Algorithmic pricing, Artificial Intelligence and the intensity of competition

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Pricing algorithms and economic analysis

- Pricing algorithms are populating markets and it is not a temporary phenomenon
- From Expert systems to modern self-learning algorithms
- Pricing algorithms are a source of efficiency and of concerns

- Exploring recent developments in the economic analysis:
  - Experiments
  - Empirical analysis
  - (some) policy implications

Autonomous algorithms: why now and what is new?

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

- Advancements in AI spun a new class of algos where programmers just specify:
  1. the aim (e.g. maximize profits)
  2. what data to monitor (e.g. prices, inventories)
  3. how to explore the environment
- Then the algos **autonomously learn from experience**, interacting with the environment, how to behave (strategies)

Some recent papers

1. (P) Protecting consumers from collusive prices due to AI, with E. Calvano, V. Denicolò, J. Harrington, S. Pastorello. Nov 27, 2020, SCIENCE.
2. (E) Algorithmic Collusion with Imperfect Monitoring, with E. Calvano, V. Denicolò, S. Pastorello, INTERNATIONAL JOURNAL OF INDUSTRIAL ORGANIZATION 2021
3. (E) Artificial intelligence, algorithmic pricing and collusion, with E. Calvano, V. Denicolò, S. Pastorello. AMERICAN ECONOMIC REVIEW, 2020
4. (S) Algorithmic Pricing: What Implications for Competition Policy? with E. Calvano, V. Denicolò, S. Pastorello, REVIEW OF INDUSTRIAL ORGANIZATION 2019
5. (S) Autonomous algorithmic collusion: Economic research and policy implications, with S Assad, E Calvano, R Clark, V Denicolò, D Ershov, J Johnson, S Pastorello, A Rhodes, L Xu, M Wildenbeest, OXFORD REVIEW OF ECONOMC POLICY 2021

Experiments with simulations

Simulations

- Pros: all elements of economic environment and algos are under control and very flexible
- Cons: must be realistic (markets and algos)

Approach

- Run numerous experiments in realistic synthetic markets: buyers (choosing the best deals) and seller-algos
- Sellers use Reinforcement Learning algos: key algorithm in unsupervised learning AI
- Let algorithms autonomously learn their strategy
- After learning took place, we study what happened in the market and the learnt strategies

AI? Reinforcement Learning

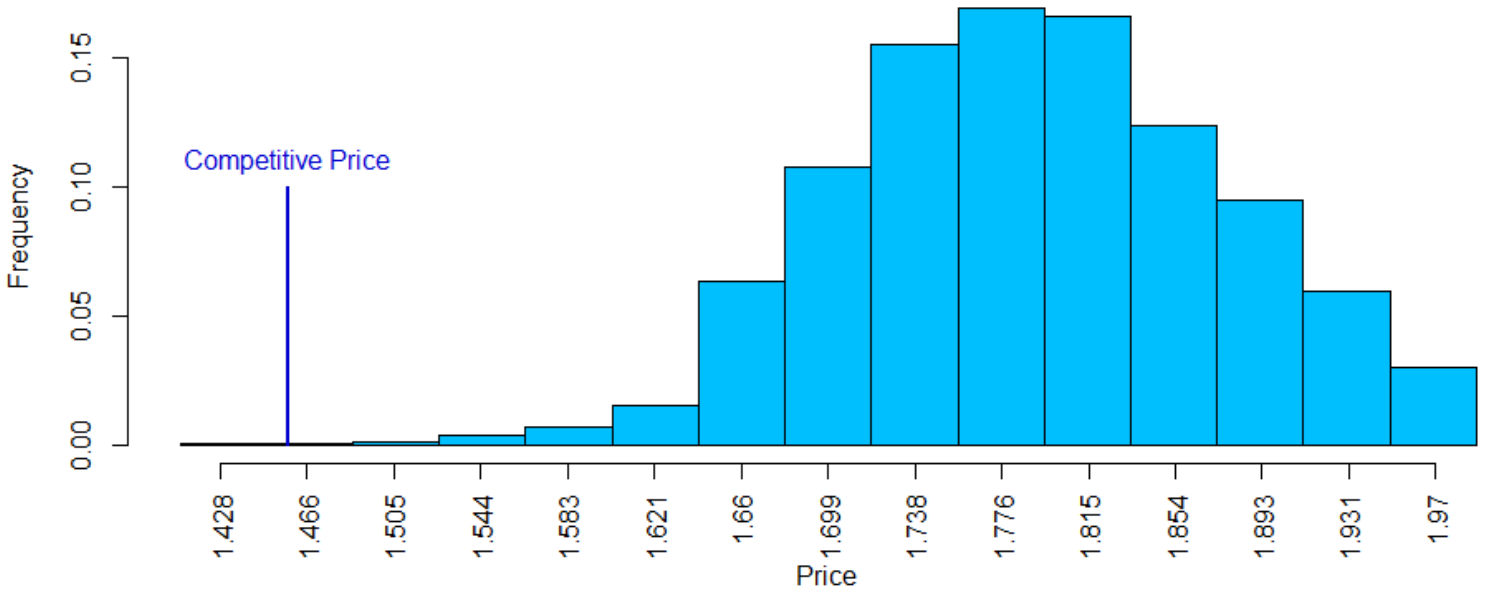
- Consider a pricing-algo aiming to maximize the (expected) discounted sum of profits over time

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

  1. chooses the price with a randomization:
     - with a given probability, it decides to **exploit** the market-environment: set the currently optimal price
     - with complementary probability, it **explores** the environment: set a price randomly chosen among all possible prices
  2. then it **learns** from experience:
     - observes realized own profits and competitors' prices
     - stores this informatiom, updating the currently optimal price
  3. [begin a new period]

- It is learning by trial-and-error

Result: Algos learn to charge high Prices



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

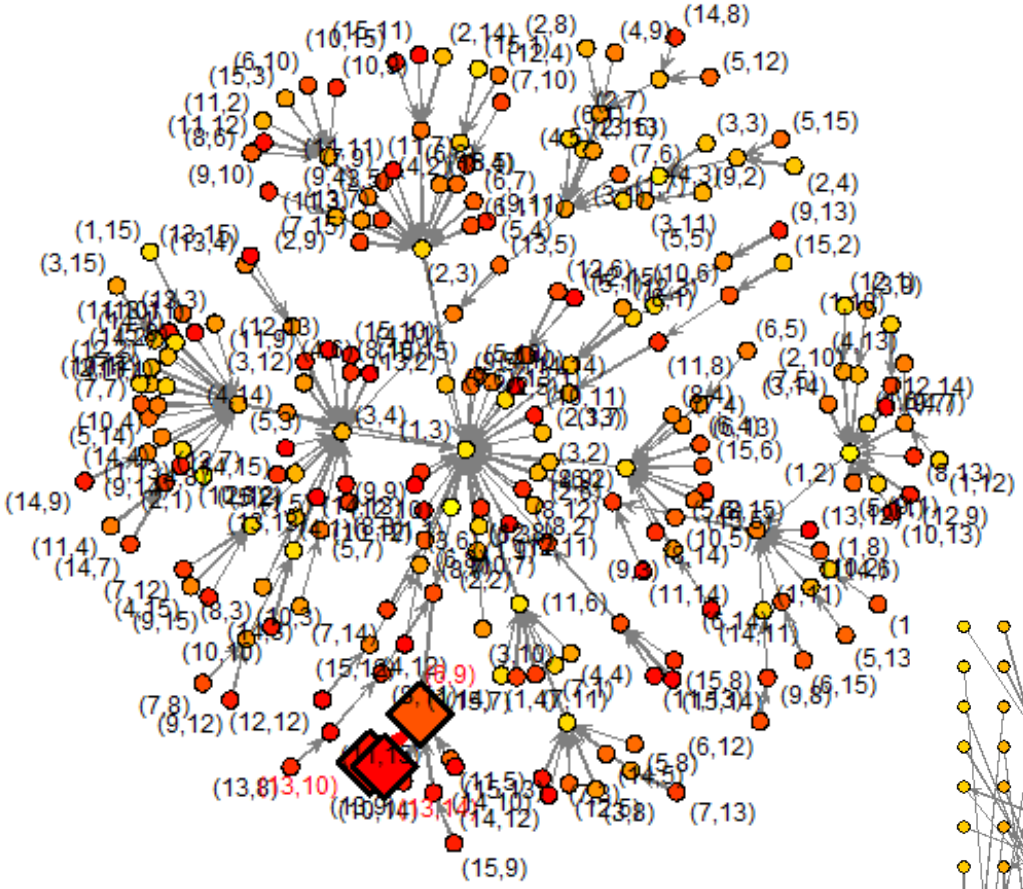
How are supra-competitive prices supported?

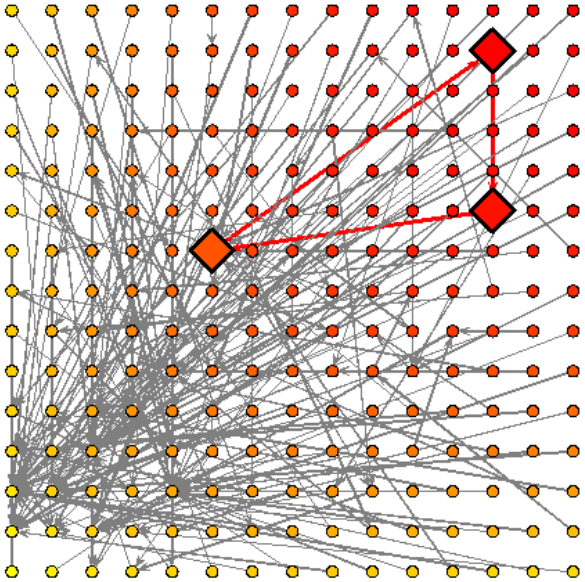
- Since algos are pricing high, why one of them doesn't undercut thus gaining all consumers?
- Do algos **fail to learn** to compete? Or...

- 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?

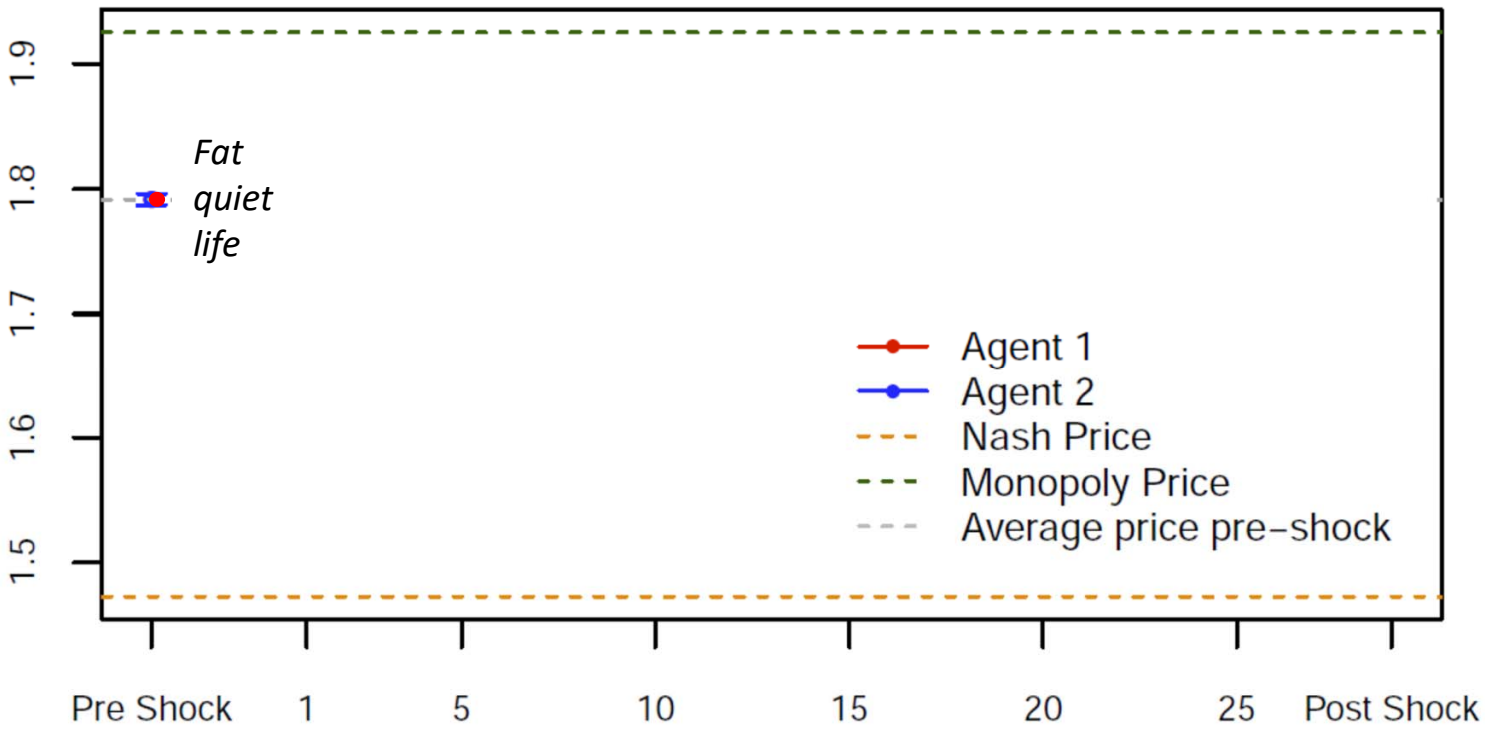




Not too informative... a **problem of AI (lack of) Explainability!** What to do?

Auditing algos

- Let agents play according to learnt strategies ("Fat quiet life")
- We force agent 1 (Red) to lower price for one period



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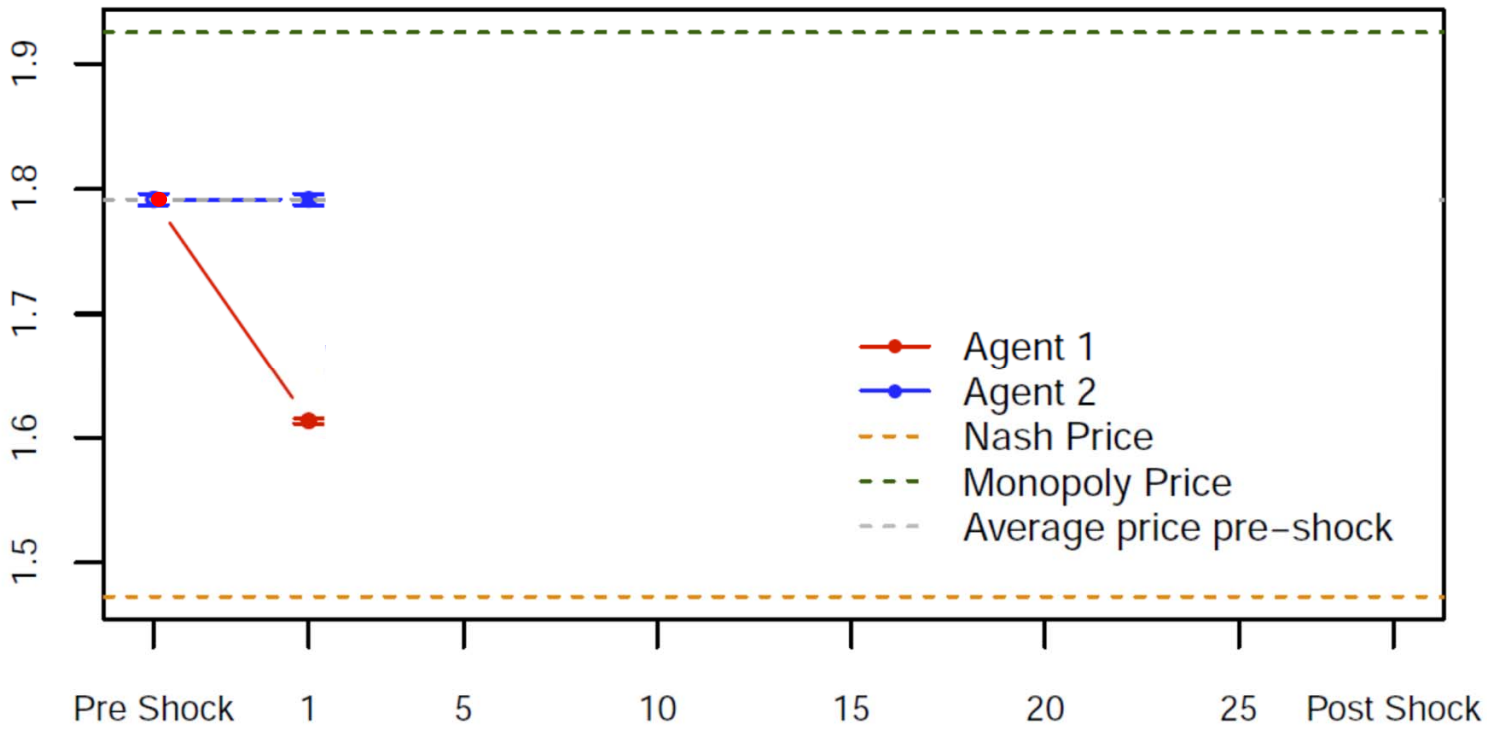

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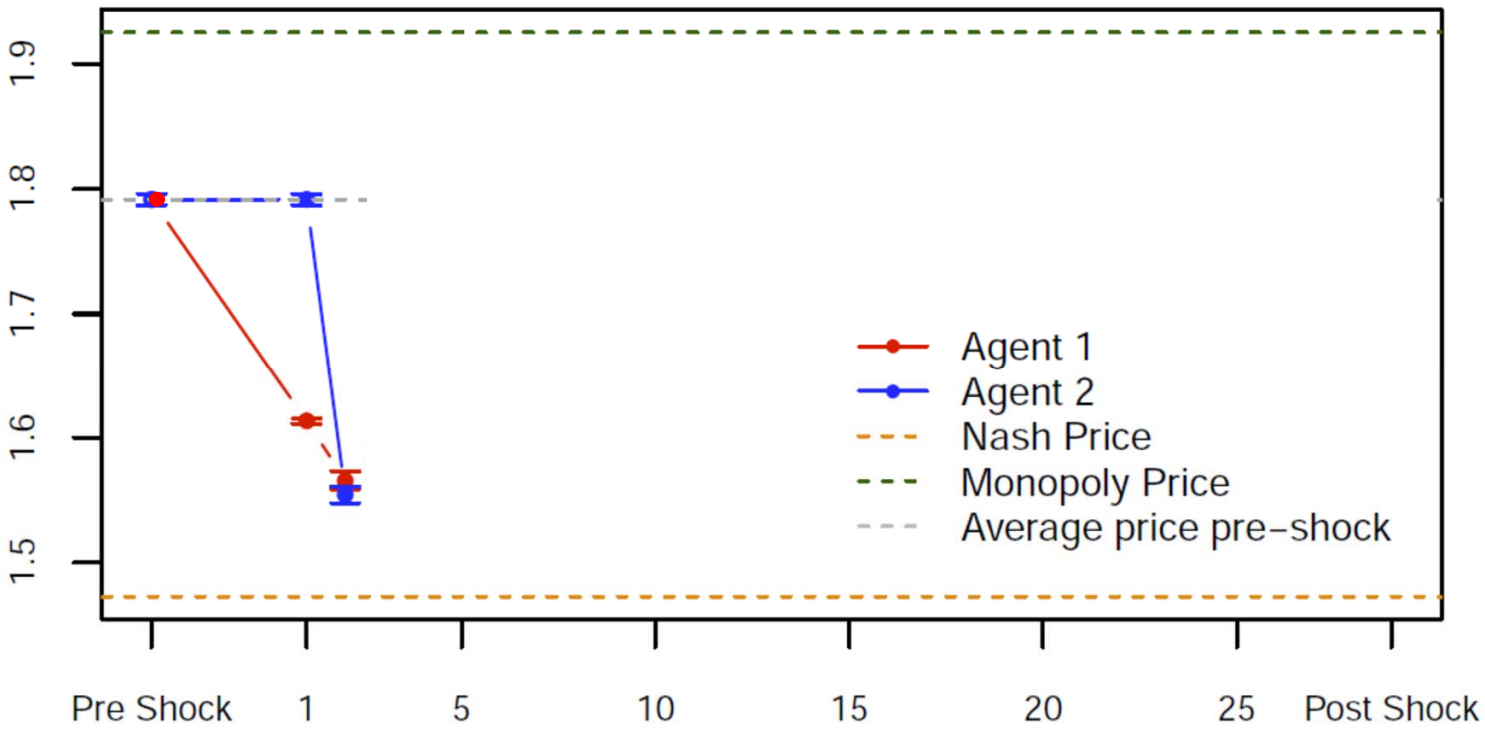

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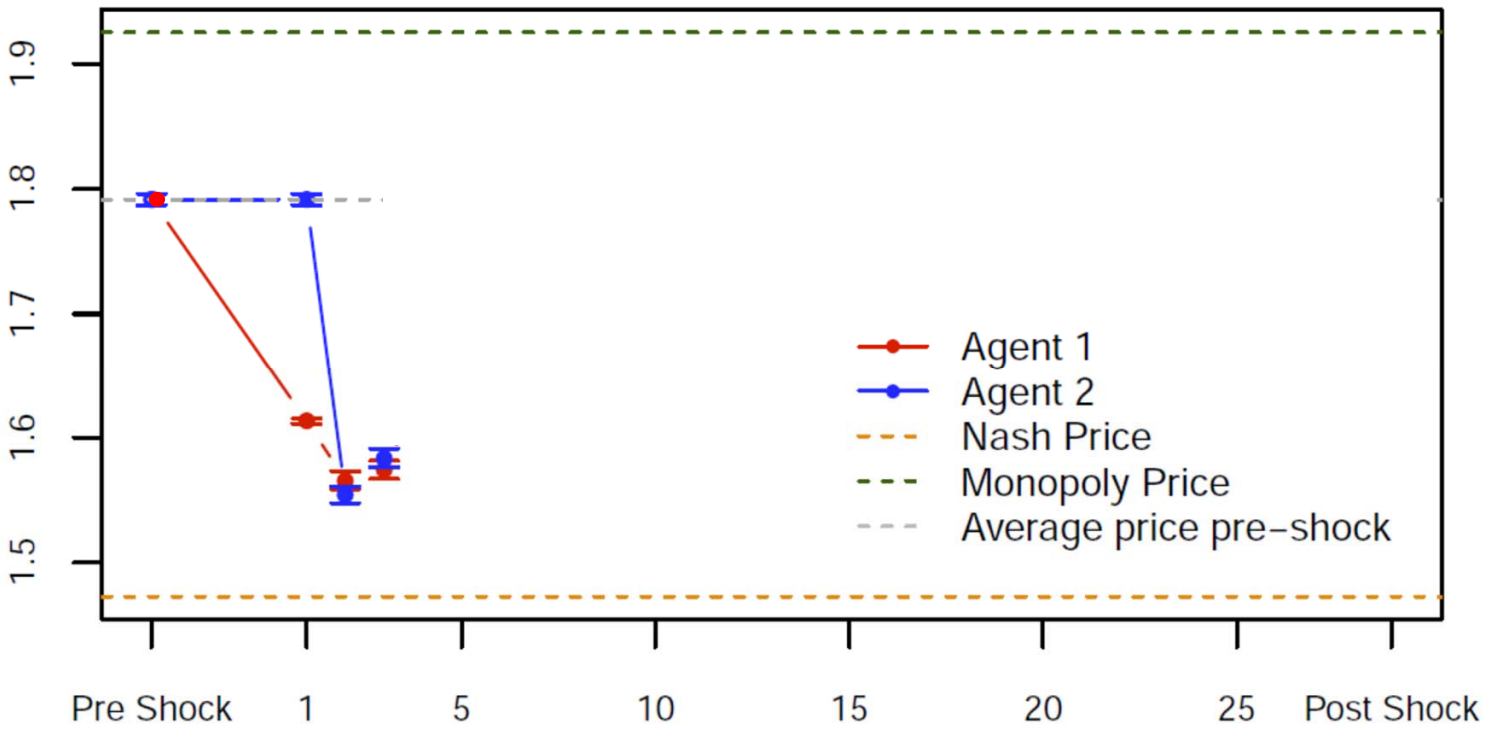

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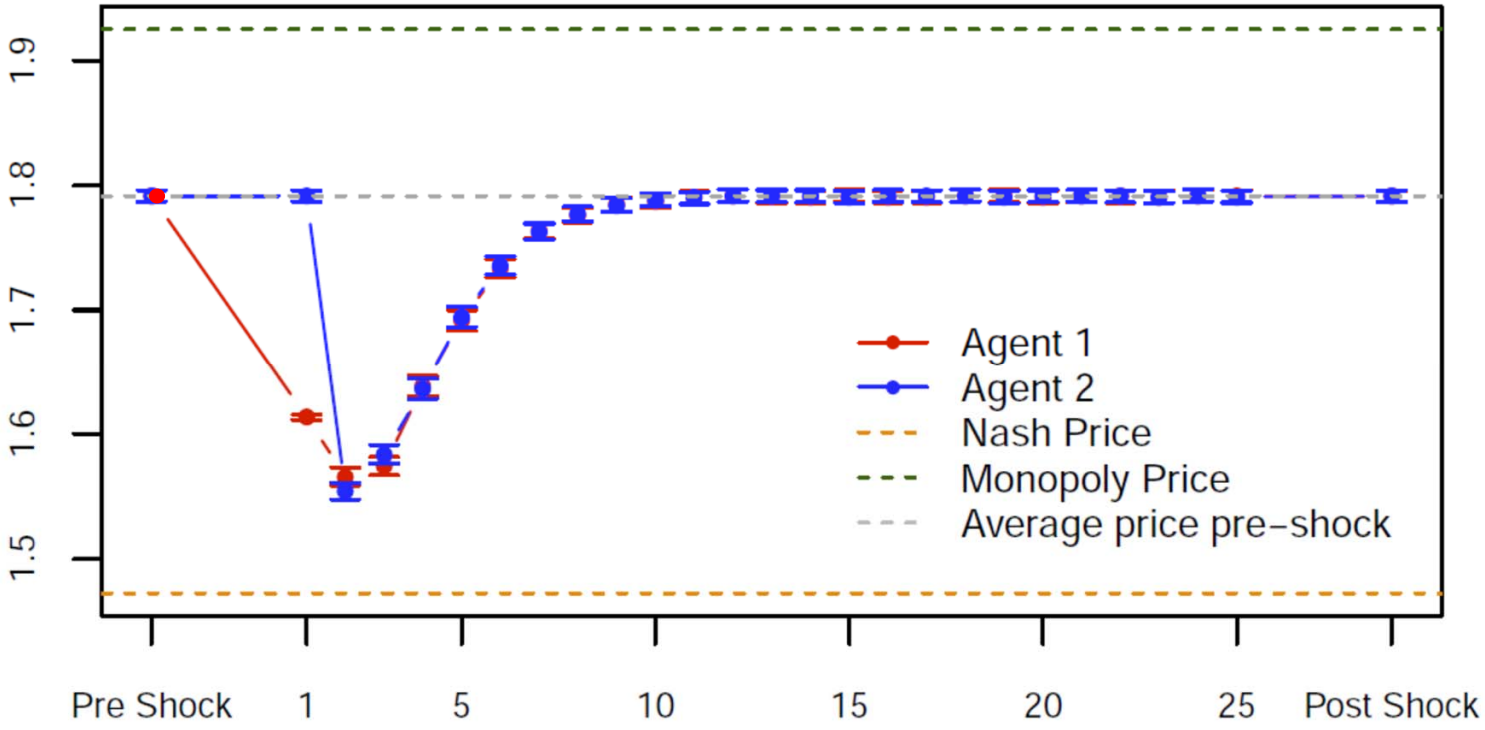
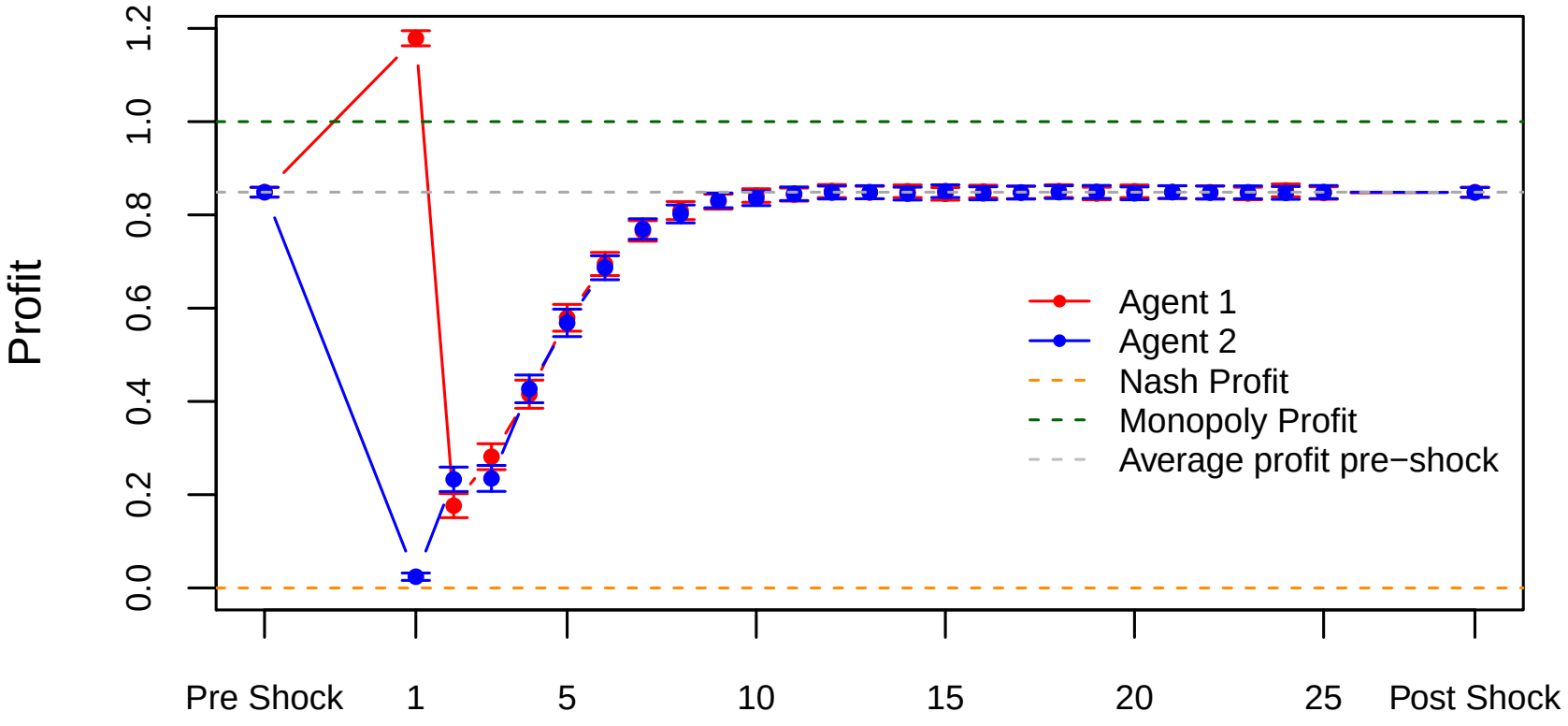


Reward-Punishment-Forgiveness

Same exercise, looking at profits

- Normalized $1 = \pi^{\text{collusive}}$



- **Blue's reaction makes price-reduction not profitable!**

Robustness: Exploiting the flexibility of experiments

- Economics (more firms, product differentiation, asymmetry, uncertainty, entry-exit, inventories, ...)
- Complexity of environment (more prices, longer memory, mixing hyper-parameters, learning entrant, imperfect monitoring, ...)
- Fast-learning (Off-line+On-line learning)
- Replications by other researchers (sequential price timing, Deep learning, other learning strategies, ...)

Stubborn and robust tendency to learn collusive (equilibrium) strategies

Empirical analysis

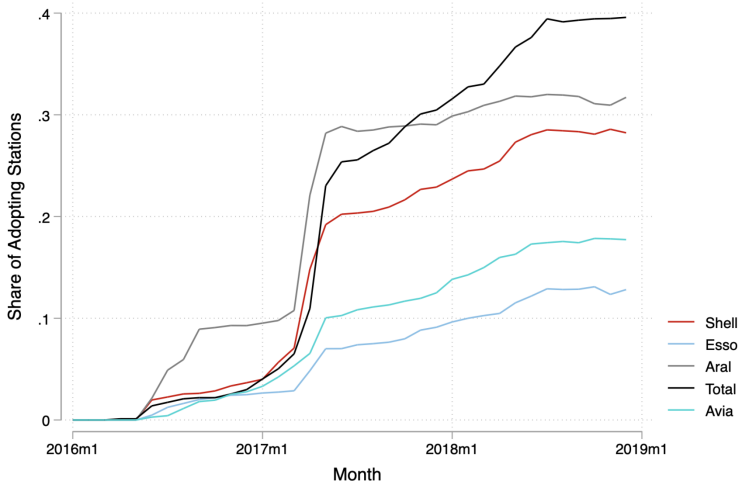
Are simulations sufficiently realistic? Empirical investigation is key.

- Pros: From proof of concept to actual proof
- Cons: Indirect identification of algos, limited comparative statics

Empirical analysis

From Assad et al. (2020) "*Algorithmic Pricing and Competition: Empirical Evidence from the German Retail Gasoline Market*", wp

- Price of gasoline in Germany, where since 2017 a software company sold repricing AI-powered algos to petrol chains



- The software "*rapidly, continuously, and intelligently react to market conditions*":
  - monitors close stations prices, traffic, weather etc.
  - accordingly sets gasoline price to maximize profits

Empirical analysis

Approach of analysis

- Step 1: identification of stations adopting algos and date of adoption (not simple: breaks in frequency of price changes)
- Step 2: measuring the causal effect of algo adoption on prices, compare outcomes of adopting vs. non-adopting stations (not simple: disentangle from other factors, IV approach with adoption by brand)

Empirical analysis: results

1. Adopting stations with no competitors: no significant changes
2. Adopters with competitors: price increase (+0.8 cents/litre)
3. In duopoly cases: if only one adopts, then no effect
4. ... but if both adopts, margin rises by 38%
5. Undercutting disappears when both stations adopt
6. Adopters more likely to respond with price drop to a rival's price decrease within 5 minutes
7. the above is more so over time when two adopters (learning) but not when only one adopter
8. Margin increase takes 1 year (learning as in experiments)

All these consistent and confirming experimental results

Pricing algorithms and concerns

- Automation and data: easier to detect and respond to deviations
  - online posters cases CMA?s Trod/GB eye decision and US v. Topkins
  - Booking.com and Expedia and wide price parity clauses (lower ranking for hotels offering cheaper rooms on rivals' websites)
- Shared algos and coordination: algo as an intermediary (hub-and-spoke model)
- Autonomous tacit collusion: algos autonomously learn to support high prices by punishing competitors? price reductions

How to deal? Policy approaches

1. Lasseiz faire — If risk is low
2. Ex-ante approaches (regulation) — If risk is high
3. Ex-post approach (antitrust, cons. protection) — If risk is moderate

How to deal? **Market Reaction**

- Algorithmic consumers (M. Gal): delegating buying decisions to bots (e.g. assistants, RoboAdvising)
- The role of platforms (Johnson et al. 2020)
- Firms/sellers?

How to deal? **Ex-ante approach**

- Systematic pre-approval
  - e.g. structured process for drugs: benefits must outweigh known potential risks
  - Sandboxing algos, vetting all algos before market deployment, and checking their rules of conduct
  - A formidable task, many variants and market specificity
- Compulsory and public notification of algo pricing
  - it's been done before, e.g. financial markets
  - A census of algos: useful and feasible
- Digital Authority with the mandate to develop targeted regulation (advocated by many Fiona Scott Morton et al 2019 report, European Commission law proposal on AI April 2021)

How to deal? **Ex-post approach**

- Current legal doctrine rooted in conspiracy
- Problem with collusion is higher prices harm consumers, but..
- ... illegality of collusion resides in the *process* which produces higher prices: consipiring with communication that allow firms to establish "meeting of minds," "concurrence of wills," "a conscious commitment" not to compete
- And there were good reasons for this

- But in this situation tacit collusion and algo collusion currently lawful

- How to improve from here?

How to deal? **Ex-post approach**

- Can we just decide that prices are too high (e.g. excessive pricing)?
  NO, impractical aka regulation and need a lot of information and time
- Can we claim algos have "intent" to collude?
  NO, unless algos as conscious machines...
- But there are interesting differences in humans vs. algos...

How to deal? **Ex-post approach**

- There are interesting differences between humans vs. algos:

	Communications	Collusive pricing rules	Collusive prices
Humans	Present, discoverable	Latent, not discoverable	Not verifiable
Algorithms	Not present	Latent, discoverable	Not verifiable

- Hence, the solution can rest in **looking inside the algos** and learnt strategies

- But we need more structure for such process...

How to deal? **Ex-post approach**

A structured approach: mixing antitrust and consumer protection

1. Patrol marketplaces (AI can be useful in screening!)
2. If test positive then subpoena and audit suspicious algos and test in artificial environments or "provoke" in actual markets

- Problem: what is the pattern of algo' strategies that we do not want? Pricing *behavior* inconsistent with competitive pricing, e.g.
  - punishments
  - negative derivative of profitability wrt own price
  - ...

How to deal? Computer Science can help

In the structured ex-post approach...

- *Explainable AI* would be very useful
  - Possibility to understand why algos act in observed way
  - Transparent by-design
  - Post-hoc explainability (ex-post convert non-interpretable AI into interpretable one)
  - What is best for markets?

- *Fair AI* would be very useful
  - Recognizing that AI can be unfair (discriminatory)
  - Fairness general principles (accountability, responsibility, awareness, competence of AI users, human oversight)
  - Fair by design (constraining algorithms for undesired behavior)

THANK YOU

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