For Related Work, See:
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The Trade Network Game: A Computational Laboratory for the Study of Agent-Based Markets

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PRESENTATION OUTLINE

- **Into to Agent-Based Computational Economics (ACE)**
- **ACE Labor Market Application**
- **Implementation via the Trade Network Game (TNG): A Computational Laboratory for ACE Market Studies**
- **Illustrative ACE Labor Market Experiments**
- **Planned Future Studies**

What is ACE?

- ACE is the computational study of economies modelled as evolving decentralized systems of autonomous interacting agents.

- ACE is thus a specialization to economics of the basic complex adaptive systems paradigm.

Primary ACE Focus:

- Macro regularities in economic processes.

Basic ACE Issue:

- The extent to which macro regularities arise and evolve over time based on micro interactions of autonomous agents.

Online ACE Resources:

- ACE surveys, an annotated syllabus of readings, teaching materials, software, pointers to researchers and research groups, and journal and meeting announcements can be found at the ACE Web Site at
  http://www.econ.iastate.edu/tesfatsi/ace.htm

ACE MODELLING OF ECONOMIC SYSTEMS

Experimental Treatment Factors
(Initial Conditions)

→ Economy Modelled as a
Complex Adaptive System
("Culture Dish")

→ Macro Regularities

BASIC ASPECTS OF AN ACE STUDY

- **Identification of key issue(s) driving the study**
- **Framework for computational implementation**
- **Agent representation (internal cognitive structure)**
- **Experimental design**
- **Data analysis**
- **Comparisons with real-world data**

ACE LABOR MARKET APPLICATION

L. Tesfatsion, **"Hysteresis in an Evolutionary Labor Market with Adaptive Search"**, ISU Econ. Rep. 50, October 1999, to appear in S. H. Chu (ed.), *Evolutionary Computation in Economics and Finance*, Springer Verlag; preprint available online at

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

Key Issue Driving the Study:

- **Observationally equivalent workers earn markedly different compensations and have markedly different employment histories.**

- **In short, labor market outcomes appear to be characterized by a high degree of PATH DEPENDENCY (HYSTERESIS).**

- **Analytical and empirical explorations of micro sources of this path-dependency face intractability problems.**

- **Can an ACE approach help?**

RECENT EMPIRICAL EVIDENCE:

Longitudinal study of French workers and employers from 1976 to 1987 by Abowd et al., *Econometrica* 67 (1999), 251–333.

- y = vector whose components give the logarithm of real annualized total compensation for worker i, $i = 1, \ldots, N$;
- X = matrix of observable characteristics for workers and employers (education and school-leaving age, total labor market experience, job seniority, gender, region, industry, etc.);
- D = matrix of indicator functions giving the identity of different workers (for measuring "person effects");
- F = matrix of indicator functions giving the identity of different employers (for measuring "firm effects");
- ϵ = vector of residual errors (to be made as small as possible by choice of regression coefficients β, θ, and ψ).

$$y \quad = \quad X\beta \; + \; D\theta \; + \; F\psi \; + \; \epsilon$$

Main Findings (Abowd et al., p. 294):

- **When D (person effects) is included in the regression, between 77 percent and 83 percent of the variability in y (worker compensations) is explained.**
- **When D is excluded from the regression, only between 30 percent and 55 percent of the variability in y is explained.**
- **Inclusion of F (firm effects), while also important for explaining variability, is much less important than inclusion of D (person effects).**

Illustration: A Two-Sided ACE Labor Market

- **Twelve workers, each with** wq **potential work offers,** $wq \geq 1$;

- **Twelve employers, each with** eq **potential job openings,** $eq \geq 1$.

Key Finding for ACE Labor Market Study

Persistent Earnings Heterogeneity is Supported by Strong Hysteresis (Path-Dependency) Effects Arising in Two Distinct Ways:

- **Behavioral Hysteresis:** Agents with same observed structural attributes end up expressing persistently different worksite behaviors, resulting in persistently different earnings.

- **Network Hysteresis:** Agents with same observed structural attributes and with same expressed worksite behaviors end up in persistently different network relationships, resulting in persistently different earnings.

TRADE NETWORK GAME (TNG) LABORATORY

A Computational Laboratory Used to Implement the ACE Labor Market Study

SimBioSys:

- A C++ class framework developed by David McFadzean (1995).
- Designed for the building of virtual worlds inhabited by coevolving populations of autonomous interacting agents.

Trade Network Game (TNG):

- Algorithmic process model developed by L. Tesfatsion (1995) for studying the formation and evolution of trade networks

TNG Laboratory = SimBioSys + TNG:

- Implementation and graphic visualization of TNG with support of SimBioSys (David McFadzean and Leigh Tesfatsion, *Computational Economics*, 1999)
- Basic TNG Lab source code available online at ACE Web site

Agent Representation in TNG/SimBioSys: A Virtual Trader

class TradeBot

{

Public Access:

// Internalized Institutional Rules

Rules governing communication among tradebots;
Rules governing the determination of trade partners;
Rules governing the conduct of trades;

Private Access Only:

// Internalized Data

My current physiological attributes;
My current beliefs;
My current preferences;
Addresses for other tradebots;
Additional data about other tradebots;

// Internalized Behavioral Rules

Rules for updating my beliefs;
Rules for updating my preferences;
Rules for strategizing my trades;
Rules for calculating my fitness score;
Rules for updating my rules;
};

Flow Diagram for the ACE Labor Market

Initialization:

- **Construct initial subpopulations:**
  Construct subpopulations of workers and employers with random worksite strategies, initial expected payoff levels, work offer/acceptance quotas, etc.

Trade Cycle:

- **Job Search/Match:**
  Workers direct work offers to preferred employers, who accept or refuse them, and each agent records any transactions costs incurred due to job search, unemployment, or vacancy.
- **Worksite Interactions:**
  Matched workers and employers engage in worksite interactions modelled as two-person games and record their worksite earnings.
- **Update Expectations:**
  All agents update their expected payoffs based on newly recorded transactions costs and worksite earnings.

Evolution Step:

- **Evolve Agent Worksite Strategies:**
  Separately evolve worksite strategies for all workers and for all employers, using mimicry of more successful strategies as well as experimentation with new ideas.
- **Re-initialize Agents:**
  Re-initialize evolved workers and employers with initial expected payoff levels, work offer/acceptance quotas, etc.

Current Implementations for ACE Labor Market Modules

- **Job Search/Match:** Choice and refusal of worksite partners via a modified Gale-Shapley matching mechanism.

- **Worksite Interactions:** Prisoner's dilemma games.

- **Update Expectations:** Updated expected payoff equals weighted average of previous expected payoff and new payoff.

- **Evolution:** Standard genetic algorithm separately applied to worksite (iterated prisoner's dilemma) strategies of workers and employers.

- **Re-initialization:** Agent memories are wiped clean at the beginning of each trade cycle loop.

Pseudo-Code for the ACE Labor Market

```
int main () {
  Init();                         // Construct initial subpopulations of
                                  //    workers and employers with
                                  //    random worksite strategies.
  For (G = 1,...,GMax) {          // Enter the generation cycle loop.
                                  // Generation Cycle:
    InitGen();                    //    Configure each agent with
                                  //       initial parameter values (initial
                                  //       expected payoff levels, quotas, etc.).
    For (I = 1,...,IMax) {        //    Enter the trade cycle loop.
                                  //    Trade Cycle:
      MatchTraders();             //       Determine contractual partners,
                                  //          given expected payoff levels,
                                  //          and record transactions costs.
      Trade();                    //       Engage in worksite interactions and
                                  //          record worksite earnings.
      UpdateExp();                //       Update expected payoff levels using
    }                             //          newly recorded transactions costs
                                  //          and worksite earnings.
                                  //    Environmental Step:
    AssessFitness();              //       Assess fitness scores.
    Output();                     //       Output agent info.
                                  //    Evolution Step:
    EvolveGen();                  //       Evolve new subpopulations
                                  //          of workers and employers.
  }
  Return 0;
}
```

Experimental Design for ACE Labor Market Study

Treatment Factor Specification
(Market Power Asymmetry)

$\rightarrow$ Contractual Networks Among
Workers and Employers

$\rightarrow$ Worksite Behaviors,
Welfare Outcomes, and
Earnings Heterogeneity

A Measure for Market Power Asymmetry

Worker Offer Quota WQ:

WQ = Maximum number of work offers that each worker can have outstanding at any time during a trade cycle.

Employer Acceptance Quota EQ:

EQ = Maximum number of job openings that each employer can supply during a trade cycle.

Excess Job Capacity, Given N Employers and M Workers:

$$\text{EJC(N,M)} = \text{N*EQ/M*WQ}$$

$$= \frac{\text{Total Potential Job Openings}}{\text{Total Potential Work Offers}}$$

Market Power Asymmetry Measure:

Degree to which EJC(N,M) differs from one.

Descriptive Statistics

- **Ex Post Classification of Persistent Contractual Networks by Distance:**
  For each tested economy (treatment) e and each initial seed value s:

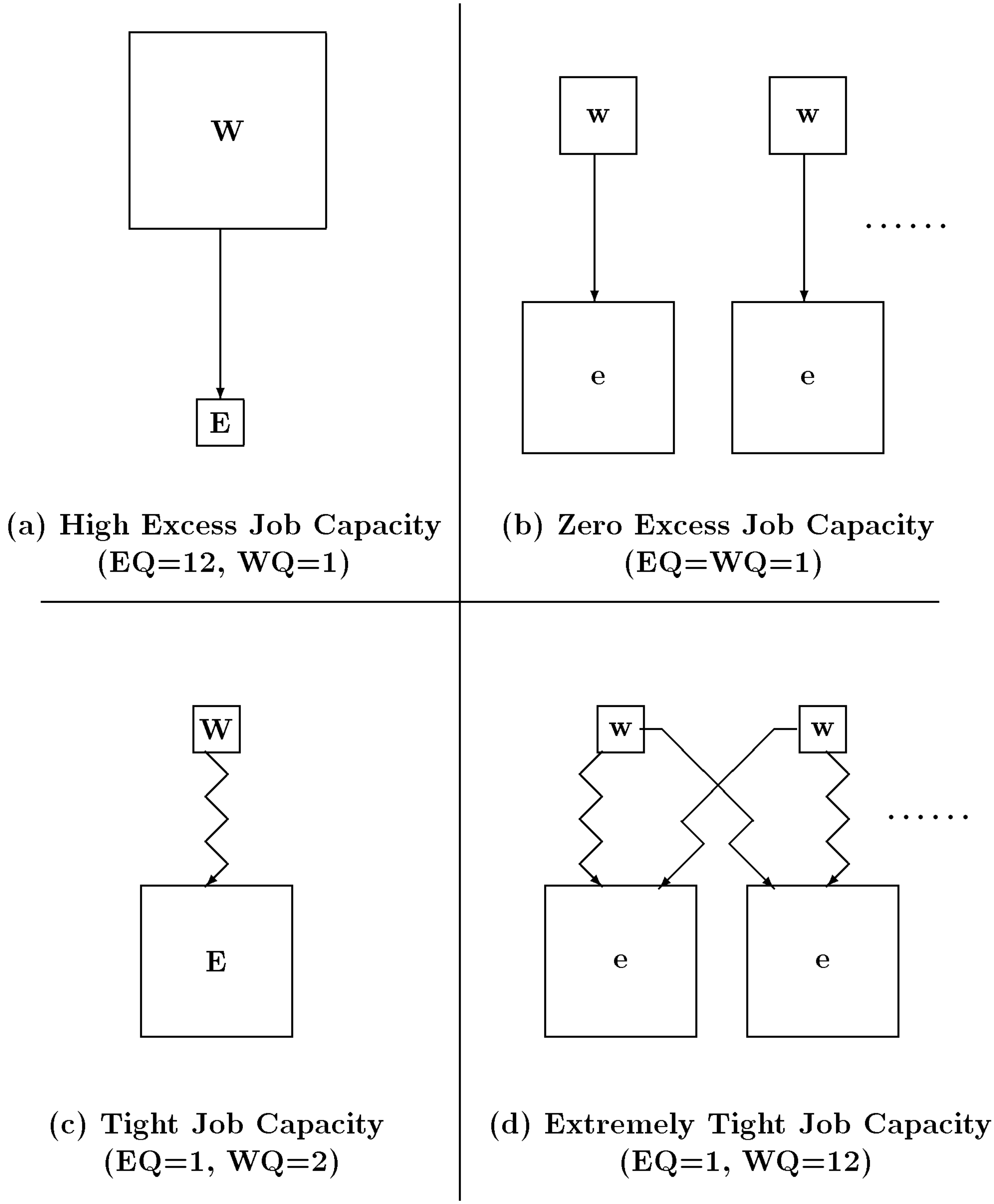
  $$D^o(s,e) \quad = \quad \text{Number of agents in the final generation of the sample economy } (s,e) \text{ that deviate from a fixed base contractual pattern.}$$

- **Ex Post Classification of Persistent Worksite Behaviors:**
  For each agent type (workers and employers) in the final generation of each sample economy (s,e), measure
  - **the percentage of unprovoked defectors (UD);**
  - **the percentage of persistent wallflowers (PWF);**
  - **the percentage of repeat defectors (RD);**
  - **the percentage of persistent cooperators (PC).**

- **Ex Post Classification of Persistent Welfare Outcomes:**
  For each agent type (workers and employers) in the final generation of each sample economy (s,e), measure the

  $$\text{EARN value} \quad = \quad \text{average payoff level}$$

  attained by this agent type.



(a) High Excess Job Capacity (EQ=12, WQ=1)

(b) Zero Excess Job Capacity (EQ=WQ=1)

(c) Tight Job Capacity (EQ=1, WQ=2)

(d) Extremely Tight Job Capacity (EQ=1, WQ=12)

Base Contractual Patterns for Two-Sided Labor Markets with Differential Job Capacities: Straight lines indicate latched relations and zig-zag lines indicate recurrent relations.

D^o Cluster	% Runs	Mean UD		Mean PWF		Mean PC		Mean EARN	
		w	e	w	e	w	e	w	e
3–9	75%	97% (5%)	16% (34%)	2% (3%)	40% (12%)	3% (5%)	39% (28%)	1.74 (.27)	0.35 (.14)
24	25%	2% (3%)	5% (7%)	2% (3%)	5% (7%)	98% (3%)	95% (7%)	1.39 (.02)	1.02 (.03)

(a): High Excess Job Capacity (wq=1, eq=12)

D^o Cluster	% Runs	Mean UD		Mean PWF		Mean PC		Mean EARN	
		w	e	w	e	w	e	w	e
0–2	75%	16% (33%)	23% (39%)	1% (3%)	1% (3%)	94% (6%)	86% (26%)	1.10 (.14)	1.33 (.22)
4	10%	50% (50%)	54% (46%)	8% (8%)	8% (8%)	50% (50%)	46% (46%)	0.57 (.05)	0.86 (.57)
24	15%	0% (0%)	22% (20%)	0% (0%)	8% (0%)	89% (16%)	78% (20%)	0.24 (.08)	1.42 (.05)

(b): Zero Excess Job Capacity (wq=eq=1)

D^o Cluster	% Runs	Mean UD		Mean PWF		Mean PC		Mean EARN	
		w	e	w	e	w	e	w	e
0–7	55%	2% (3%)	5% (9%)	19% (10%)	4% (7%)	81% (10%)	96% (6%)	0.30 (.05)	1.35 (.09)
13–17	15%	100% (0%)	69% (43%)	47% (14%)	19% (18%)	8% (12%)	14% (20%)	0.32 (.04)	0.76 (.13)
24	30%	100% (0%)	100% (0%)	100% (0%)	100% (0%)	100% (0%)	100% (0%)	-0.10 (0)	-0.02 (0)

(c): Tight Job Capacity (wq=2, eq=1)

D^o Cluster	% Runs	Mean UD		Mean PWF		Mean PC		Mean EARN	
		w	e	w	e	w	e	w	e
0–6	35%	1% (3%)	1% (3%)	12% (4%)	1% (3%)	86% (7%)	96% (6%)	0.31 (.03)	1.37 (.06)
15–17	20%	10% (14%)	92% (14%)	35% (7%)	2% (4%)	17% (20%)	25% (34%)	0.35 (.17)	1.22 (.20)
24	45%	100% (0%)	100% (0%)	100% (0%)	100% (0%)	0% (0%)	0% (0%)	-0.10 (.00)	-0.01 (.00)

(d): Extremely Tight Job Capacity (wq=12, eq=1)

Experimental Findings for Two-Sided Labor Markets with Differential Job Capacities

Principal Experimental Findings to Date

1. **One-to-Many Mapping (Multiple "Equilibria"):**

   - For each treatment, a distribution of persistent outcomes
   - For each treatment, a histogram for persistent network formations consisting of a small number of isolated peaks
   - Strong correlation between market power asymmetry and relative welfare outcomes for workers and employers

2. **Strong Hysteresis (Path-Dependency) Effects Supporting Persistent Earnings Heterogeneity:**

   - Behavioral Hysteresis
   - Network Hysteresis

3. **Important Role of Job Search Costs:**

   - Strongly affect network formation
   - Strongly affect relative welfare outcomes

Extensions in Progress

1. **Use the ACE labor market framework To:**

   - Conduct additional parameter sensitivity studies.
   - Experiment with alternative module specifications (initialization, job search/matching, worksite interactions, expectation updating, worksite strategy evolution).

2. **Extend ACE Labor Market Framework to Permit:**

   - Signalling among agents (e.g., wage bids and offers,...).
   - Endogenization of market power asymmetries.
   - Effects of government regulations (e.g., minimum wage laws).
   - Coevolution of market structure, partner selection mechanism, and worksite strategies.

3. **Test Against Real-World Labor Market Data**

   - Natural data, survey data, human-subject lab data, ...

4. **Better Graphical Visualization (e.g., TNG Lab)**

Some General Issues Facing ACE Researchers

1. Building ACE Frameworks
   (a) Language availability and capabilities
   (b) Framework design
   (c) Graphical visualization and portability

2. Agent Representation in ACE Frameworks
   (a) Learning level/plasticity
   (b) Learning implementation
   (c) Evolvability (the adapted mind?)

3. ACE Experimental Design and Data Analysis
   (a) Data reporting (descriptive statistics)
   (b) Hypothesis testing and goodness of fit
   (c) Parameter sensitivity testing and robustness
   (d) Replicability across hardware platforms

4. Applications/Policy Use of ACE Frameworks
   (a) Thought tools?
   (b) Descriptive analyses?
   (c) Forecasting?
   (d) Normative analyses?

General ACE Resources:

1. The ACE Web site at

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

   This continually updated site includes ACE surveys, an annotated syllabus of ACE-related readings, ACE teaching materials, pointers to ACE-related software, pointers to researchers and research groups engaged in ACE-related research, pointers to other ACE-related Web sites, ACE news notes, etc.

2. Epstein/Axtell's Sugarscape monograph. J. Epstein and R. Axtell, *Growing Artificial Societies: Social Science from the Bottom Up*, MIT Press/Brookings, Cambridge, 1996.

   The authors argue the case for an agent-based computational approach to the study of dynamic social systems. They illustrate their arguments by means of an agent-based simulation framework ("Sugarscape"), implemented in Object Pascal, in which agents equipped with a sugar-metabolism and vision inhabit a two-dimensional grid of sugar-bearing sites. Issues explored include migration, wealth accumulation, sexual reproduction, cultural transmission, trade, and disease transmission.