Do Capacity Constrained Bots Collude?

Presentation at BECCLE, feb. 2025

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Motivation

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When Margrethe Vestager takes antitrust battle to robots

Self-teaching algorithms could collude in ways that are impossible to detect, much less prevent.

Motivation

Feb. 8, 2024, 11:00 AM GMT+1

ANALYSIS: Antitrust Bills Aim at AI Pricing Collusion

Eleanor Tyler
Legal Analyst

Recent bills introduced in the Senate aim to augment the current antitrust laws by calling out algorithmic collusion—which can be

Motivation

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Tina Søreide

Tina Søreide, konkurransedirektør

Innlegg

Kunstig intelligens utfordrer konkurransen

Velfungerende markeder er en forutsetning for vår velferd og samfunnsutvikling, men nå utfordres kontrollen med konkurranse på nye måter. EUs nye regler for kunstig intelligens kan være en del av løsningen.

Motivation

Artificial Intelligence, Algorithmic Pricing, and Collusion†

By Emilio Calvano, Giacomo Calzolari, Vincenzo Denicolò, and Sergio Pastorello*

Increasingly, algorithms are supplanting human decision-makers in pricing goods and services. To analyze the possible consequences, we study experimentally the behavior of algorithms powered by Artificial Intelligence (Q-learning) in a workhorse oligopoly model of repeated price competition. We find that the algorithms consistently learn to charge supracompetitive prices, without communicating with one another. The high prices are sustained by collusive strategies with a finite phase of punishment followed by a gradual return to cooperation. This finding is robust to asymmetries in cost or demand, changes in the number of players, and various forms of uncertainty. (*JEL* D21, D43, D83, L12, L13)

Motivation

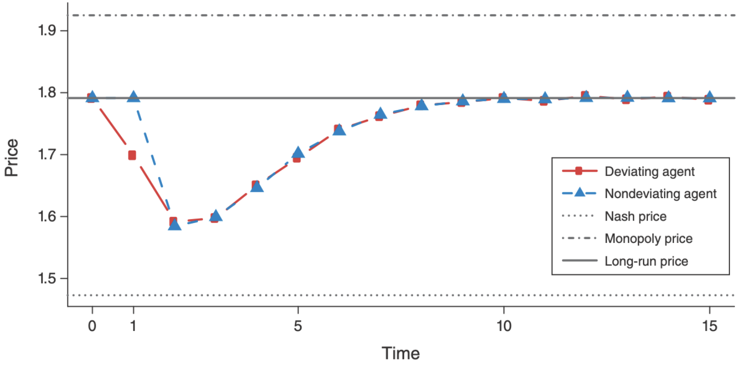
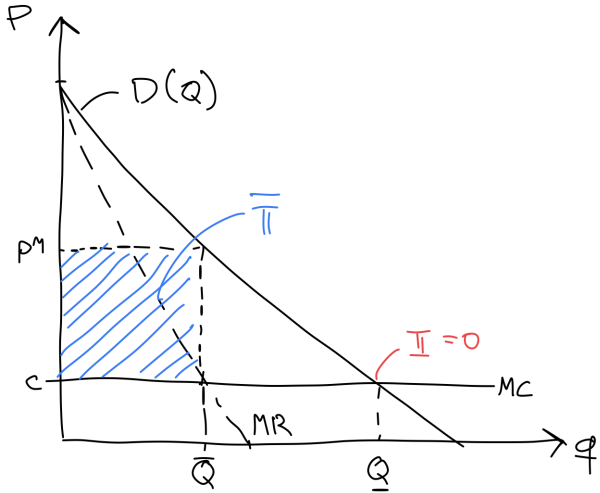


FIGURE 6

Notes: This figure is similar to Figure 4, except that the exogenous price cut is smaller. As a result, prices fall further down in period $\tau = 2$. In other words, the impulse-response function exhibits "overshooting."

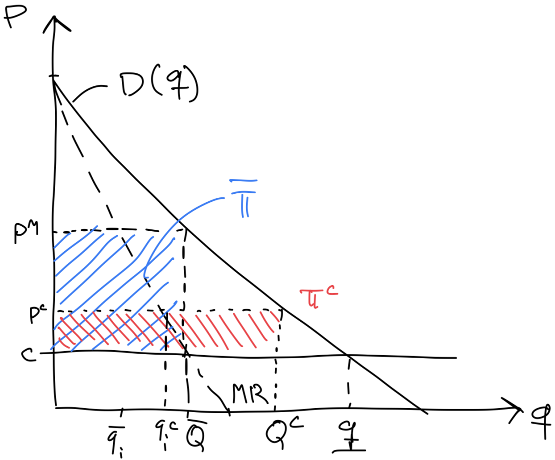
Bertrand and incentive to collude



Cooperation with quantities

- In Bertrand the cooperative gain is large, deviation profit is also large, and the punishment hurts
- In Cournot the cooperative gain is moderate, deviation profit is also moderate, and the punishment is weak

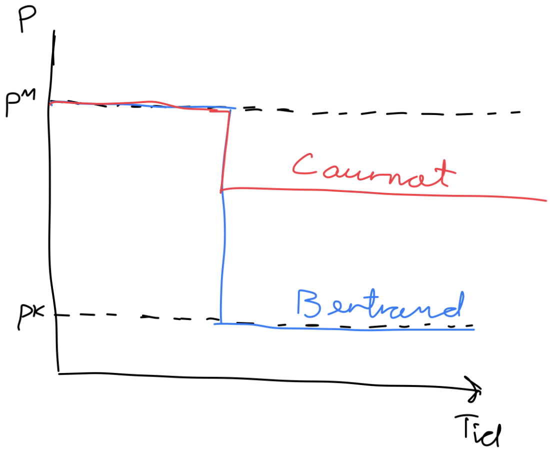
→ The incentive to cooperate is very different between when prices and quantities are binding



Cooperation with quantities: profits

- Bertrand: $\underline{\pi}_i + \delta\underline{\pi}_i + \delta^2\underline{\pi}_i + \cdots = 0$
- Cournot: $\pi_i^C + \delta\pi_i^C + \delta^2 + \cdots > 0$

- Cooperation: $\overline{\pi}_i + \delta\overline{\pi}_i + \delta^{\overline{\pi}_i + \cdots}$

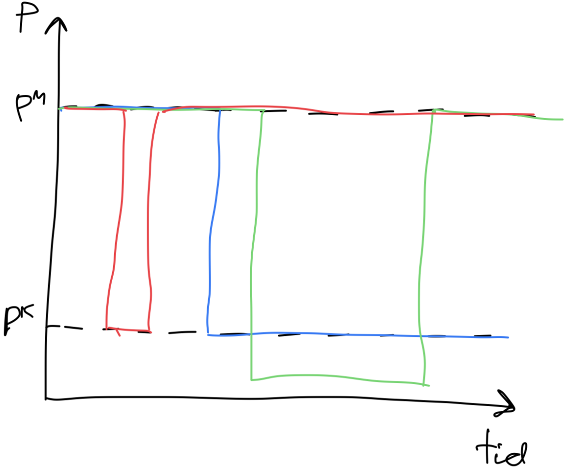


Cooperation with quantities: strategies

- Grim trigger: $p^M + 0 + 0 + \ldots$

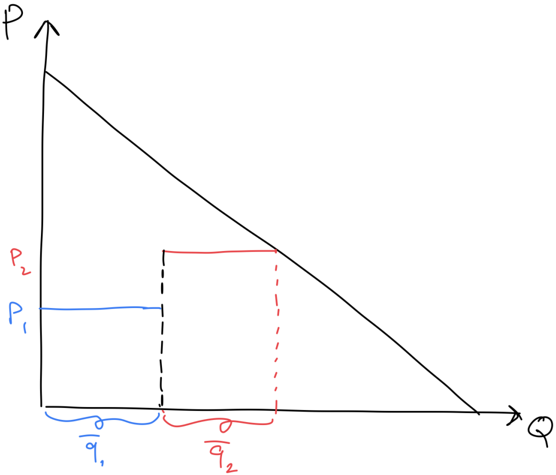
- Tit-for-tat (1): $p^M + 0 + p^M + \ldots$
- Tit-for-tat (2): $p^M + p^M + 0 + p^M + \ldots$

- Stick-and-carrot: $p^M + \widetilde{p} + \widetilde{p} + p^M + \ldots$



Capacity constraints

- The firms have a given maximum capacity/inventory, $\overline{q_i}$, men compete in prices
- If $p_1 = \min\{p_1, p_2\}$, and $D(p_1) > \overline{q_1}$, then $D_2 = D(p_2) - \overline{q_1} > 0$, i.e. both can sell
- Efficient rationing, those with highest willingness to pay gets served first.



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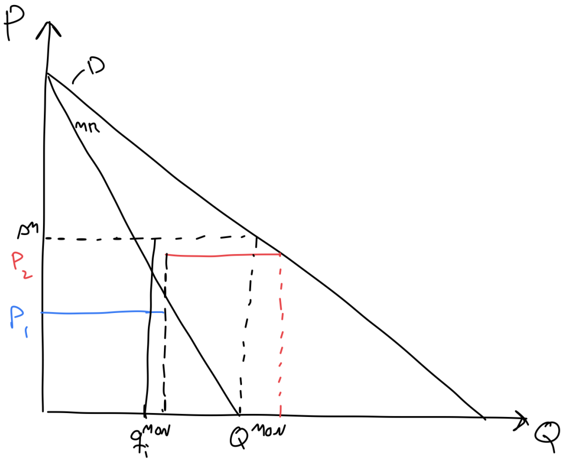
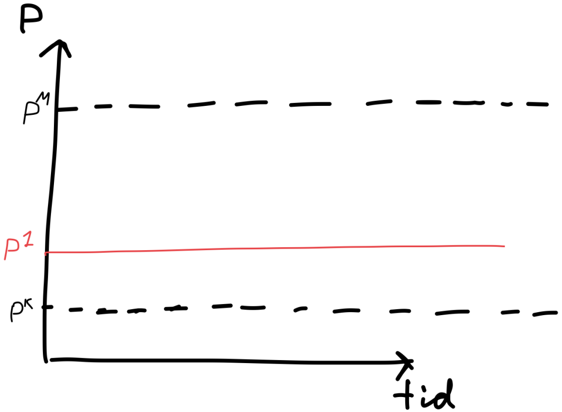


Price observations

- Economic theory abstracts away realistic distractions
- Empirics is limited by the world as it has been

→ Can simulating unite them in harmony?



Academic background

- Advances in artificial intelligence - AlphaGo, AlphaZero (Silver, Huang et al., 2016; Silver, Hubert et al., 2018)
- Tools used for pricing based on the same technology (Chen, Mislove and Wilson, 2016; Brown and MacKay, 2023; Assad et al., 2024; Spann et al., 2024)
- Should we worry about AIs learning to collude on their own? Ezrachi and Stucke 2016; 2017; 2018, and Mehra, 2016 think so.
- Hard to investigate theoretically (Bloembergen et al., 2015) and empirically (Assad et al., 2024).
- Calvano et al. 2020 suggested simulation to investigate possibly collusive AI.

Problem and what we do

- Calvano et al. argue that AIs learn to collude in repeated pricing games 2020; 2021.
- There are similar results for dynamic pricing games (Klein, 2021) and first-price auctions (Banchio and Skrzypacz, 2022).
- But the results are not very robust (Eschenbaum, Mellgren and Zahn, 2022; Banchio and Mantegazza, 2022; Asker, Fershtman and Pakes, 2024).
- Models are obviously stylized. Simulation may have little external relevance.
- We ask: **Do AIs learn to collude when they are constrained in how much they can sell?**
  - Preview: We find little evidence for collusion, but prices are higher and may be more dispersed.

A (somewhat) technical slide

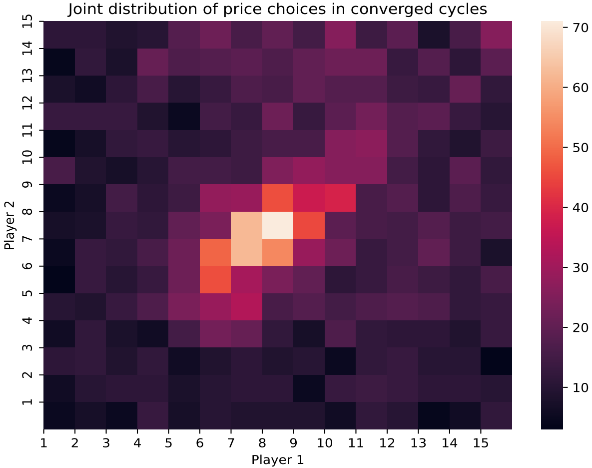
- Two firms, represented by two AIs, compete in prices given an external limit on how much they can sell.
- Price setting happens simultaneously, based on past own and opponent price and what experience the AI already has.
- A game is considered converged, i.e., done, once the AIs have played the same prices for a number of rounds.
- Each converged game is subject to a test:
  - One AI is forced to deviate from whatever price it converged on, while the other AI reacts according to what it has learned.

Theoretical predictions and reward-punishment

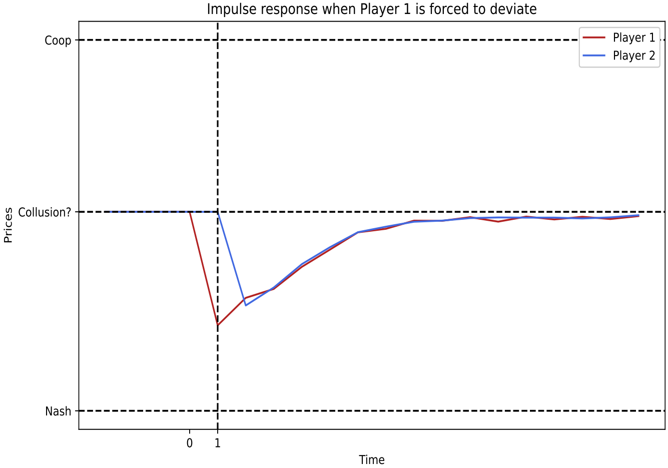
- The game we simulate a Edgeworth-Bertrand game.
- May lead to quantity competition (Kreps and Scheinkman, 1983; Osborne and Pitchik, 1986) or mixing/cycling (Edgeworth, 1925; Davidson and Deneckere, 1986) depending on the assumptions made.
- In repeated games, there is a multiplicity of equilibria (Brock and Scheinkman, 1985; Benoit and Krishna, 1987), assuming firms employ a grim-trigger strategy.
- We work with the more general definition in Harrington, 2019: Rewarding for abiding by a supracompetitive price, punishing from departing.

Results

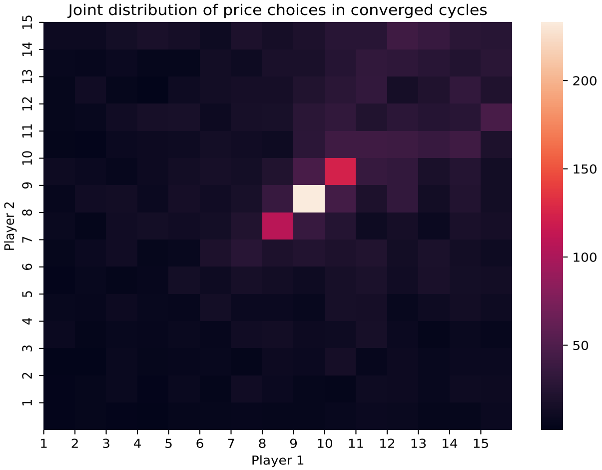
AI pricing - Replication of Calvano et al. 2020



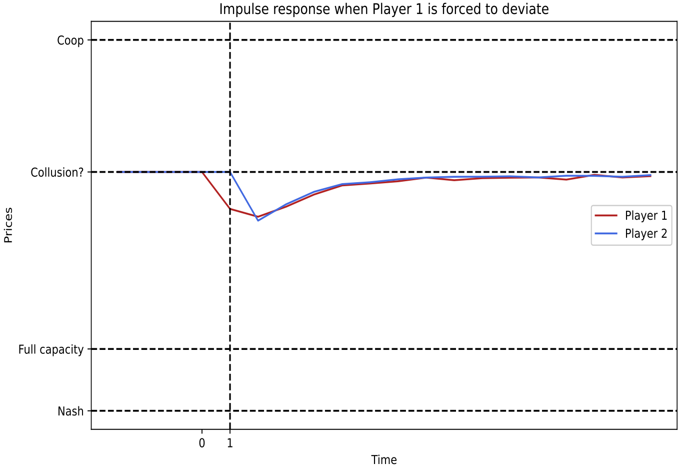
Collusion? - Replication of Calvano et al. 2020



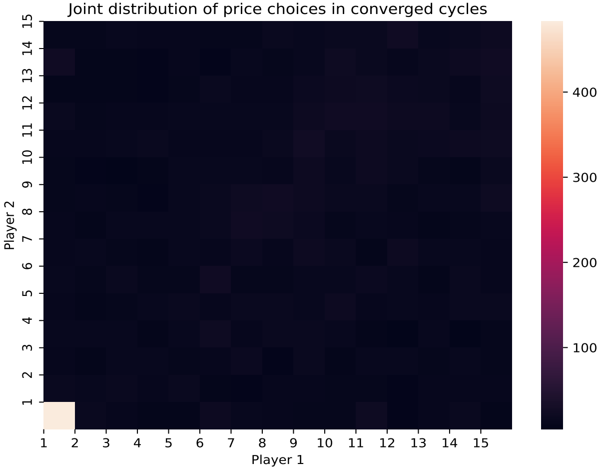
Capacity constrained pricing, no instructions for rationing



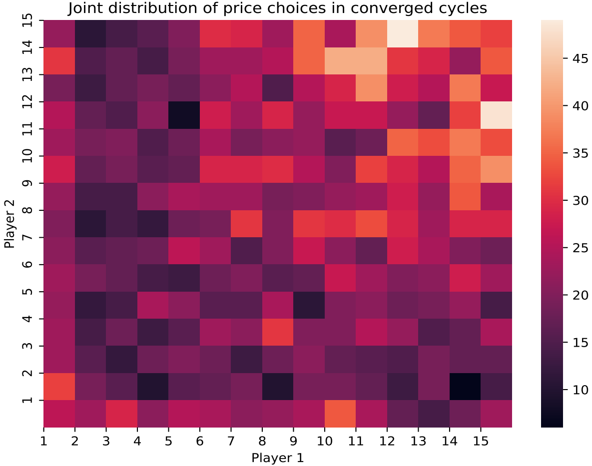
Do capacity constraints facilitate collusion?



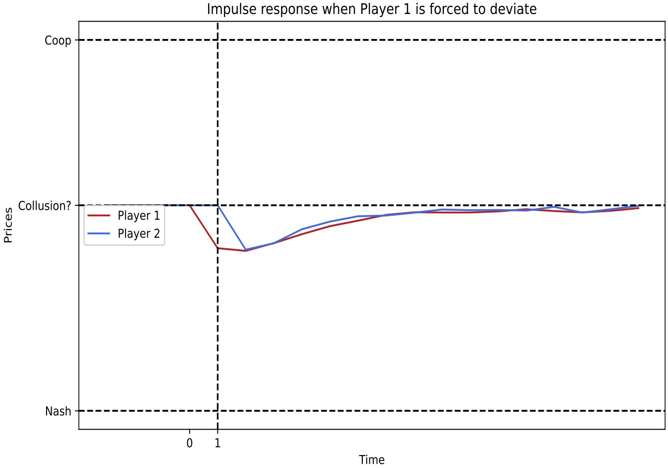
Capacity constrained pricing, high WTP served first



Capacity constrained pricing, customers served as they arrive



Any collusion?



Conclusion

- We simulate a model where AIs price under an exogenous constraint on how much they can supply.
- The results differ widely depending on the type of instructions the AIs are given.
  - Not surprising that there are many possible outcomes of a repeated pricing game.
  - Predictions also vary with the type of rationing/queue assumed.
- In two versions of our model the prices are higher on average than in a game without capacity constraints.
- We are hard pressed to interpret our results as being due to collusive strategies.

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