Explainability and Algorithmic Pricing

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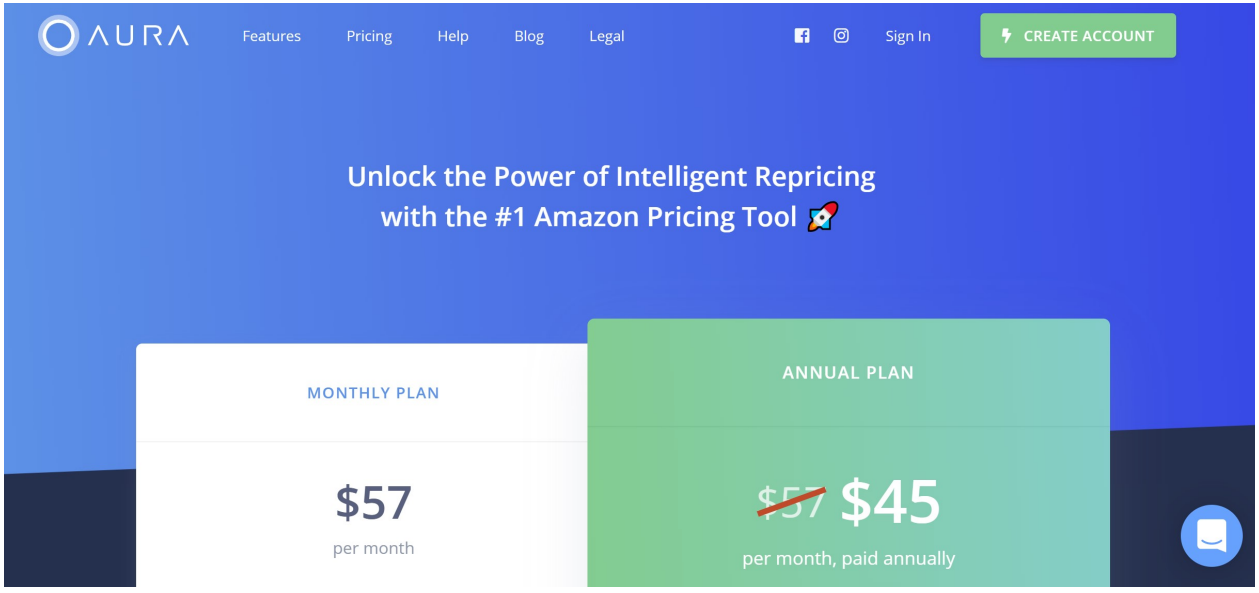
Explainability e mercati?

- Un esempio dell'importanza di Explainability quando AI viene impiegata nei mercati
- basato su ricerca "Algorithmic Pricing and Collusion" with E. Calvano, V. Denicoló, S. Pastorello (UNIBO)

Pricing algorithms are populating markets

- Sellers are increasingly adopting algorithms to price their goods and services, examples:
  - AMAZON: more than 30% of sellers on Amazon mktplace use algorithmic pricing (2014, Chen et al. 2016)
  - Many gas stations in north Europe use AI (real time) pricing algos
  - Financial markets and algorithmic trading

- Why? Algos are much more effective than humans: more flexible and faster in adapting to market conditions
- Large efficiency gains for all, sellers and buyers, in principle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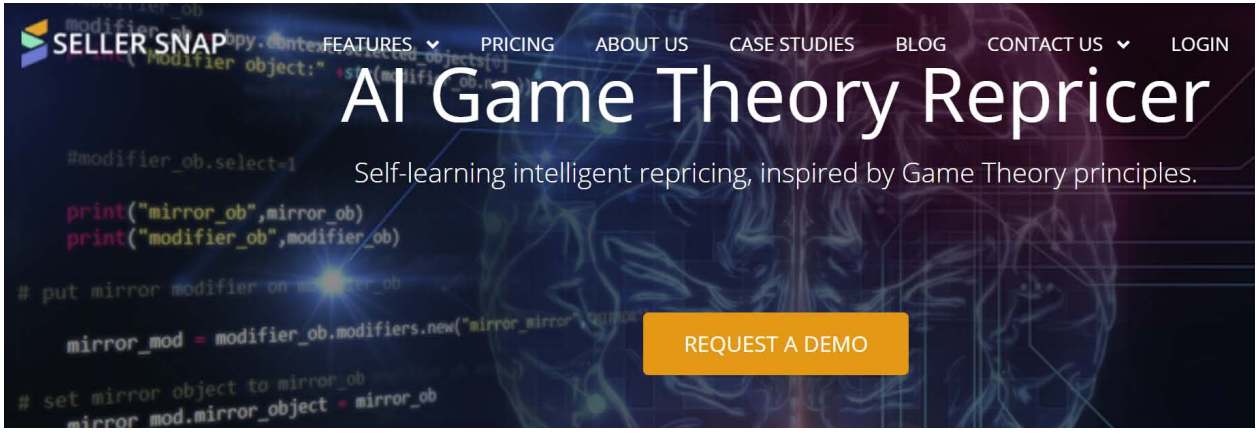
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TECH

Why Do Gas Station Prices Constantly Change? Blame the Algorithm

Retailers are using artificial-intelligence software to set optimal prices, testing textbook theories of competition; antitrust officials worry such systems raise prices for consumers

- Widespread adoption of pricing algos in Danish and German retail gasoline markets

What is new?

- Algorithmic pricing not new (since '80s e.g. hotels, airlines and financial markets)
  These algos were are **fixed rules**: that is a set of pre-specified instructions (possibly very rich)

- Advancements in the field of AI spun a new class of algos where:
  - Programmers just specify an aim (e.g. maximize profits) & which data to use
  - New AI-algos then autonomously **learn from experience** what to do and **how to behave**

- What autonomous AI-powered algos will learn to do in markets? First an interlude...

Collusion: a renown problem in markets

- **Definition of Collusion**: managers of otherwise competing firms agree to sell at high prices ("price fixing")
- It typically relies on threats of punishment so that managers have no incentive to reduce prices
- It negates the competitive pressure that can make markets efficient (low prices for consumers, incentives to innovate etc.)

- Hence, collusion among firms is universally forbidden: hurts consumers (high price) and market efficiency

- Collusion among managers takes place, although difficult to put in place
- How authorities fight collusion?

Fighting collusion

- In theory: any agreement on prices, even if **implicit** (just "meeting of minds"), is forbidden and sanctioned
- In practice:
  - sanctioning presumed implicit agreements may run into many false positive and over-enforcement
  - to avoid this, in practice, only **explicit cartels** are sanctioned, when managers are caught writing emails, making phone calls...

Hard evidence of price fixing

- But what about if collusion is obtained by autonomous algorithms? A movie fantasy?

Research on AI-pricing algorithms

- We built synthetic but realistic markets: buyers (choosing the best deal available in the market) and sellers-algos
- We run experiments/simulations with AI-powered pricing-algos
- We studied the learned behavior of AI-pricing algos

- Note: interaction between AI learning algos

What type of AI?

AI? Reinforcement Learning algorithms

Consider a pricing-algo,

- that, repeatedly over time sets the price of "its" product (p_t^i)
- aiming to maximize the discounted sum of profits over time ($\sum_{t=0}^{T} \delta^t E[\pi_t]$)

At any period, the Reinforcement Learning (Q-Learning) algo:

1. chooses the price deciding with randomization if to **"exploit"** the market-environment (i.e. setting a price currently considered optimal) or to **explore** the environment (i.e. setting some random suboptimal price)
2. **learns** from experience observing own profits and competitors' prices in that period

Reinforcement Q-Learning algorithm

Store the (present-discounted) value of using price p when market is in 'state' s into $Q_t(p, s)$. Then $\forall t$:

1. Set price: with prob ε (uniformly) randomize (EXPLORATION); with prob. $1 - \varepsilon$ choose 'greedy price' for current state s, i.e.

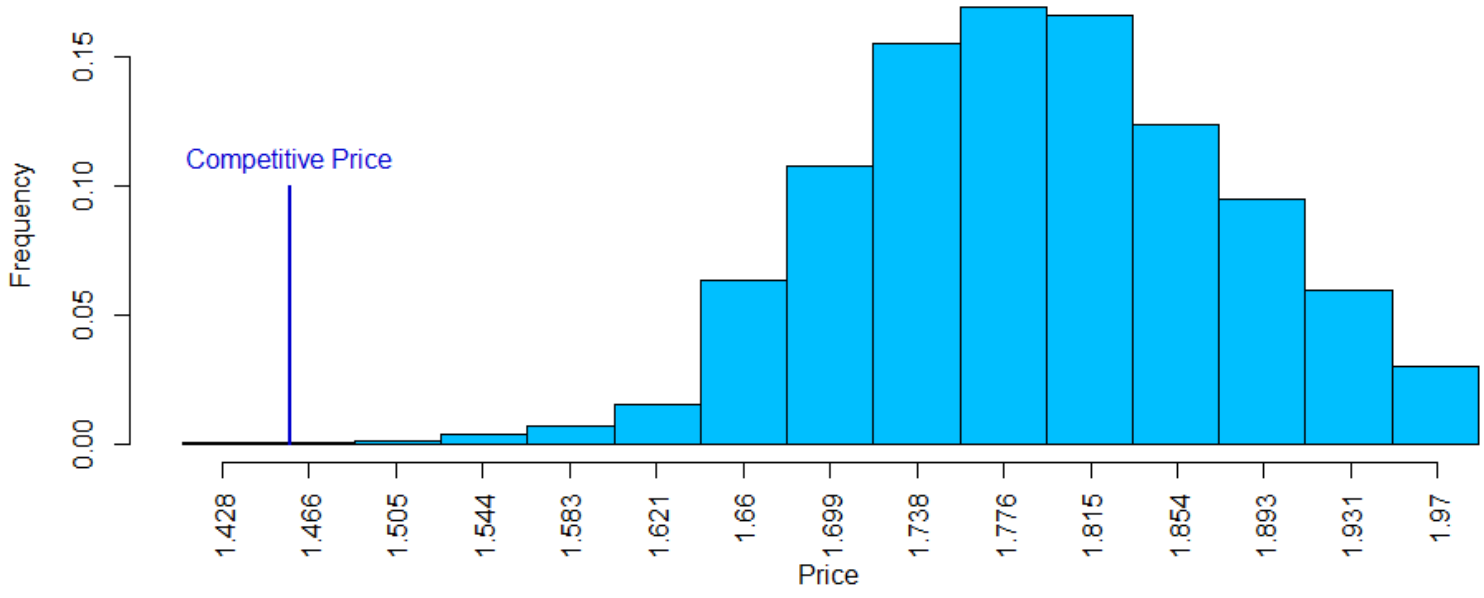
$$\arg\max_p Q_t(p, s),$$

2. Observe realized profit π_t and new state s', then update the Q (LEARNING):

$$Q_{t+1}(p, s) = (1 - \alpha) Q_t(p, s) + \alpha \left(\pi_t + \delta \max_{p'} Q_t(p', s') \right) \quad (1)$$

.

Result 1: Algos learn to charge high Prices



Price distribution (many sessions, for given hyper-parameters)

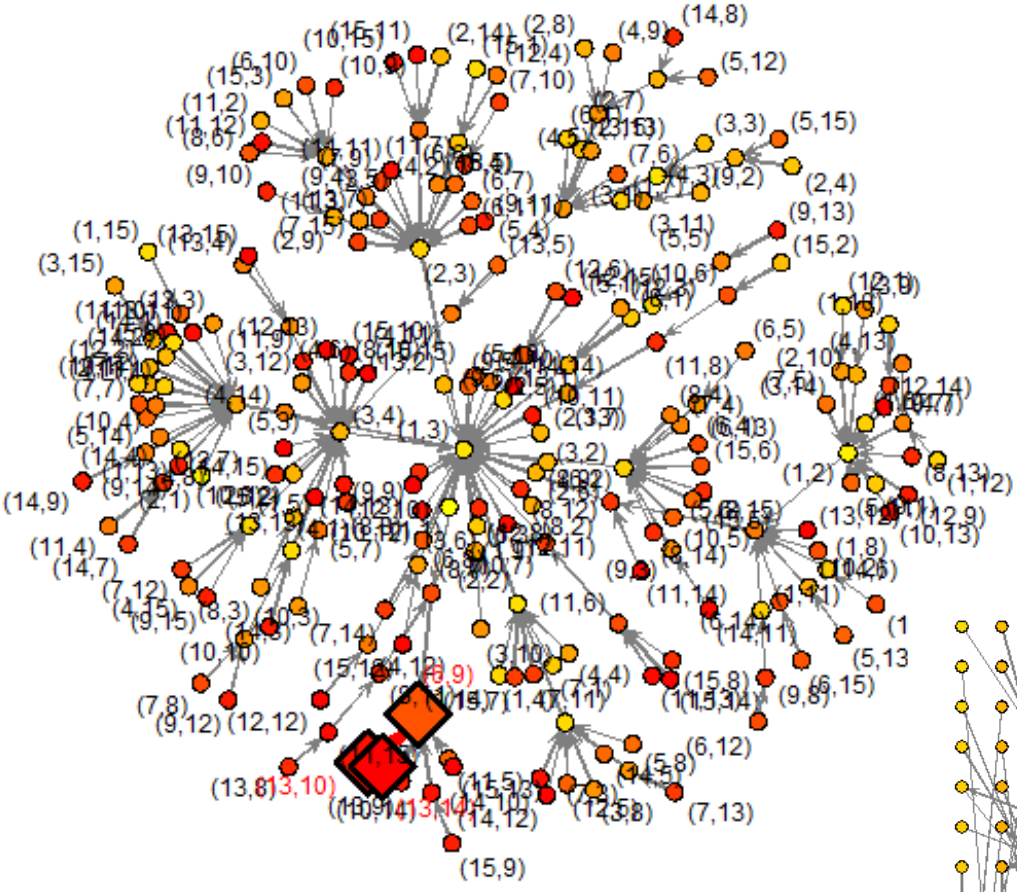
How are supra-competitive prices supported?

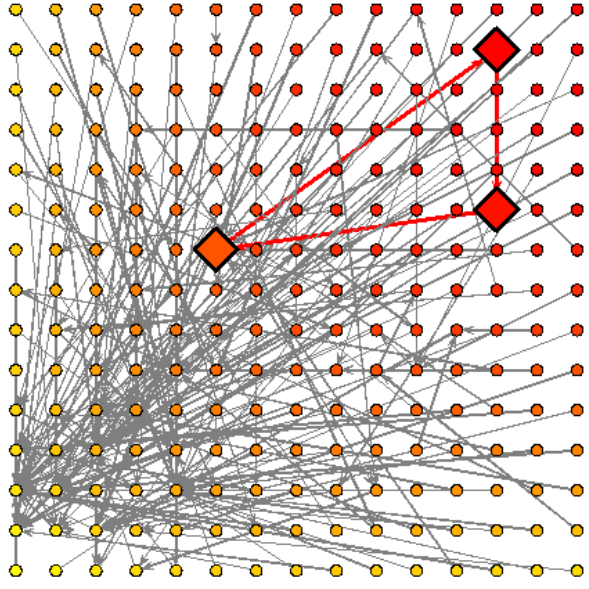
- Since algos are pricing high, why one of them doesn't undercut thus gaining all consumers?
- Do algos **fail to learn** to compete? Or...

- Answering this question is key for Policy implications: if it is just failing to learn we can go home ...

- To answer, need to open up the AI-algos and look inside
- What is the learnt mapping: from past-period prices to current price?

Looking inside the AI-algos?

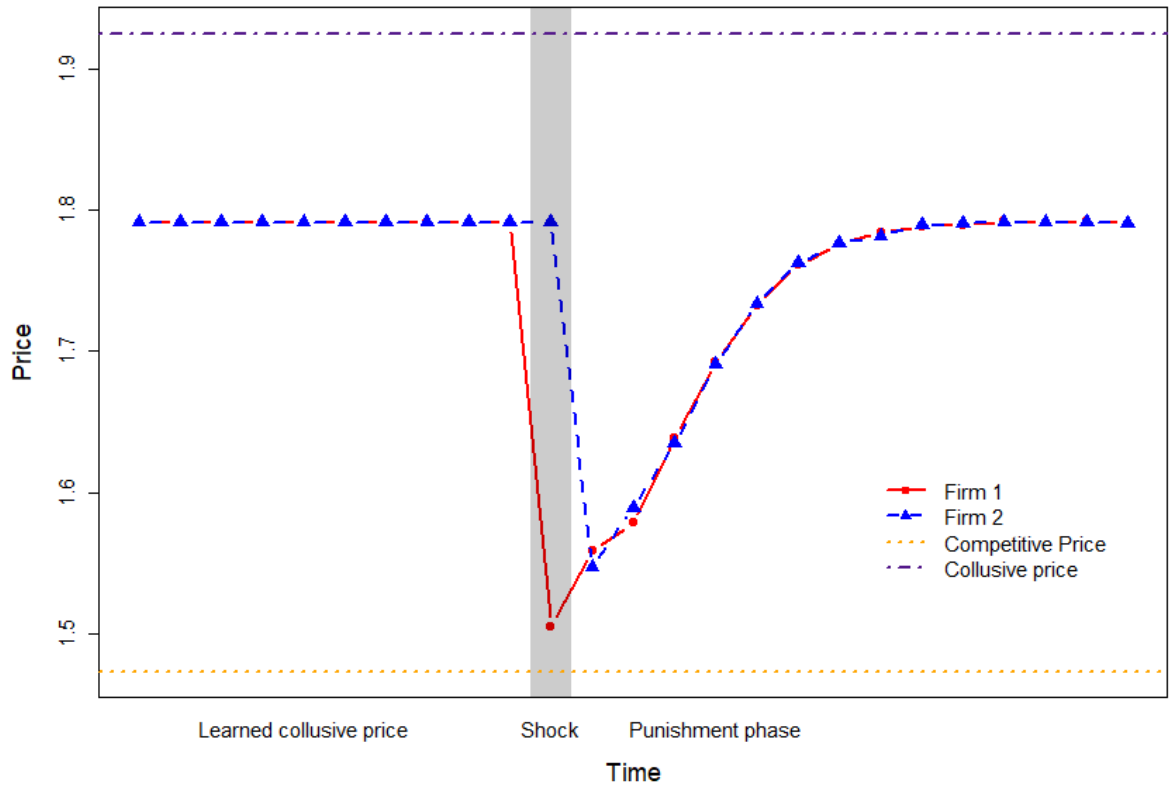




Not too informative... a
problem of Explainability!
What to do?

Result 2: Algos learn to collude

- We force algo 1 (Red) to reduce its price (just one period)
- And check their behavior (auditing)



Reward-Punishment-Forgiveness autonomously learnt: with this sophisticated strategy none of the algos has incentive cut price!

Algorithmic collusion

- Pricing algos *autonomously learn* to collude
- They learn to collude with no need to explicit communication, thus *no hard evidence*
- Hence currently not identifiable, and not sanctionable!

- How to fight algorithmic collusion?

Fighting algorithmic collusion: problems

Dealing with autonomously colluding algos

- Can we just decide that prices are too high? NO aka regulation and need a lot of information
- Can we claim algos have "intent" to collude? NO (unless algos as conscious machines...)
- Can we look inside the algo and see what it learned? NO, even with our simple algos
- Solution could be making AI-pricing algos Explainable for Competition Policy...

Fighting algorithmic collusion: Explainability

Can we Explain in real markets why algos charge high prices?

- Can we impose "white-box"? Seems impractical in markets
- Audit for causality of behavior (post-hoc)
  - virtual markets where testing algos
  - looking for reward-punishment as cause
  - we did it, but we were in the best condition (we created the market)
  - in general, difficult to distinguish competition from collusion
- Making AI-pricing algos Explainable for Competition Policy?
- Best case for interdisciplinary policy-relevant research