# Shopbots and Pricebots:

## How will bots affect markets?

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# Economics of Information

## George Stigler [1961]

- price dispersion is attributed to costly search procedures

## Shopbots Today (Yesterday!)

- shopbots specialize in collecting and distributing price information at low cost

## Pricebots Tomorrow (Today!)

- automated agents that set prices in attempt to maximize profits for sellers, just as shopbots seek to minimize costs for buyers

# Overview

## Sellers

- Game-Theoretic Equilibrium
- Strategic Pricebot Dynamics

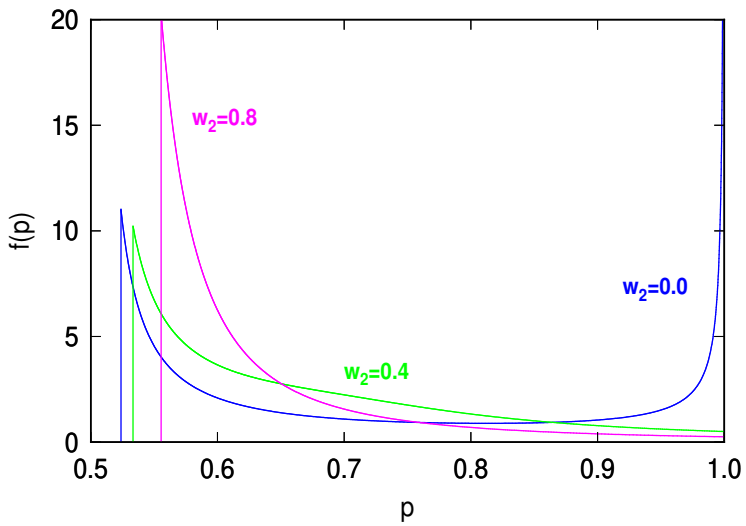
## Buyers

- Game-Theoretic Equilibrium
- Rational Buyer Dynamics

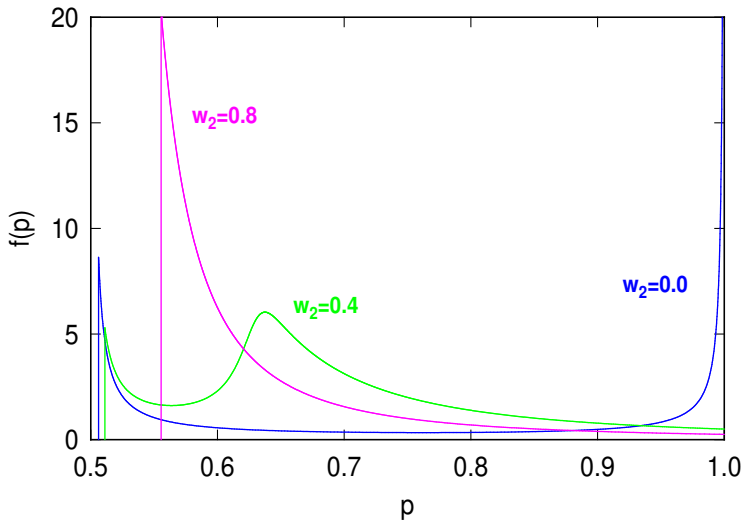
# Game-Theoretic Pricebot Strategy

Mixed strategy Nash equilibrium Rational pricebots choose prices at random according to probability distribution.

5 pricebots, $w_1 = 0.2$, $w_2 + w_5 = 0.8$.




20 pricebots, $w_1 = 0.2$, $w_2 + w_{20} = 0.8$.

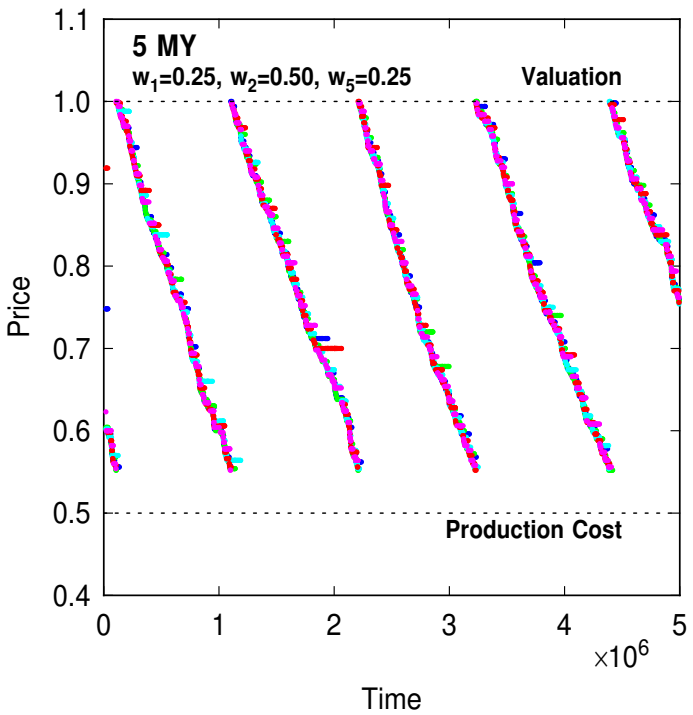


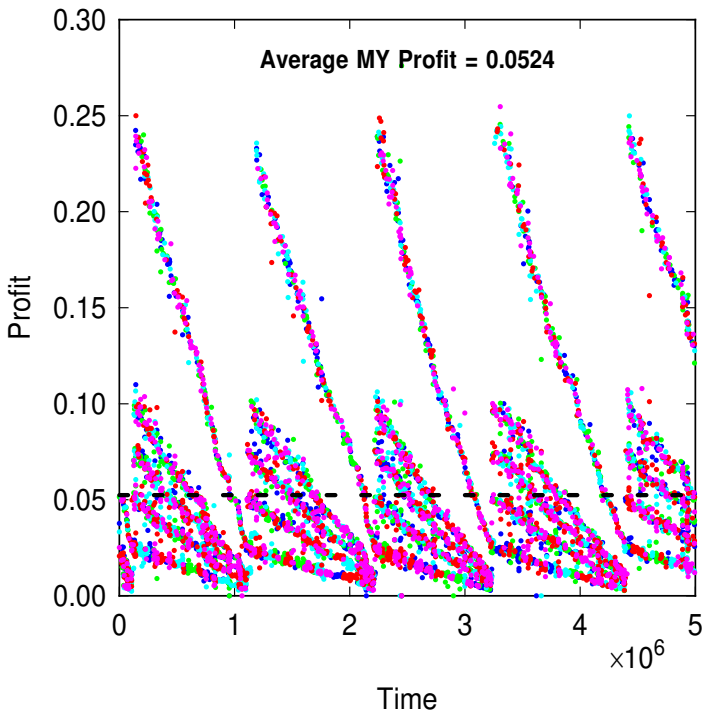

Do adaptive (not necessarily rational) pricebots learn game-theoretic equilibrium of stage game over repeated plays?

# Informed, Adaptive Pricebot Strategy

Myopically-optimal (MY) Strategy Rational best-response to others' current prices, given buyer demand function

5 MY Pricebots . . .



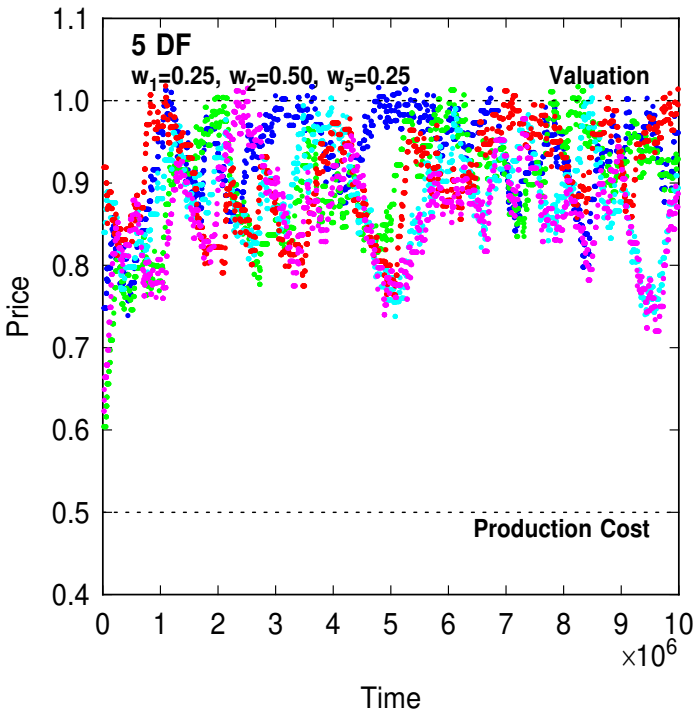



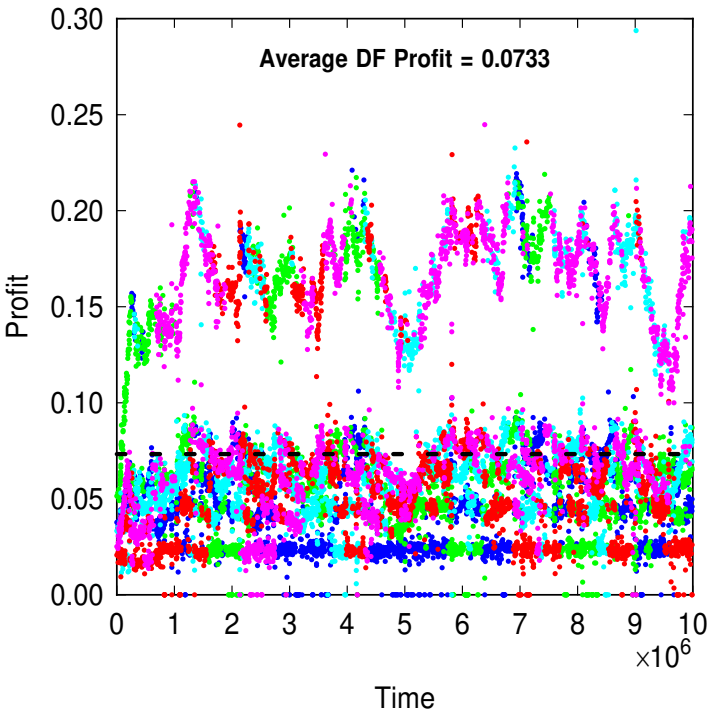

- MY profits (0.0524) more than twice GT profits (0.025);
- but instabilities in the form of cyclical price wars arise;
- and MY pricebot requires knowledge of buyer demand and other sellers' prices, which may be costly to obtain.

# Naive, Adaptive Pricebot Strategy

Derivative-following (DF) Strategy Adjust price in same direction as long as profit increases; otherwise reverse the direction of price adjustment.

5 DF Pricebots . . .

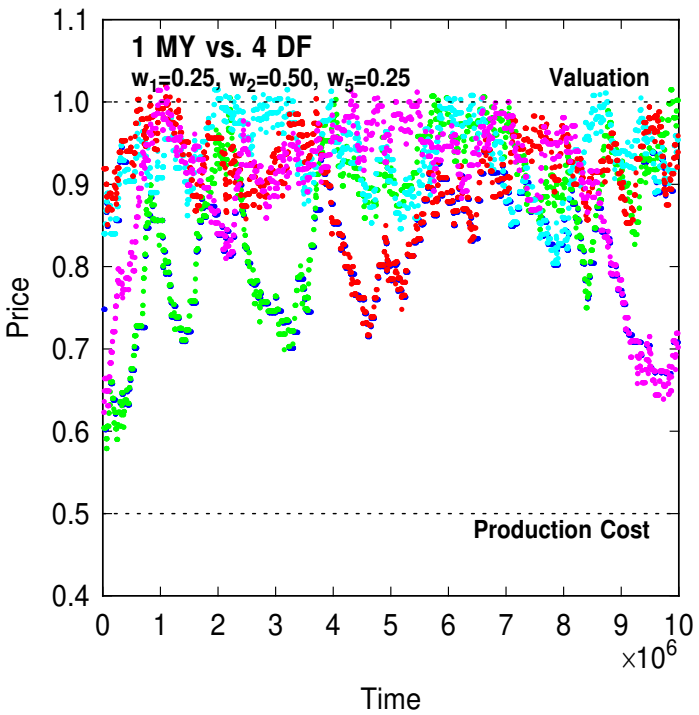


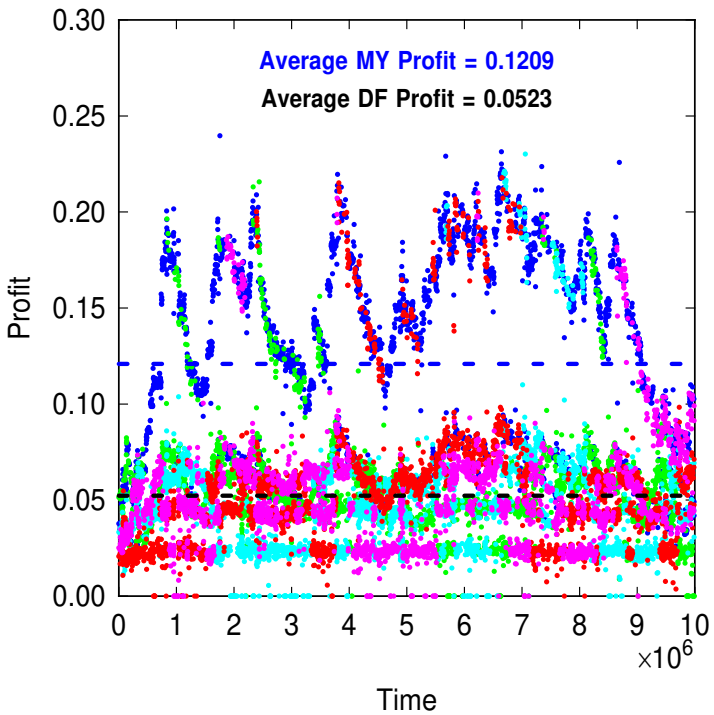




- Tacit collusion results: *i.e.*, an effective cartel despite no actual communication!
- Average profit is nearly 3 times that of GT pricebots. Perfect cartel would achieve profit of 0.1 per pricebot.
- Requires no knowledge of sellers' prices or buyer demand; price-setting mechanism based on historical observations.

# Informed vs. Naive Pricebots

Introduce 1 MY pricebot into group of 4 DF pricebots . . .



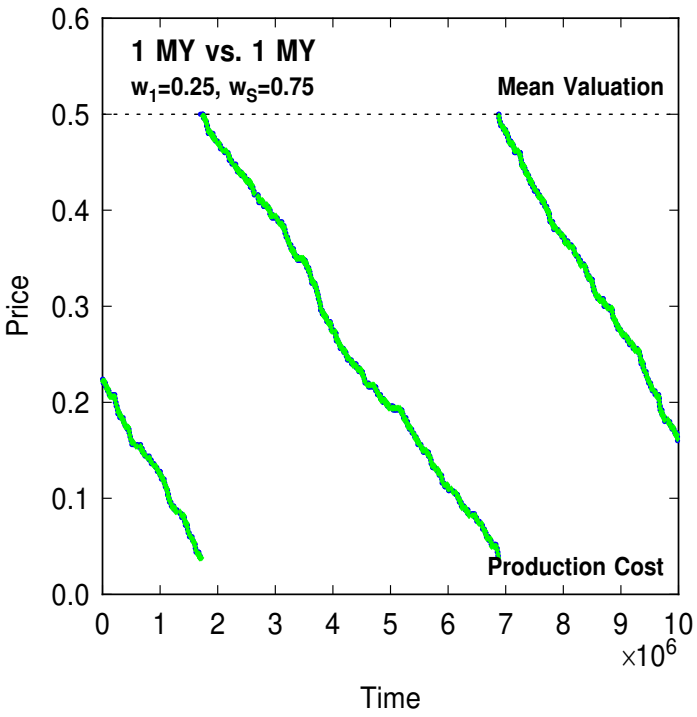




. . . and it will exploit them mercilessly, stealing their profits, earning more than twice (0.121) what they do (0.052)!

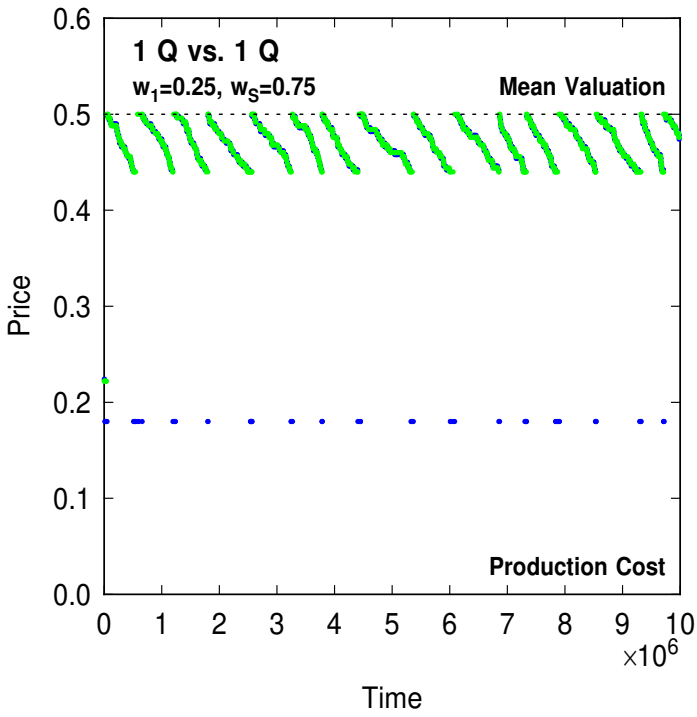
# Q-Learning Pricebots

Watkins, 1989 Reinforcement Learning Scheme

2 MY Pricebots . . .




2 Q Pricebots . . .

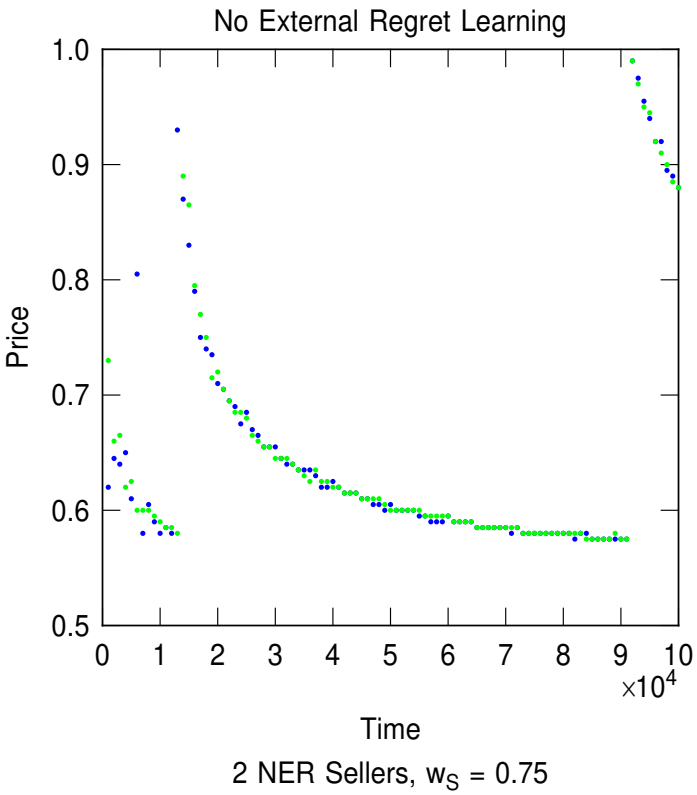



- Q pricebots detect and abandon price wars early on
- Q profits (0.125, 0.117) exceed MY profits (0.089, 0.089)

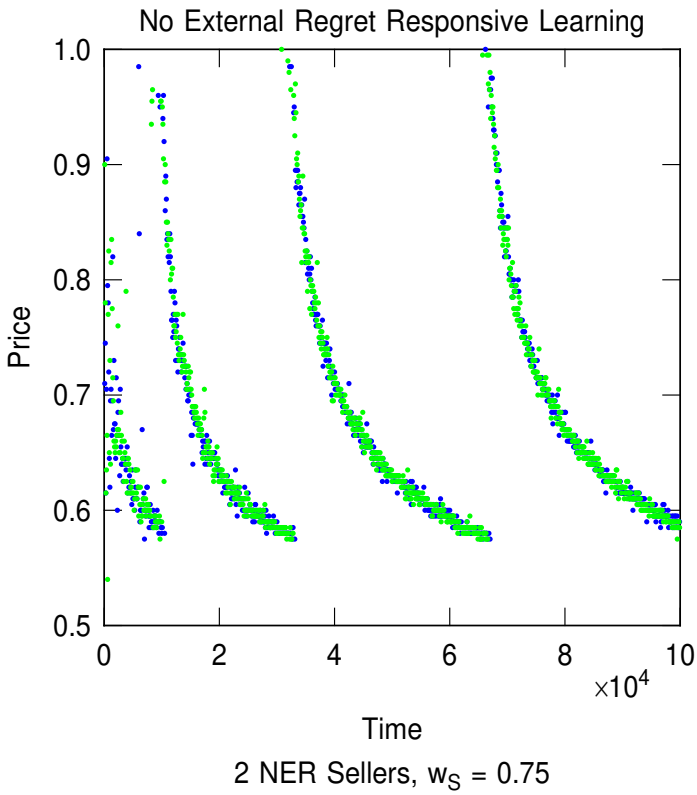
# No External Regret Pricebots

Freund and Schapire, 1995 Probabilistic Updating Scheme

2 NER Pricebots . . .




2 NER Sellers, $w_S = 0.75$



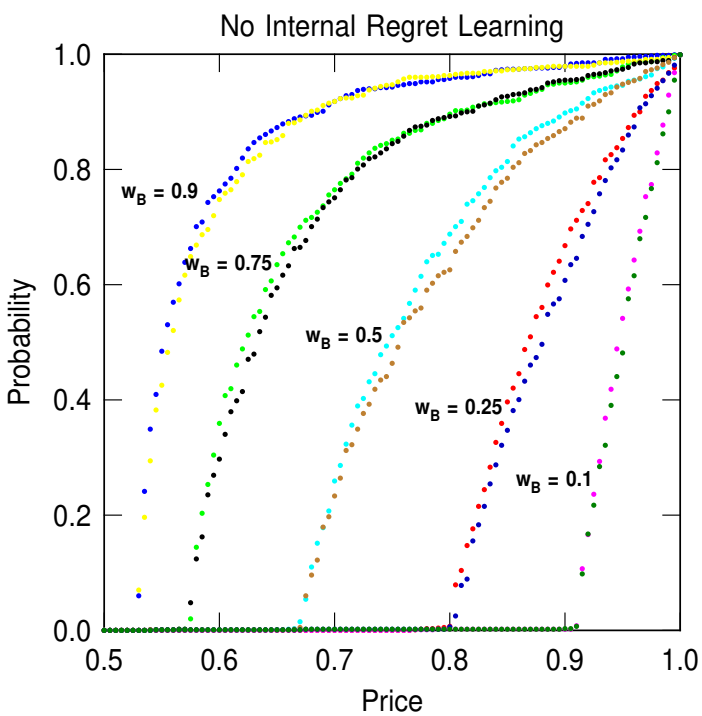

2 NER Sellers, $w_S = 0.75$

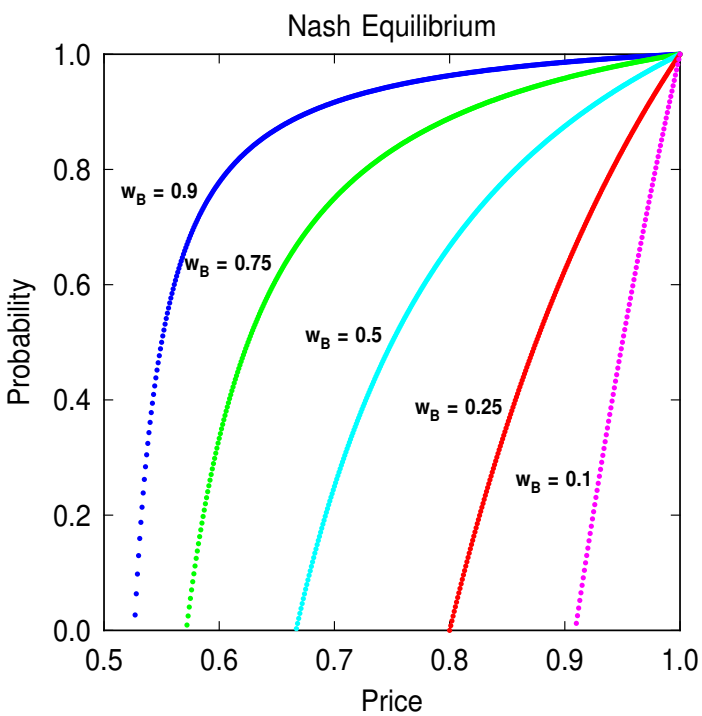
- NER pricebots cycle through prices exponentially
- responsive NER pricebots engage in limited price wars

# No Internal Regret Pricebots

Foster and Vohra, 1997 Converge to Correlated Equilibrium

2 NIR Pricebots . . .



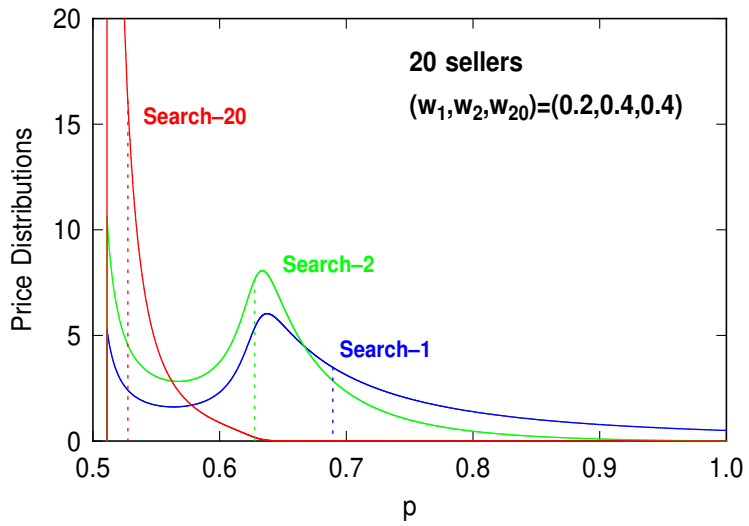




. . . learn Nash equilibrium!

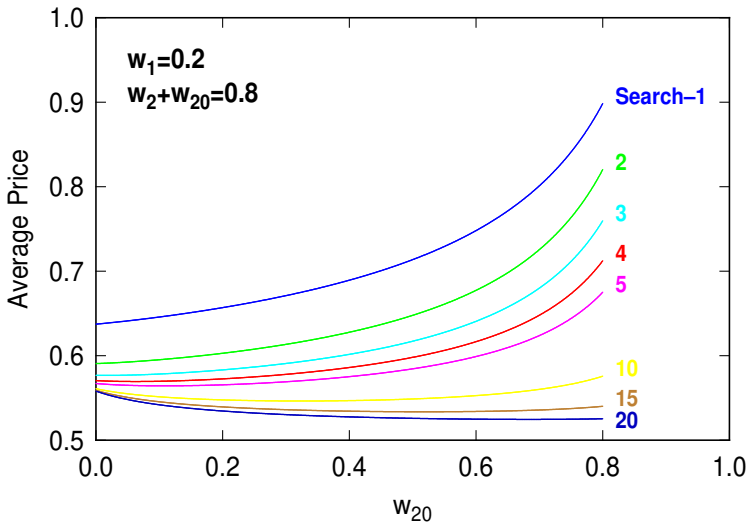
# Rational Buyer Strategy

Total Buyer Expenditure = Expected Price + Search Costs

Buyer Price Distributions




Average Buyer Prices

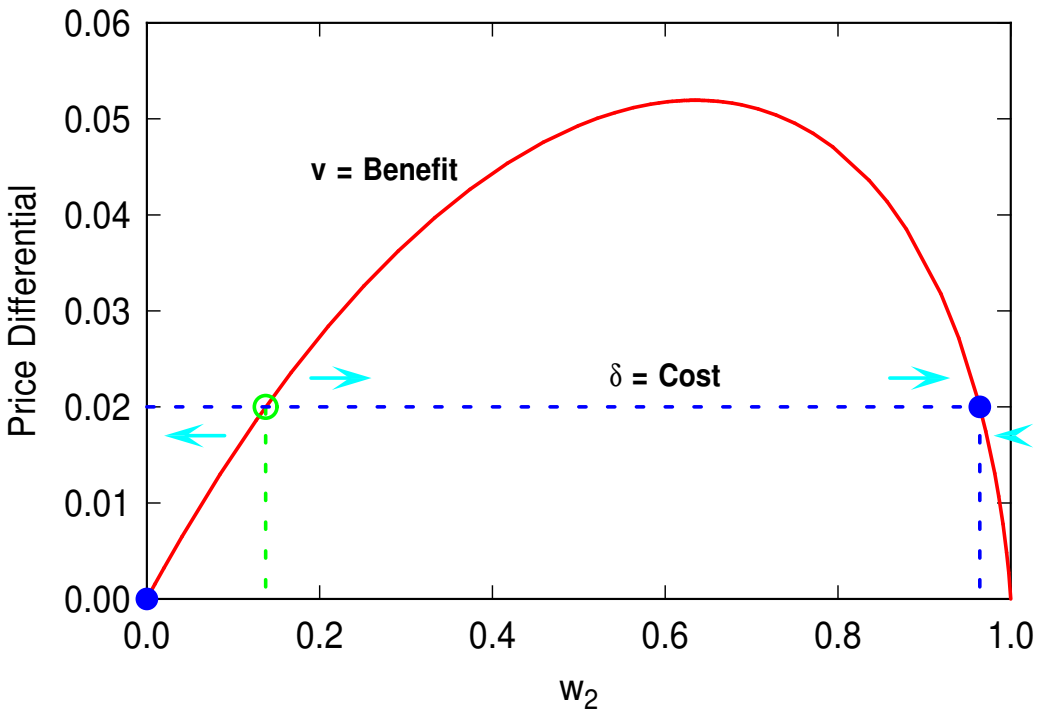



Value of Information = Willingness to Pay = Price Differential

# Game-Theoretic Equilibrium

One unstable and two stable game-theoretic equilibria.

Marginal Cost-Benefit Analysis




Burdett and Judd, 1983 Linear search costs yield $w_1 + w_2 = 1$.

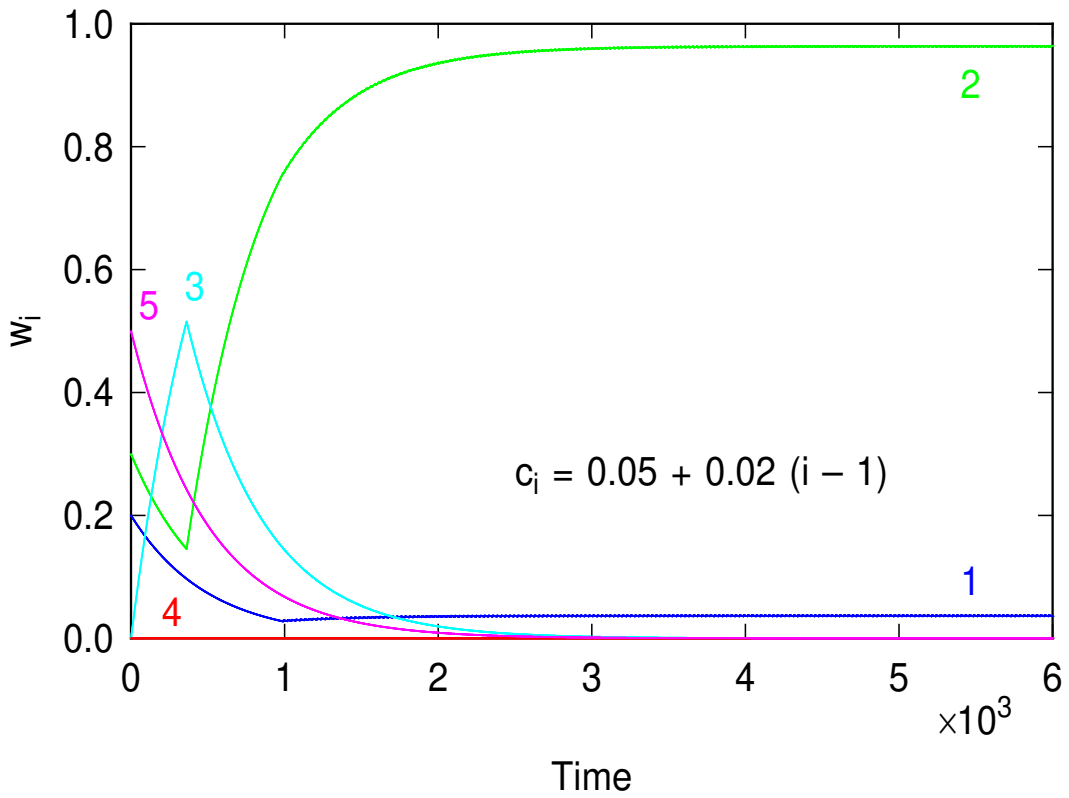
# Adaptive Buyer Strategy

At each time $t$

1. Small fraction of buyers switch from their present search strategy to current optimum.

2. Sellers compute new game-theoretic pricing strategy.

Linear Search Costs

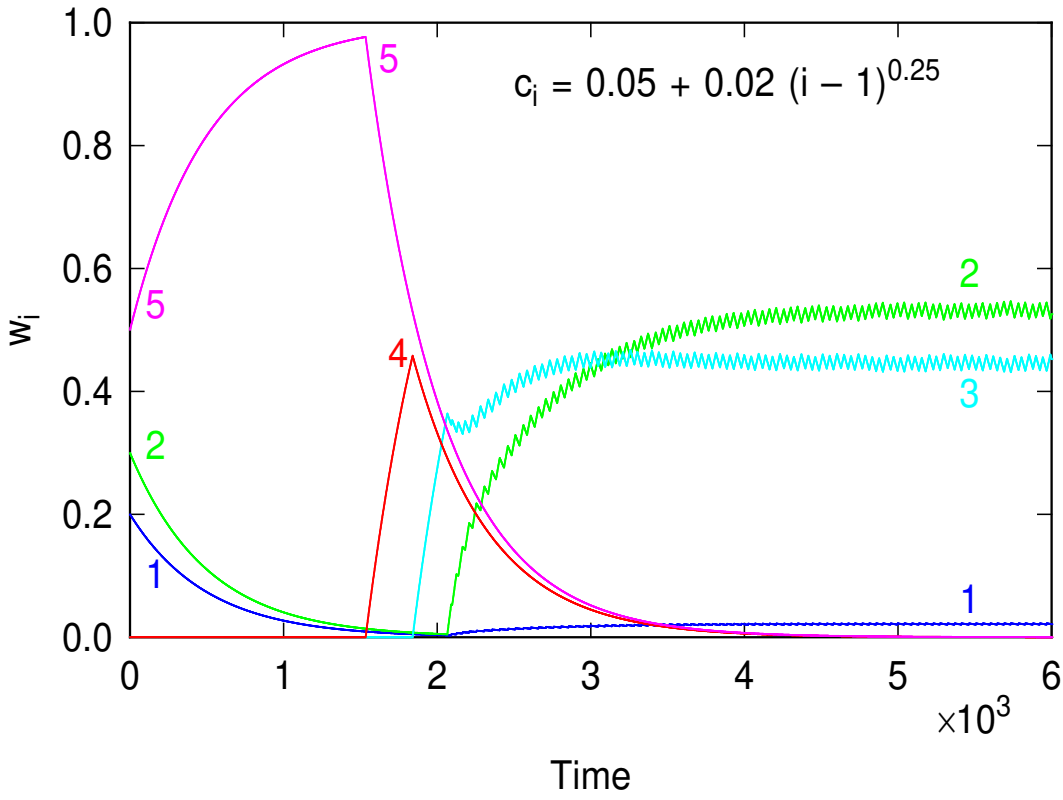



Initial state: $(w_1, w_2, w_5) = (0.2000, 0.4000, 0.4000)$.
Final state: $(w_1, w_2, w_5) = (0.0141, 0.9859, 0.0000)$.

# Adaptive Buyer Strategy

Shopbots drastically lower search costs Assume costs are nonlinear in the number of searches.

Nonlinear Search Costs



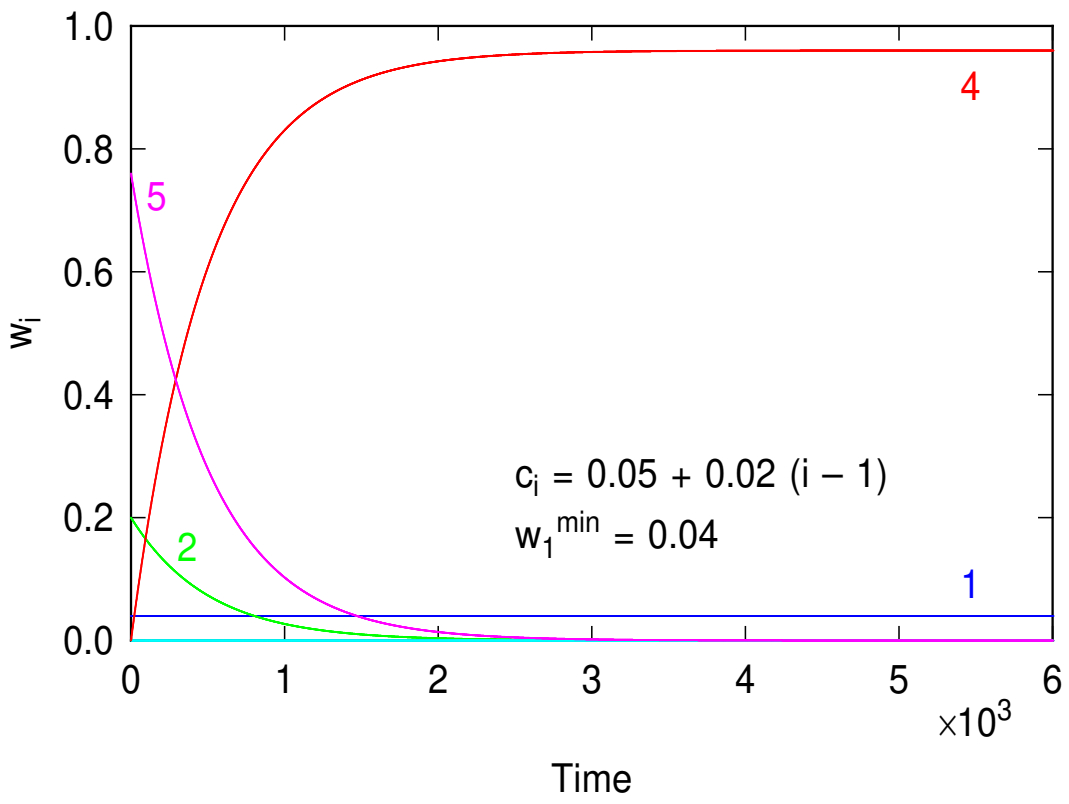

Initial state: $= (0.200, 0.300, 0.000, 0.000, 0.500).$
Final state: $= (0.020, 0.550, 0.430, 0.000, 0.000).$

Nonlinear search costs can yield more complex, even chaotic, mixtures of strategies.

# Fixed + Adaptive Buyers

Suppose small fraction of buyers fixate on search-1, regardless of what strategy is optimal, while other buyers adapt.

4% Fixed Search-1 Buyers




Initial state: $= (0.040, 0.200, 0.000, 0.000, 0.760).$
Final state: $= (0.040, 0.000, 0.000, 0.960, 0.000).$

Mixture of fixed and adaptive buyer behavior can lead to strategies other than just search-2 co-existing with search-1.

# Future Work

- Study dynamics of adaptive buyers and sellers
- Investigate strategic interplay of shopbot pricing
- Dynamic pricing of price and product information in full-fledged economy of software agents, consisting of buyers, sellers, and economically motivated shopbots

Shopbot Economics forms part of the Information Economies project at IBM Research Institute for Advanced Commerce. The project goal is to:

> accurately describe and predict collective interactions of billions of economically motivated software agents, and use insights so gained to design agent strategies, protocols, and infrastructures.

Project description and research papers available at:

**www.research.ibm.com/infoecon**