ACE Market Game Examples

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Outline

- Example 1: ACE double-auction trading game

- Example 2: ACE posted-auction trading game

Example 1: ACE Double-Auction Trading Game

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

Two Key Issues Addressed

✱ Sensitivity of market performance to changes in ***market structure:***

RCON =: Relative seller/buyer **concentration**

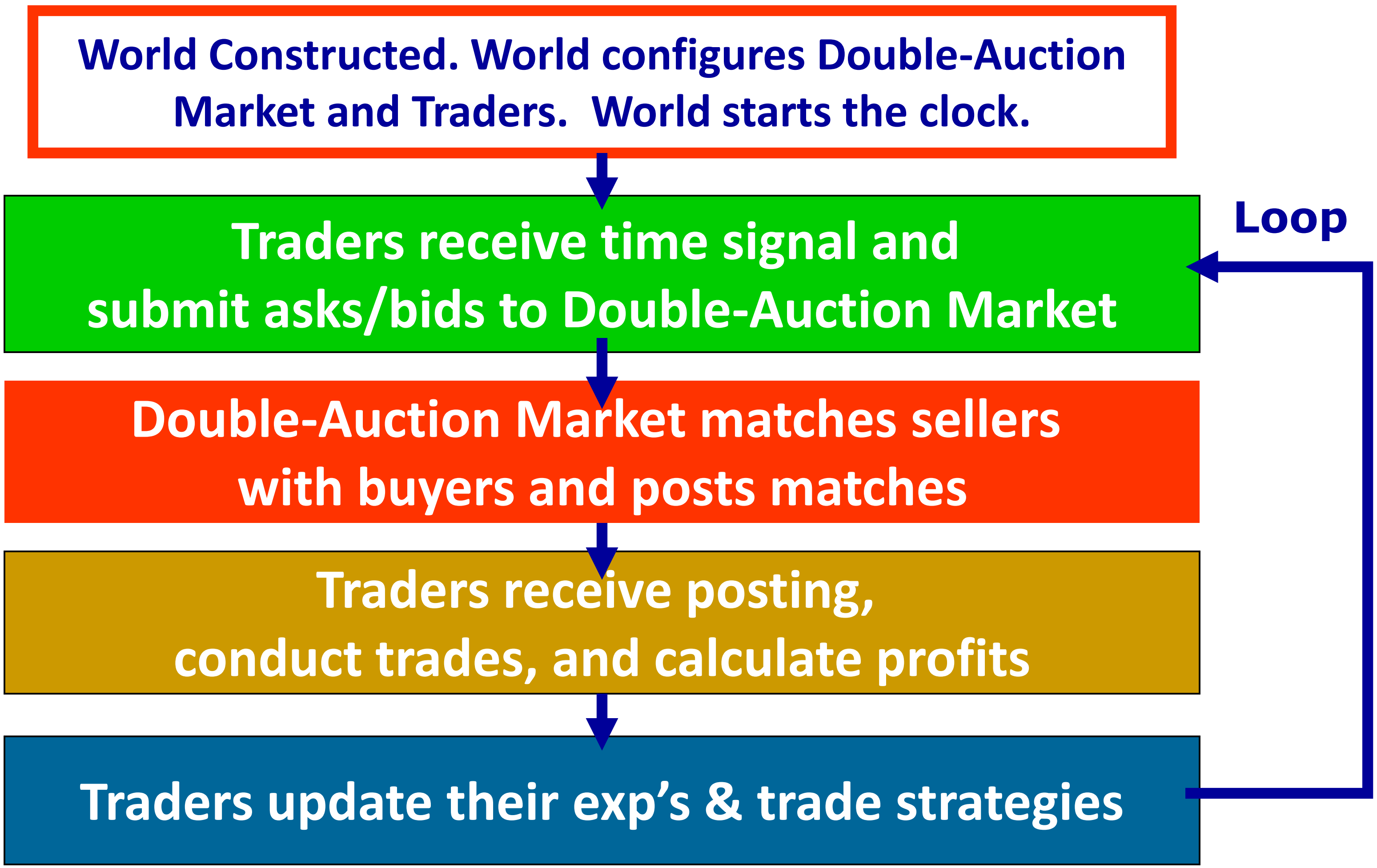
RCAP =: Relative demand/supply **capacity**

✱ Sensitivity of market performance to changes in ***trader learning methods:***

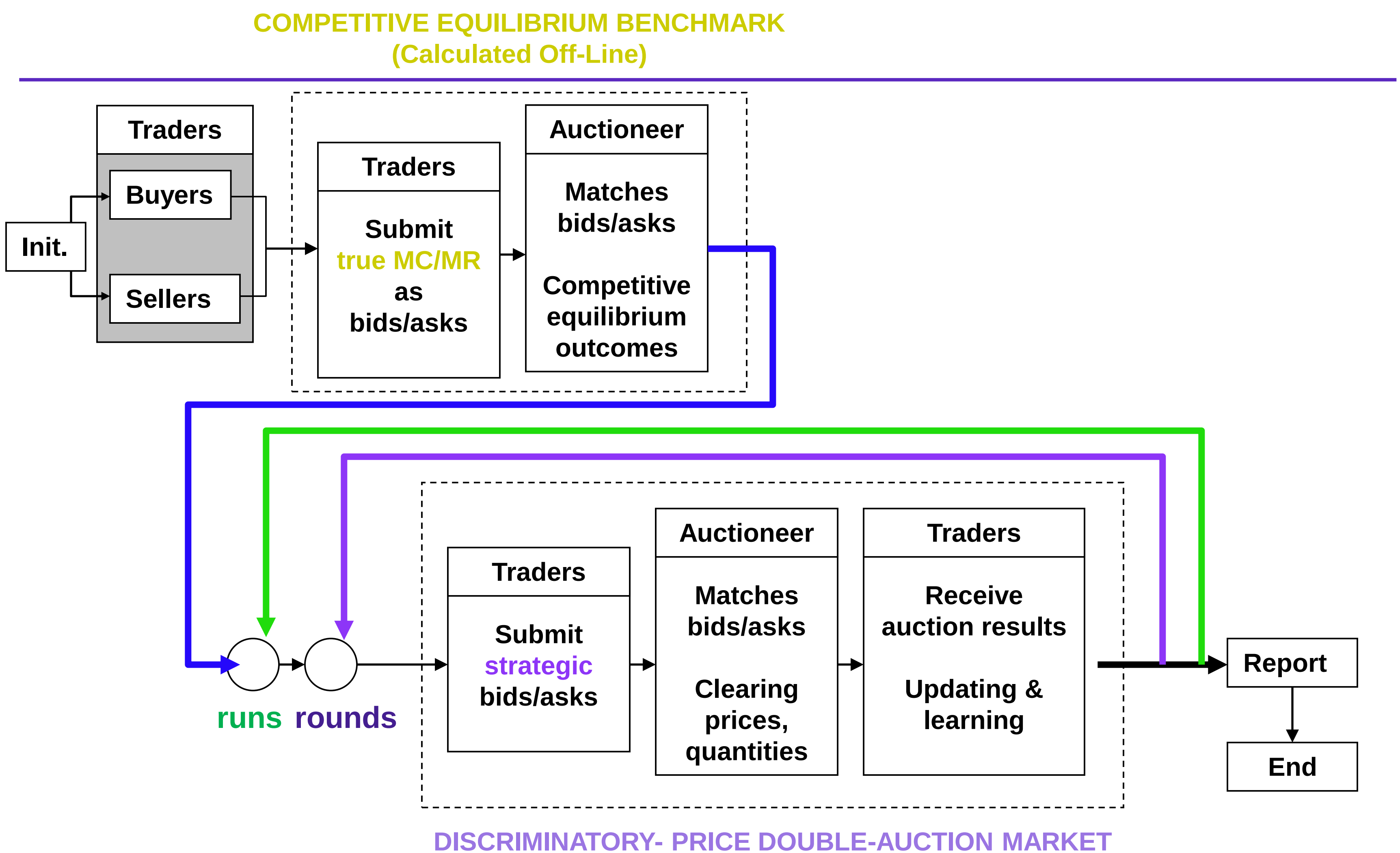
-- **Learning Treatment 1:** Individual **Reinforcement Learning (RL)**

-- **Learning Treatment 2:** Social **Genetic Algorithm (GA)** learning

Dynamic Flow of the Double-Auction World



Dynamic Activity Flow for the Double-Auction Market



Nine Structural Treatments Tested for Each Learning Treatment

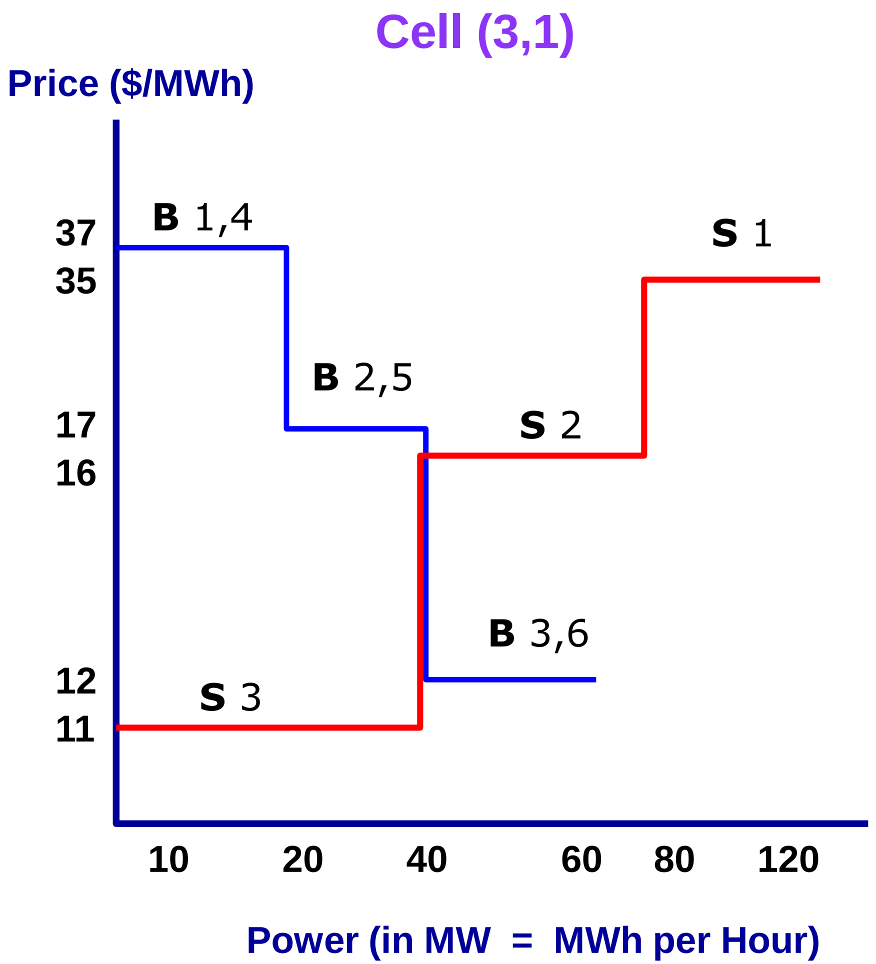
Each Structural Treatment Consists of Four Distinct Market Structural Settings plus **True** Trader Demand and Supply Schedules

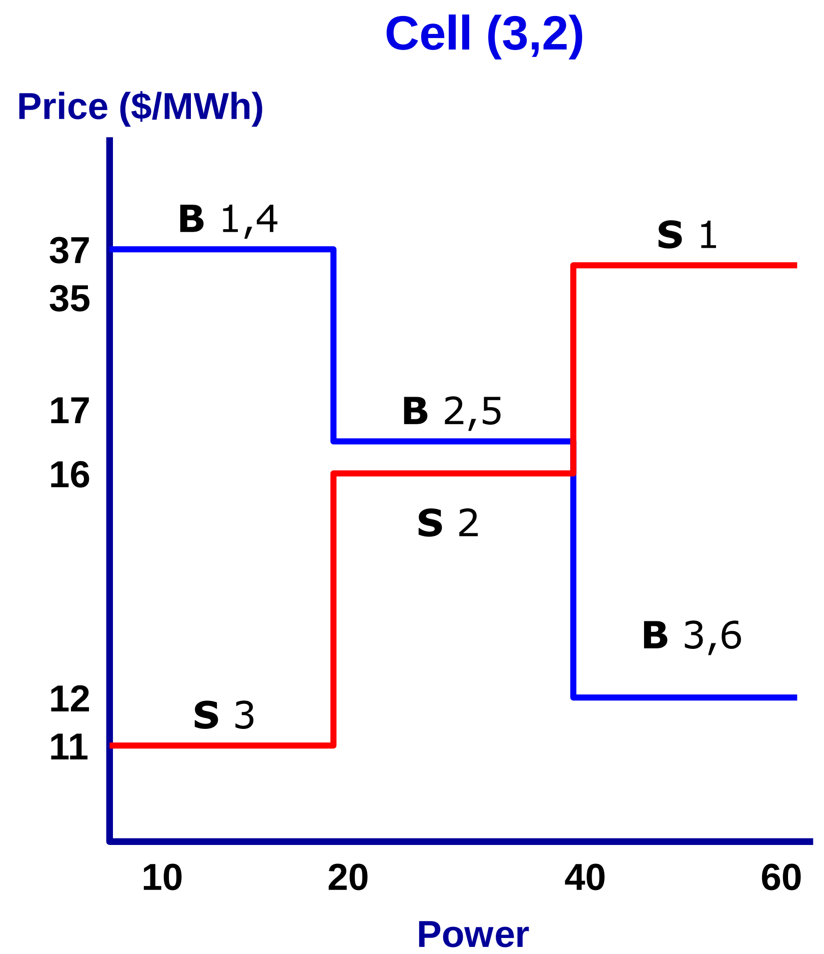
Ns = Number of Sellers
Nb = Number of Buyers
Cs = Seller Supply Capacity
Cb = Buyer Demand Capacity

		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

Cell (3,1) Cell (3,2)

True <u>Aggregate</u> Demand and Supply Schedule Specifications are Illustrated below for Structural Treatments (3,1) and (3,2)





The Double-Auction World Agent

Public Access:

// **Public Methods**

World Event Schedule, i.e., a system clock that permits inhabitants to time and synchronize activities **(submission of asks/bids into the day-ahead 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 and Attributes**

Attributes; **(spatial configuration, ...)**

Sub-agents; **(day-ahead market, traders, ...)**

Stored data.

The Double-Auction Market Agent

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
Protocols governing the public posting of bids/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 and Attributes**

Data recorded about sellers; **(seller offers, ...)**
Data recorded about buyers; **(buyer bids, ...)**
Address book. **(communication links, ...)**

A Double-Auction 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**

Methods for gathering, storing, and sending data;

Methods for calculating expected & actual profit outcomes;

Method for updating my bid/offer strategy. **(learning)**

// **Private Data and Attributes**

Econ data/attributes; **(history, profit function, wealth, ...)**

Data about external world; **(rival trader bids/offers, ...)**

Address book. **(communication links)**

What Do Seller & Buyer Traders Learn?

Strategically Reported Supply Offers and Demand Bids

- **Offer for each Seller i =** ***reported*** supply q_i^S of real power measured in units of Megawatts (MWs) together with a ***reported*** unit price p_i for real power measured in U.S. dollars $ per MW.

- **Bid for each Buyer j** = ***reported*** demand q_j^D (MWs) for real power together with a ***reported*** unit price p_j ($/MW).

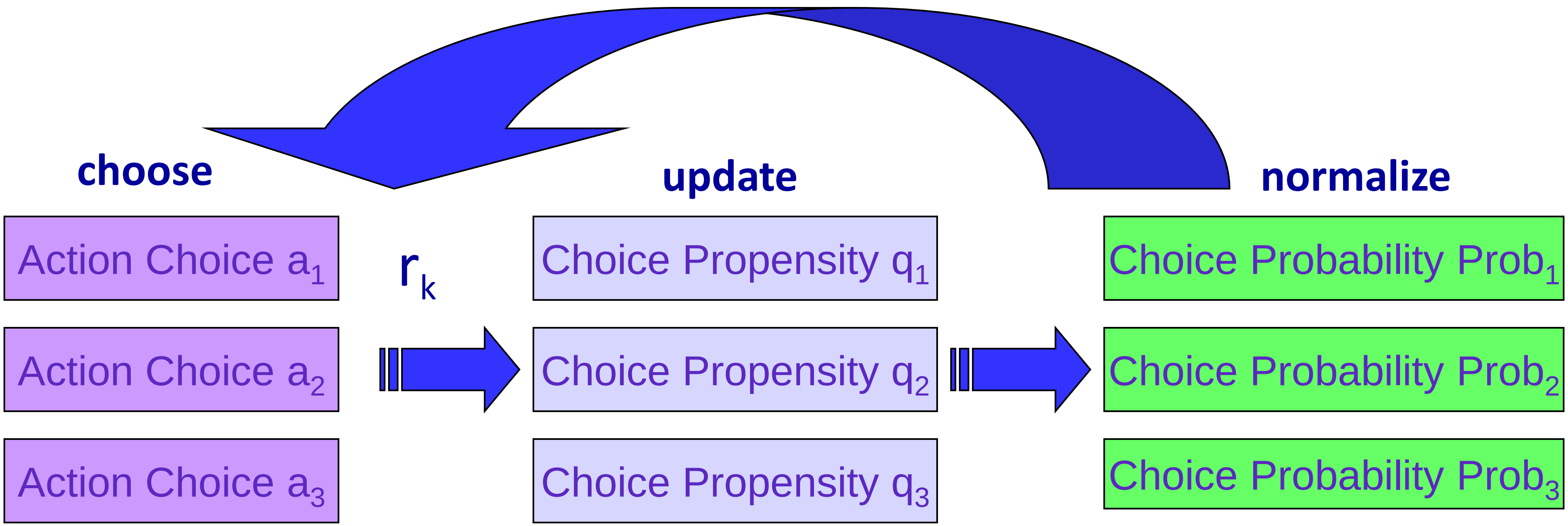
- **Action choice set for sellers** = Their *possible reported offers*

- **Action choice set for buyers** = Their *possible reported bids*

Reactive Reinforcement Method Used for Learning Treatment 1:

MRE Reactive Reinforcement Learning

(MRE = Modified Roth-Erev, see Nicolaisen et al., 2001)



- Each trader maintains action choice propensities q, normalized to action choice probabilities Prob, to choose actions. A good (bad) profit r_k for action a_k results in a strengthening (weakening) of the propensity q_k for a_k and hence in the probability of choosing a_k .

Modified Roth-Erev Reactive Reinforcement Learning (MRE RRL)

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 for the last chosen action.
5. **Repeat** from Step 2.

MRE RRL: Updating of Action Propensities

Parameters:

- $q_j(1)$ Initial propensity
- ϵ Experimentation
- ϕ Recency (forgetting)

Variables:

- a_j Current action choice
- q_j Propensity for action a_j
- a_k Last action chosen
- r_k Reward for action a_k
- t Current time step
- N Number of actions

$$q_j(t+1) = [1-\phi]q_j(t) + E_j(\epsilon, N, k, t)$$

$$E_j(\epsilon, N, k, t) = \begin{cases} r_k(t)[1-\epsilon] & \text{if } j = k \\ q_j(t)\frac{\epsilon}{N-1} & \text{if } j \neq k \end{cases}$$

MRE RRL: From Propensities to Probabilities

$$p_j(t) = \frac{q_j(t)}{\sum_{j=0}^{N-1} q_j(t)}$$

$p_j(t)$ = Probability of choosing action j at time t

N = Number of available actions at each time t

Table of Experimental Results for Learning Treatment 1: MRE Reactive Reinforcement Learning

TABLE VI

EXPERIMENTAL MARKET POWER AND EFFICIENCY OUTCOMES FOR THE BEST FIT MRE ALGORITHM WITH 1000 AUCTION ROUNDS AND PARAMETER VALUES $s(1) = 9.00$, $r = 0.10$, AND $e = 0.20$

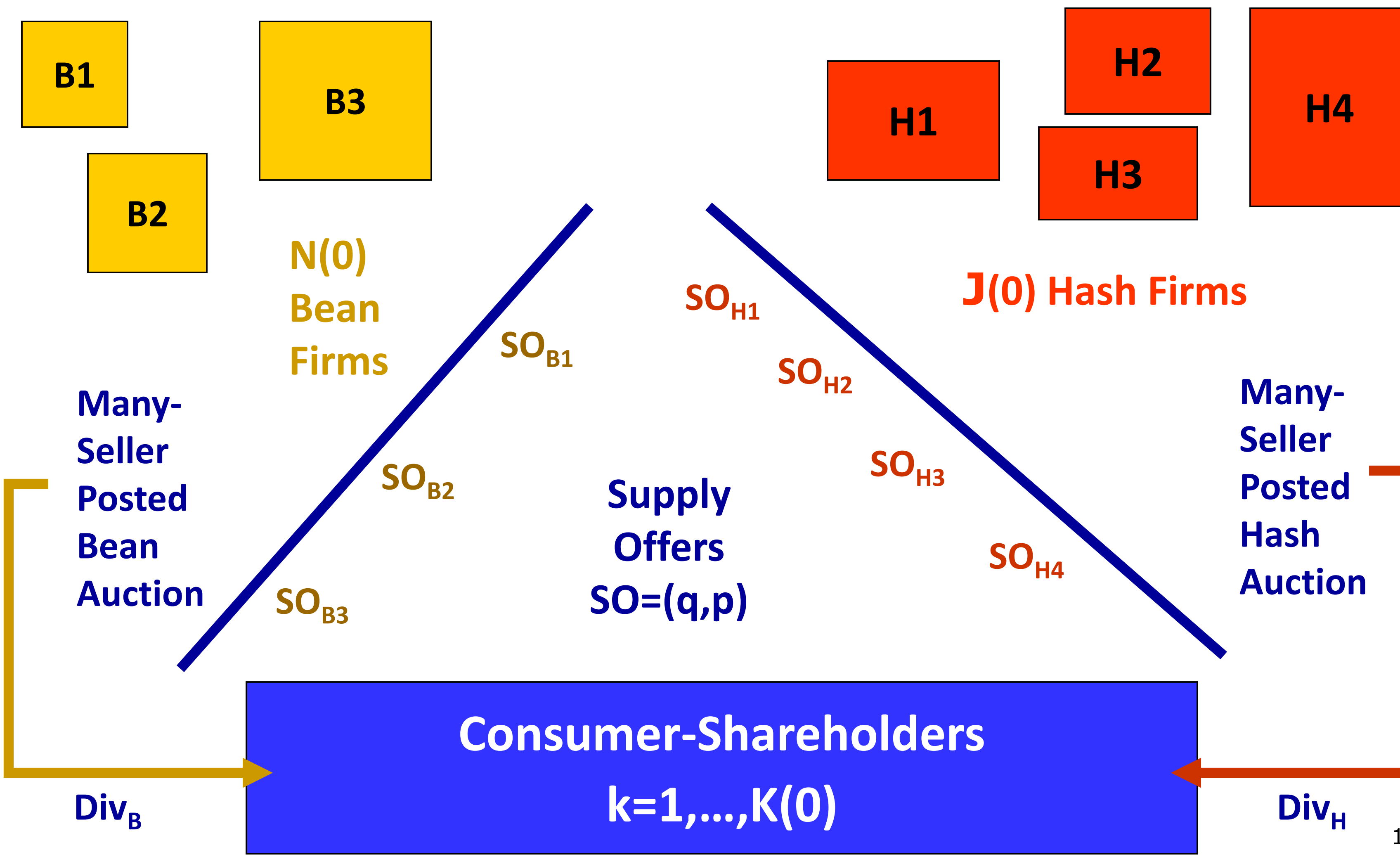
Relative Concentration		Relative Capacity 1/2: MP	1/2: StdDev	Relative Capacity 1: MP	1: StdDev	Relative Capacity 2: MP	2: StdDev
2	All Buyers:	-0.13*	(0.09)	-0.15*	(0.09)	0.10	(0.30)
	All Sellers:	0.55*	(0.38)	0.38*	(0.33)	-0.10	(0.25)
	Buyer[1]:	-0.12*	(0.08)	-0.13*	(0.10)	0.10	(0.30)
	Buyer[2]:	-0.20	(0.40)	-0.75*	(0.33)	ZP	(0.00)
	Buyer[3]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[1]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[2]:	ZP	(0.00)	-0.50	(1.34)	-0.12	(0.34)
	Seller[3]:	0.54	(0.63)	0.45*	(0.40)	-0.10	(0.22)
	Seller[4]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[5]:	ZP	(0.00)	-0.42	(1.67)	-0.08	(0.36)
	Seller[6]:	0.55	(0.60)	0.46*	(0.41)	-0.09	(0.24)
	Efficiency:	99.81	(0.02)	96.30	(0.05)	99.88	(0.06)
1	All Buyers:	-0.22*	(0.12)	-0.13*	(0.10)	0.13	(0.33)
	All Sellers:	0.80*	(0.53)	0.28	(0.35)	-0.10	(0.26)
	Buyer[1]:	-0.21*	(0.11)	-0.11*	(0.10)	0.13	(0.33)
	Buyer[2]:	-0. 31	(0.44)	-0.80*	(0.40)	ZP	(0.00)
	Buyer[3]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[1]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[2]:	ZP	(0.00)	-0.37	(1.89)	-0.10	(0.34)
	Seller[3]:	0.76*	(0.63)	0.34	(0.45)	-0.11	(0.24)
	Efficiency:	92.13	(0.09)	94.59	(0.07)	100.00	(0.00)
1/2	All Buyers:	-0.21*	(0.12)	-0.14*	(0.08)	0.09	(0.24)
	All Sellers:	0.67*	(0.46)	0.30	(0.31)	-0.07	(0.19)
	Buyer[1]:	-0.18*	(0.12)	-0.14*	(0.10)	0.09	(0.27)
	Buyer[2]:	-0.37	(0.47)	-0.77*	(0.44)	ZP	(0.00)
	Buyer[3]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Buyer[4]:	-0.20*	(0.11)	-0.11	(0.11)	0.10	(0.25)
	Buyer[5]:	-0.38	(0.47)	-0.73*	(0.46)	ZP	(0.00)
	Buyer[6]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[1]:	ZP	(0.00)	ZP	(0.00)	ZP	(0.00)
	Seller[2]:	ZP	(0.00)	0.14	(2.69)	-0.08	(0.27)
	Seller[3]:	0.63*	(0.55)	0.32	(0.48)	-0.07	(0.17)
	Efficiency:	91.84	(0.09)	94.24	(0.07)	100.00	(0.00)

ZP indicates that zero profits were earned both in the auction and in competitive equilibrium.

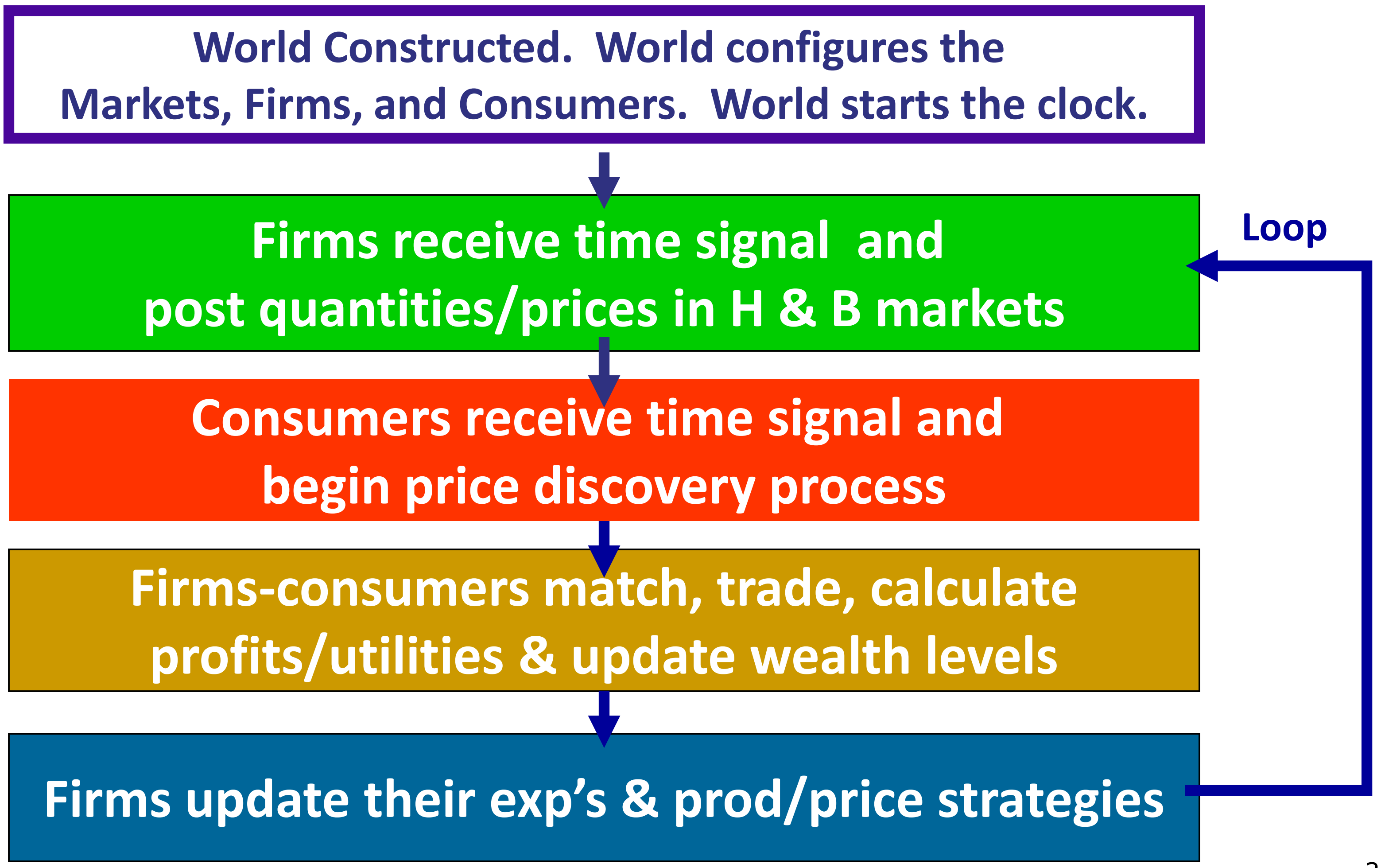
Summary of Policy-Relevant Findings for Example 1: A Double-Auction Market Economy

- **Market Efficiency:** Generally high when traders use MRE-RRL (Modified Roth-Erev Reactive Reinforcement Learning) **but not** when traders use GA (Genetic Algorithm) social mimicry (***type of learning matters***).
- **Structural Market Advantage:** Market microstructure is strongly predictive for the relative market advantage of the seller and buyer traders (***structural aspects matter***).
- **Strategic Market Advantage:** Traders are **not** able to change their relative market advantage through learning alone (***the importance of built-in structural market advantage***).

Example 2: An ACE Posted-Auction Hash-and-Beans Economy



Dynamic Flow of ACE H&B Economy



Dynamic Flow of Activity for H & B Firms

- Each firm f starts out (T=0) with ***money $M_f(0)$*** and a ***production capacity $Cap_f(0)$***
- Firm f's ***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 selects a ***supply offer =: (production level, unit price)***
- At end of $T \geq 0$, firm f is **solvent** if it has a ***NetWorth(T) =: $[Profit(T)+M_f(T)+ValCap_f(T)] \geq 0$***
- If solvent, firm f allocates its ***profits (+ or -)*** between M_f, CAP_f, and dividend payments.

Dynamic Flow of Activity for H&B Consumers

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

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

- In each $T \geq 0$, consumer k's **utility** is measured by

$$U_k(T) = (hash(T) - h_k^*)^{\alpha_k} \bullet (beans(T) - b_k^*)^{[1-\alpha_k]}$$

- In each $T \geq 0$, consumer k seeks to secure maximum utility by **searching** for hash and beans to buy at **lowest possible prices**.

- At end of each $T \geq 0$, consumer k **dies** unless consumption meets ***subsistence needs for hash and beans:***

$$(h_k^*, b_k^*).$$

Experimental Design Treatment Factors

- **Initial size of consumer sector** [K(0)]
- **Initial concentration** [N(0), J(0), Cap(0) values]
- **Firm learning** (supply offers & profit allocations)
- **Firm cost functions**
- **Firm initial money holdings** [$M_f(0)$]
- **Firm rationing protocols** (for excess demand)
- **Consumer price discovery processes**
- **Consumer money endowment profiles**
  (rich, poor, ↗ , ↘ , life cycle u-shape)
- **Consumer preferences** (θ values)
- **Consumer subsistence needs** (b*,h*)

The ACE H&B World Agent

Public Access:

// **Public Methods**

The ***World Event Schedule,*** i.e., a system clock that permits inhabitants to time and synchronize activities; **(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 and Attributes**

Attributes; **(spatial configuration, …)**

Sub-agents; **(H & B markets, firms, consumers, …)**

Stored data.

An ACE H&B 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 and Attributes**
Data recorded about firms; **(sales, ...)**
Data recorded about consumers; **(purchases, ...)**
Address book. **(communication links, ...)**

An ACE H&B 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 my budget constraint;
Method for searching for lowest prices.

// **Private Data and attributes**

My econ data/attributes; **(history, utility function, wealth, …)**
Data about external world; **(posted supply offers, …)**
Address book. **(communication links, …)**

An ACE H&B 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 expected & actual profit outcomes;
Method for allocating my profits to my shareholders;
Method for updating my supply offers. **(Learning)**

// **Private Data**

My econ data/attributes; **(history, profit function, wealth, …)**
Data about external world; **(rivals' posted supply offers, …)**
Address book. **(communication links)**

Interesting Issues for Exploration

- Initial conditions $\longrightarrow$ **carrying capacity ?**
  (Survival of firms/consumers in long run)

- Initial conditions $\longrightarrow$ **market clearing ?**
  (Walrasian equilibrium benchmark)

- Initial conditions $\longrightarrow$ **market efficiency ?**
  (Walrasian equilibrium benchmark)

- Standard concentration measures at T=0 $\longrightarrow$
  good predictors of long-run market advantage ?

- Importance for market performance of **trader learning abilities vs. market structure ?** *(Gode/Sunder, JPE, 1993)*

ACE Hash-and-Beans Economy: Computational Laboratory Implementation

Christopher Cook and Leigh Tesfatsion, **"An Agent-Based Computational Laboratory for the Experimental Study of Complex Economic Systems"**

- Computational laboratory for the ACE Hash-and-Beans Economy
- Programming language C#/.Net (all WinDesktops)
- Development initiated for Econ 308 (ACE course)
  https://www2.econ.iastate.edu/classes/econ308/tesfatsion/
- Superseded by later ACE macroeconomic model developments
  https://www2.econ.iastate.edu/tesfatsi/amulmark.htm

ACE Hash & Beans Economy: Computational Laboratory Main Screen