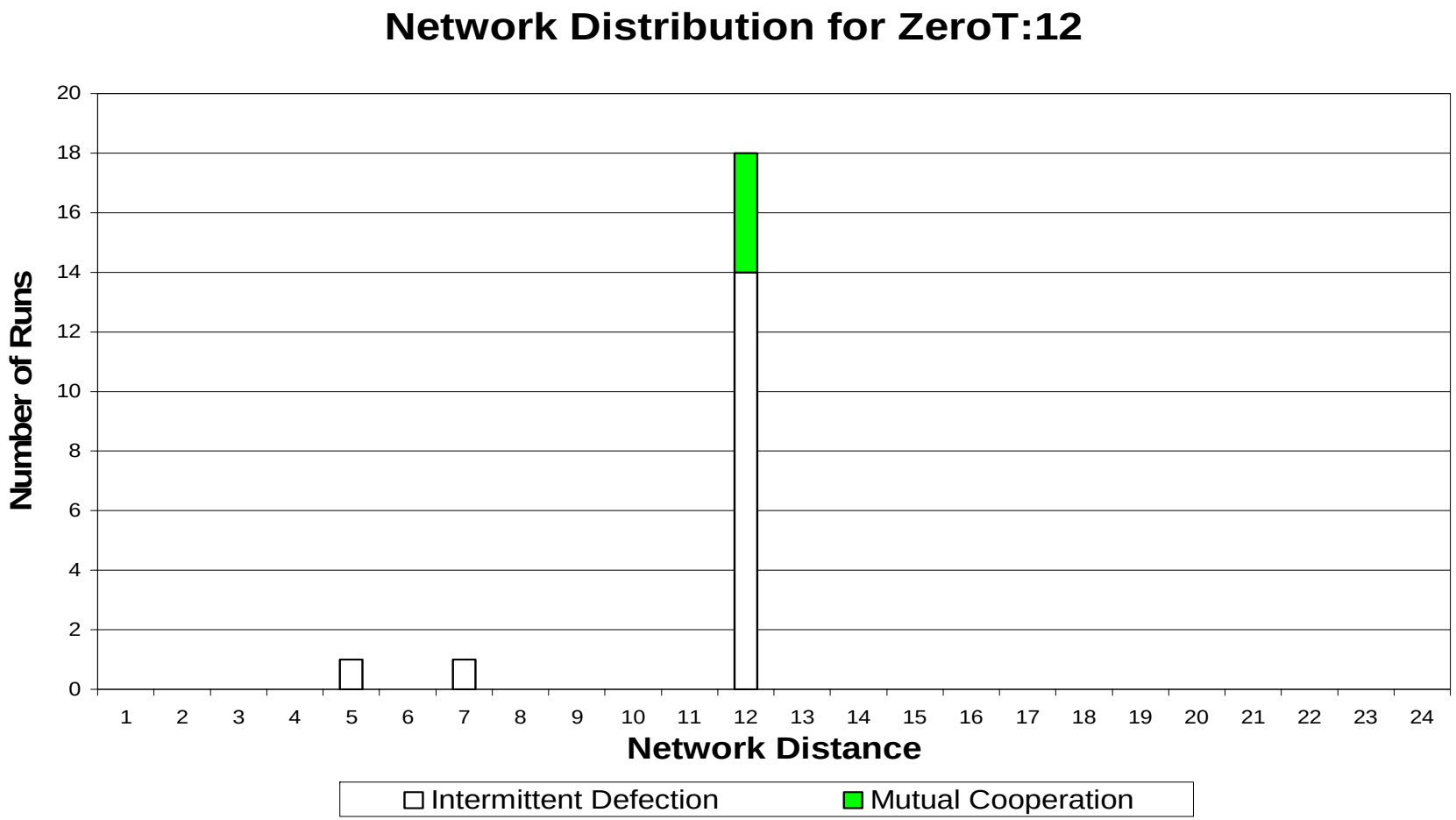
12 = Latched in pairs 

...

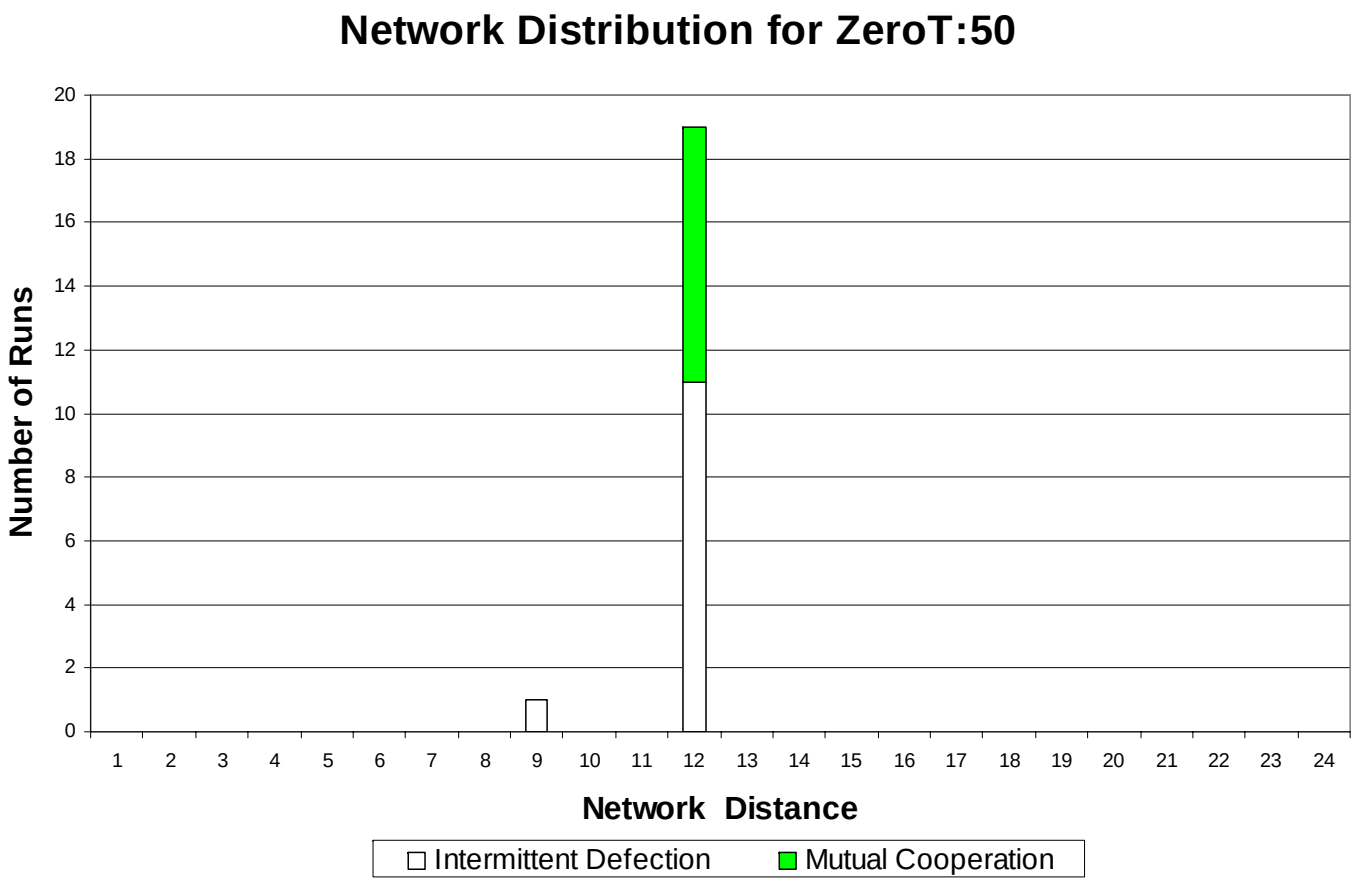
24 = Completely disconnected

② Worksite behaviors supported by these network outcomes

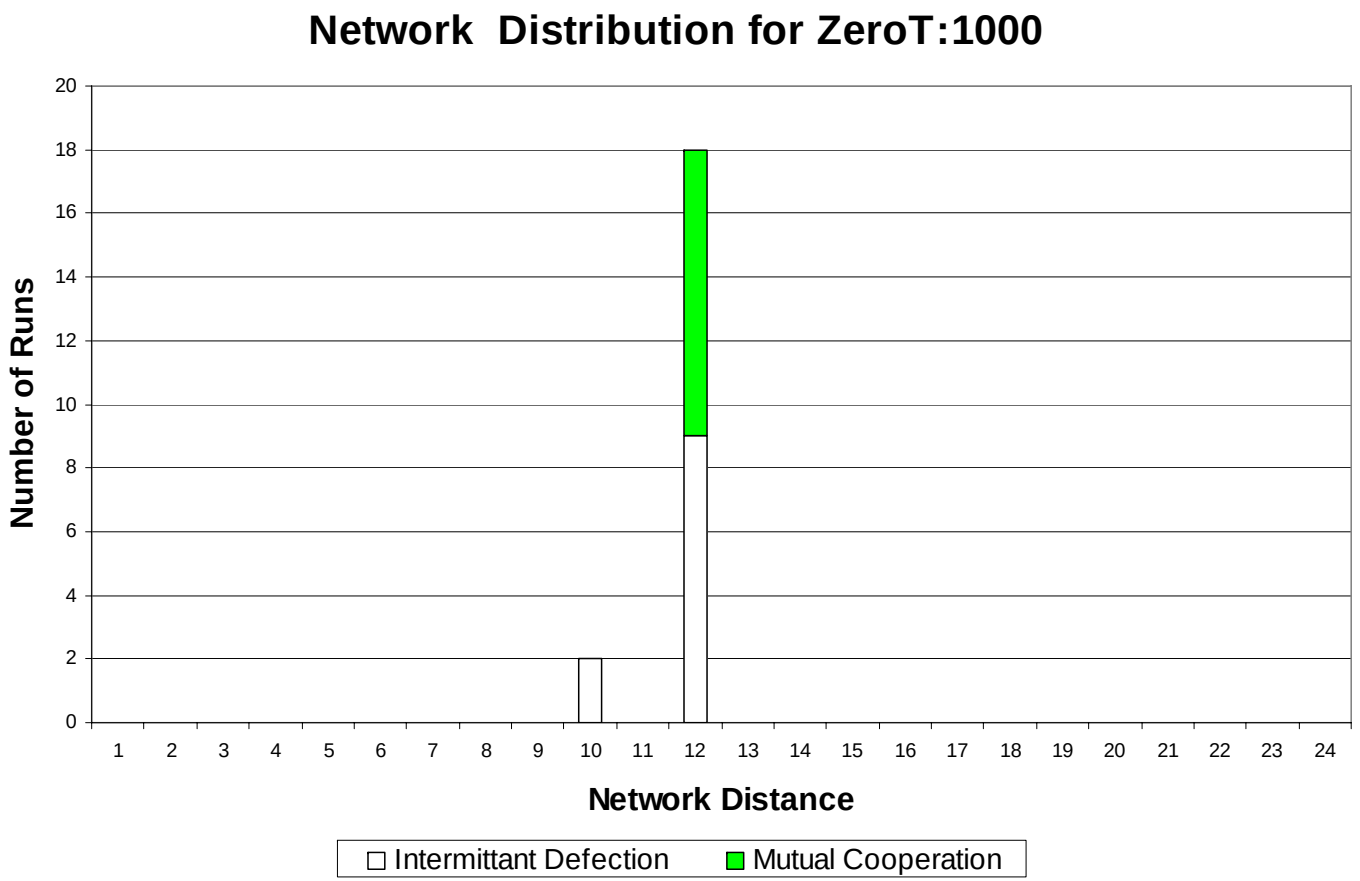
Network Distribution for UB=0 Sampled at End of Generation 12



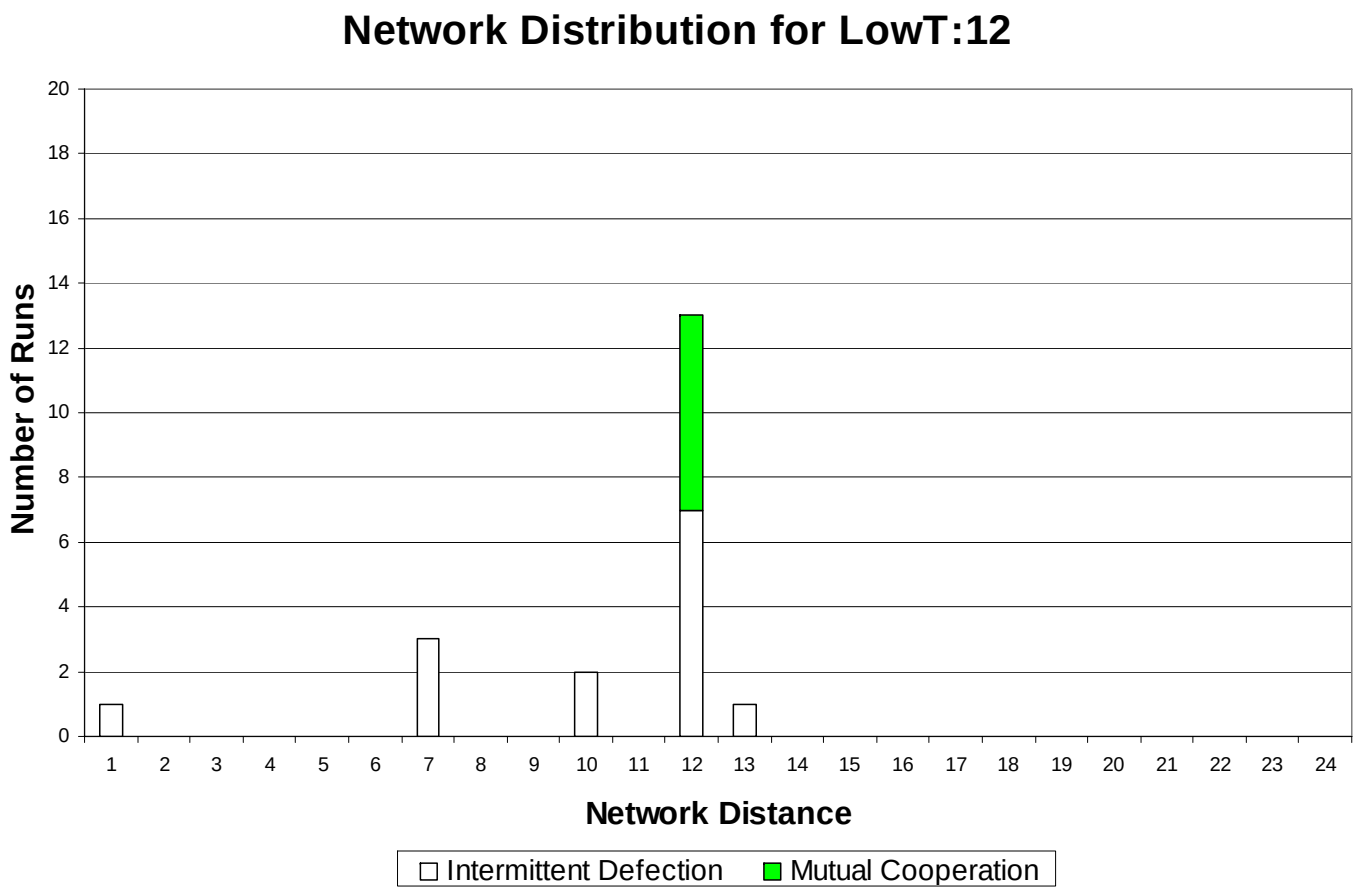
Network Distribution for UB=0 Sampled at End of Generation 50



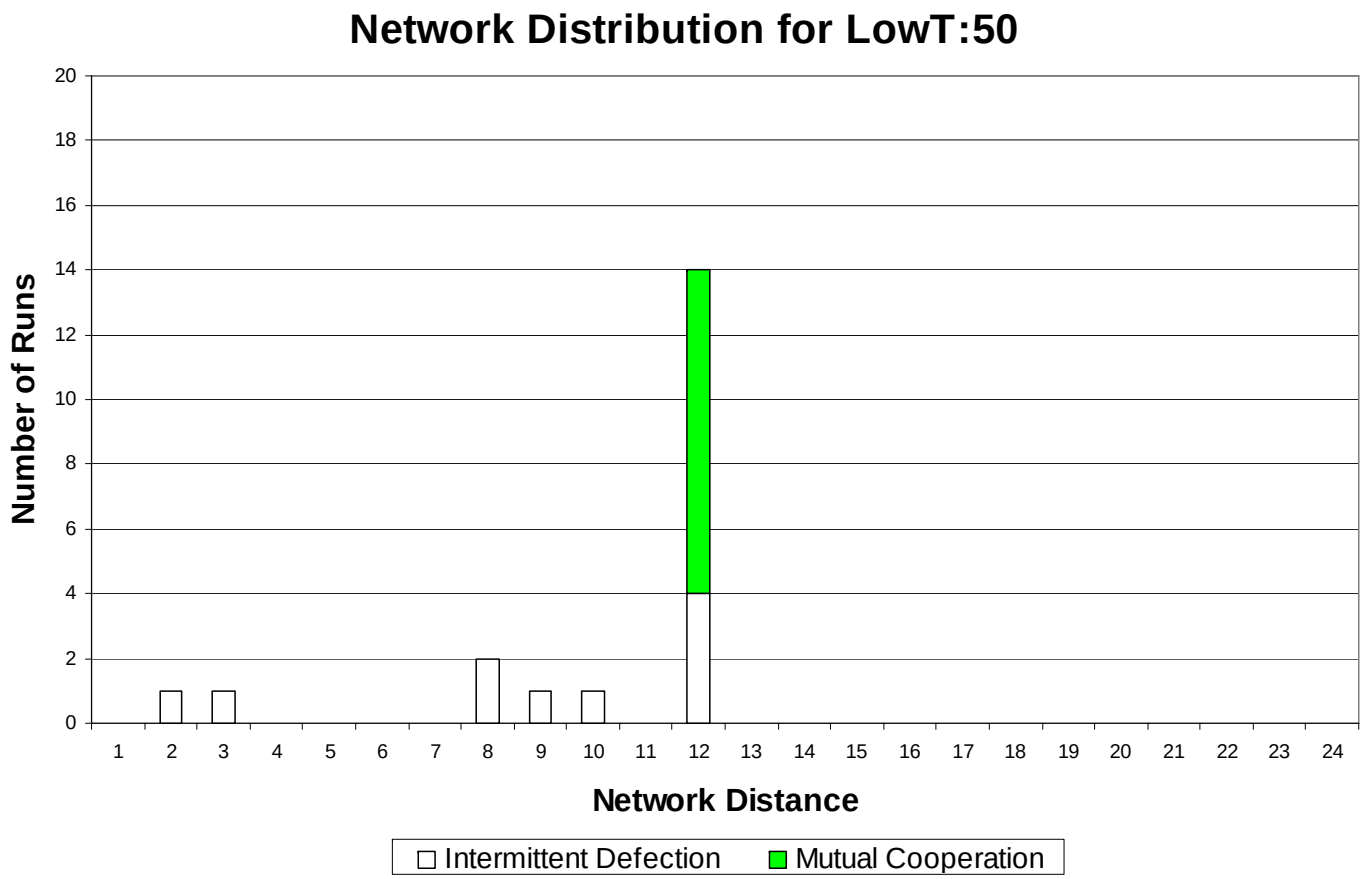
Network Distribution for UB=0 Sampled at End of Generation 1000



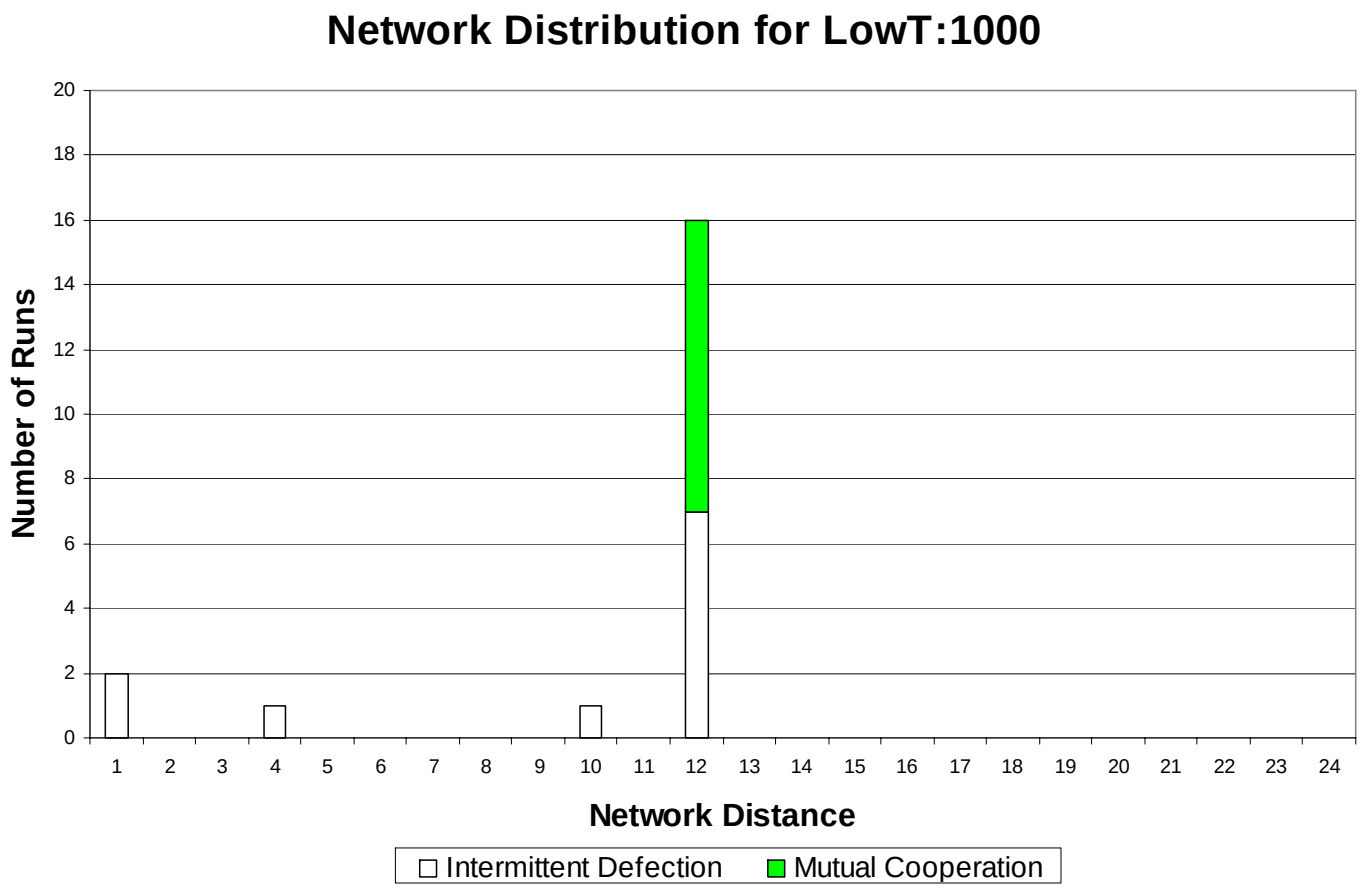
Network Distribution for UB=15 Sampled at End of Generation 12



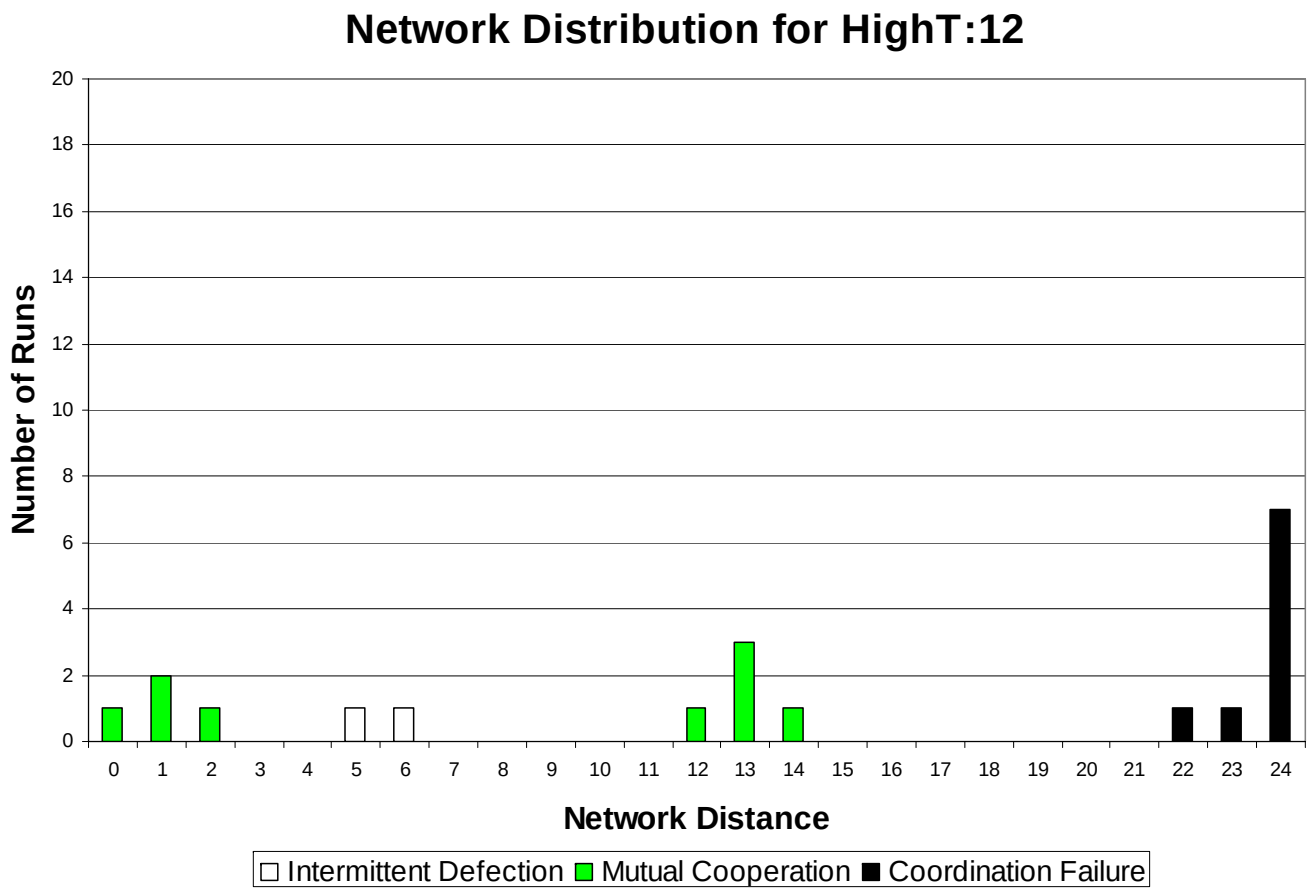
Network Distribution for UB=15 Sampled at End of Generation 50



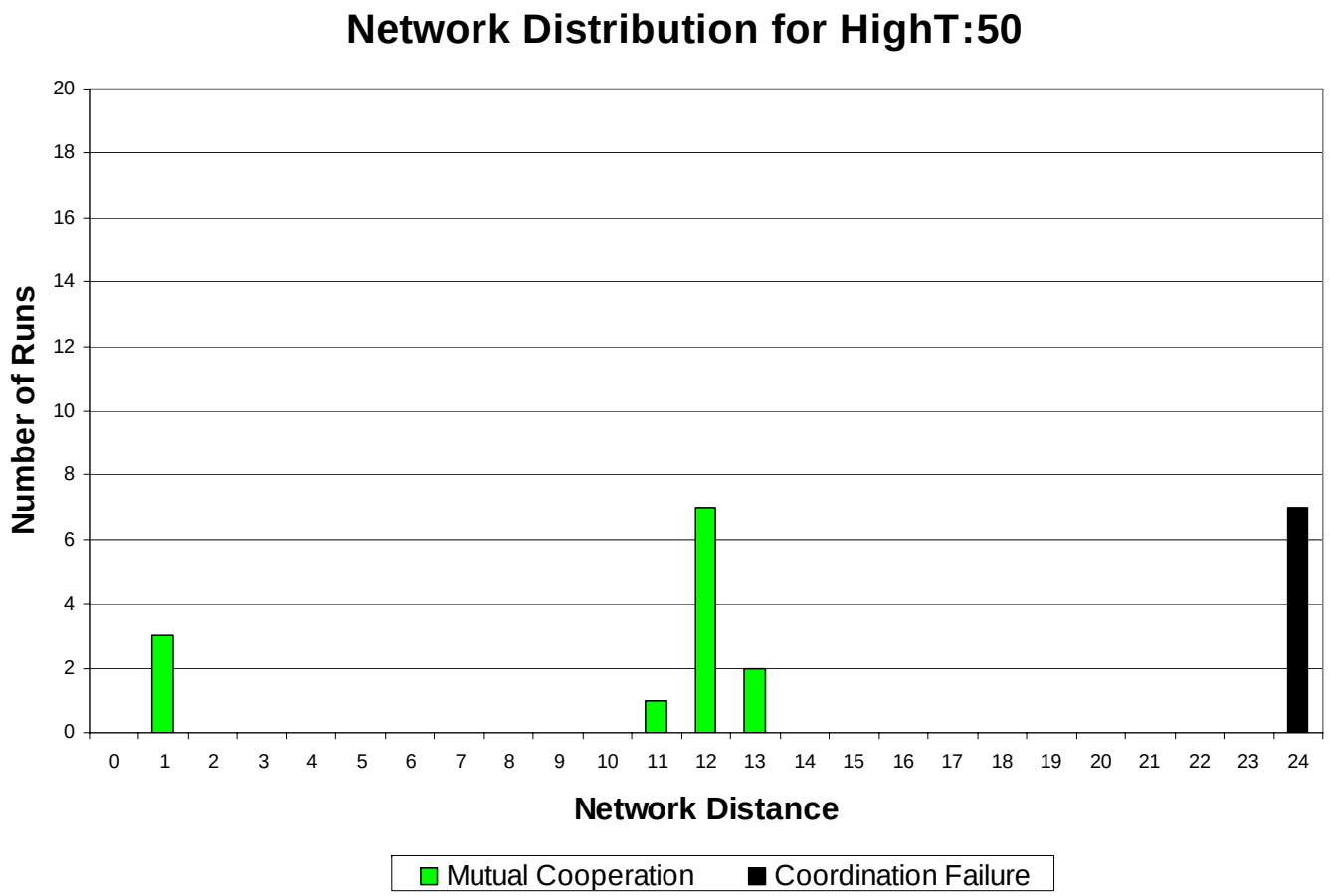
Network Distribution for UB=15 Sampled at End of Generation 1000



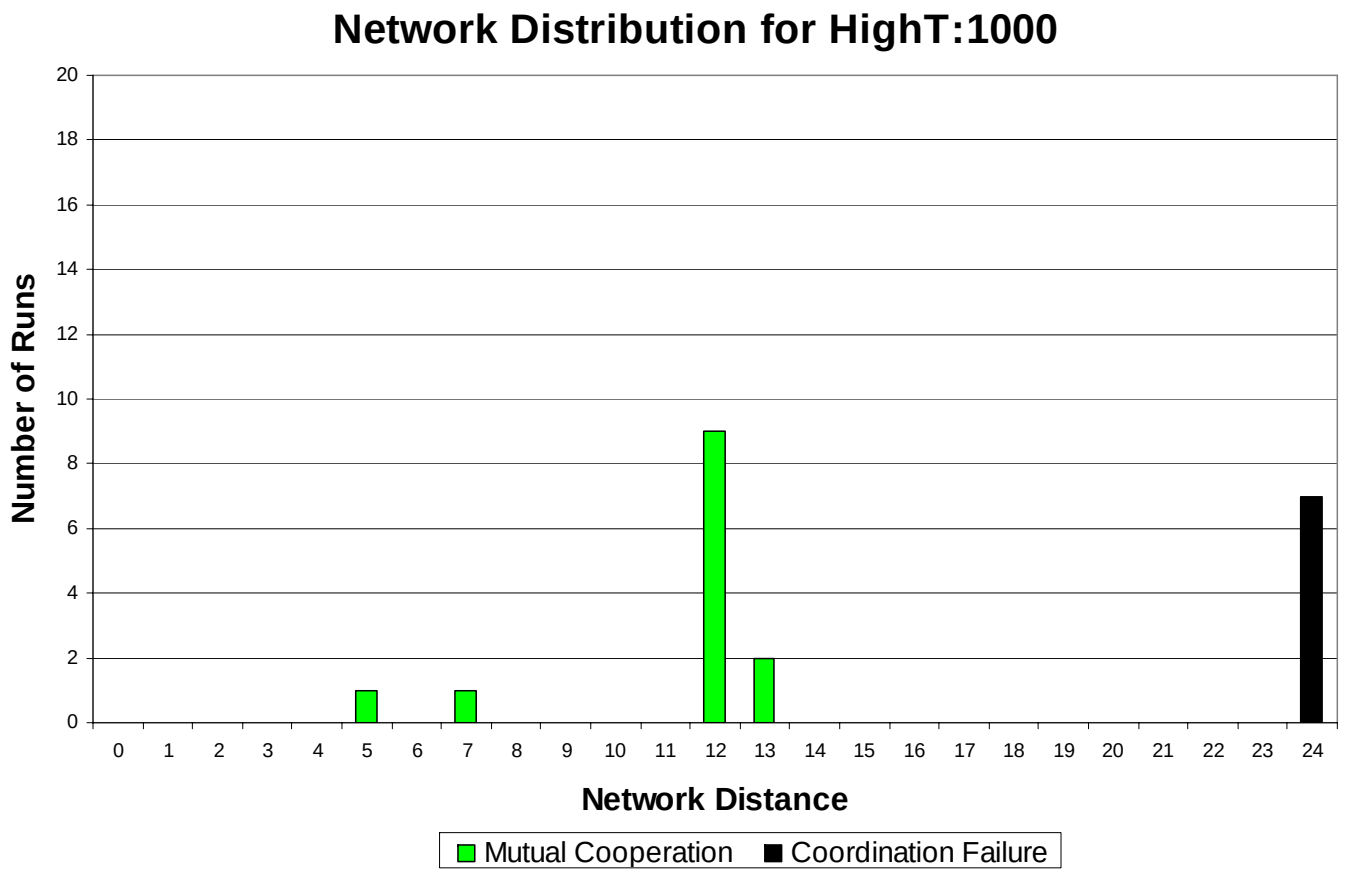
Network Distribution for UB=30 Sampled at End of Generation 12



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



Network Distribution for UB=30 Sampled at End of Generation 1000



Four Main Strands of ACE Research

- **Normative Understanding**
  (**institutional design**, policy selection, …)
- **Empirical Understanding**
  (possible reasons for empirical regularities)
- **Qualitative Insight/Theory Generation**
  (self-organization of decentralized markets, …)
- **Methodological Advancement**
  (representation, visualization, empirical validation, …)

ACE and Institutional Design

Key Issue: Does an institutional design ensure **efficient, fair, and orderly social outcomes over time** despite attempts by participants to "game" the design for their own personal advantage?

ACE Approach:

- ***Construct an agent-based world*** capturing salient aspects of the institutional design.
- ***Introduce agents with behavioral dispositions, needs, goals, beliefs, etc.*** Let the world evolve. Observe and evaluate resulting social outcomes.

EXAMPLES: Unemployment benefit programs, Internet auctions, stock markets, negotiation protocols, electricity markets…

ACE and Empirical Regularities

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

ACE Approach:

- ***Construct an agent-based world*** capturing salient aspects of the empirical situation.
- Investigate whether the empirical regularities can be ***reliably generated*** as outcomes in this world.

Example: ACE financial market research seeking the simultaneous explanation of financial market "stylized facts"
www.econ.iastate.edu/tesfatsi/afinance.htm

ACE and Qualitative Analysis

Illustrative Issue: What are the performance capabilities of decentralized markets? *(Adam Smith, F. von Hayek, John Maynard Keynes, J. Schumpeter …)*

ACE Approach:

- ***Construct an agent-based world*** qualitatively capturing key aspects of decentralized market economies (firms, consumers, circular flow, limited information, …)
- ***Introduce traders with behavioral dispositions, needs, goals, beliefs, etc.*** Let the world evolve. Observe the degree of coordination that results.

EXAMPLES: Decentralized exchange economies (no "Walrasian Auctioneer"), double-auction markets (learning traders vs. "zero intelligence" traders),…

Potential Disadvantages of ACE for Economic Modeling

- **Intensive experimentation is often needed**
  (fine sweeps of parameter ranges to attain robust findings)
- **Multi-peaked rather than central-tendency outcome distributions can arise**
  (strong path dependence possible)
- **Can be difficult to ensure platform robustness**
  (i.e., results that are independent of the hardware and/or software implementation of a model)
- **Effort to gain computer modeling skills can be significant** (creative computer modeling as opposed to use of existing comp labs requires good programming knowledge)

Potential Advantages of ACE for Economic Modeling

- **Permits systematic experimental study** of empirical regularities, economic institutions, and dynamic behaviors of complex economic processes in general.

- **Facilitates creative experimentation** with realistically rendered economic processes:

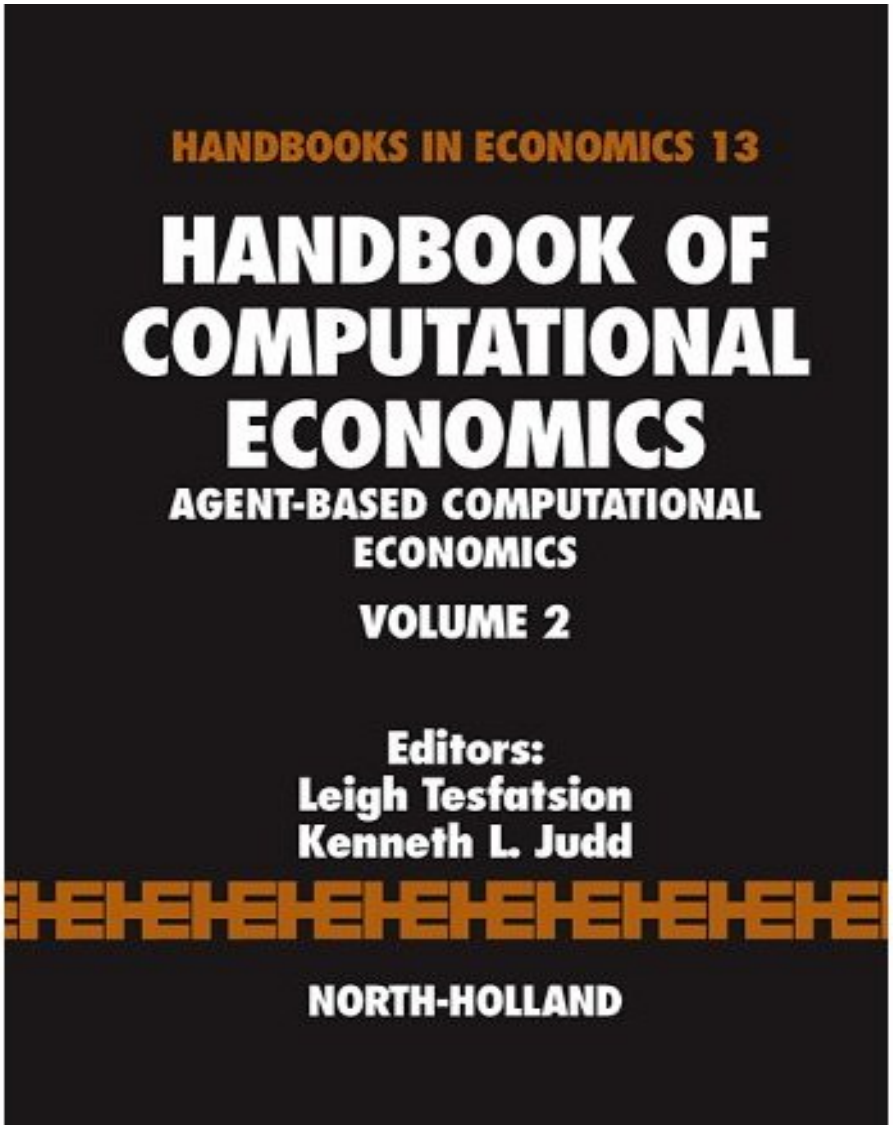
  - Using ACE comp labs, researchers/students can evaluate interesting conjectures of their own devising, with immediate feedback and no original programming required

  - Modular form of ACE software permits relatively easy modification/extension of features.

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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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!***