

Algorithmic Collusion of Pricing and Advertising on E-commerce Platforms

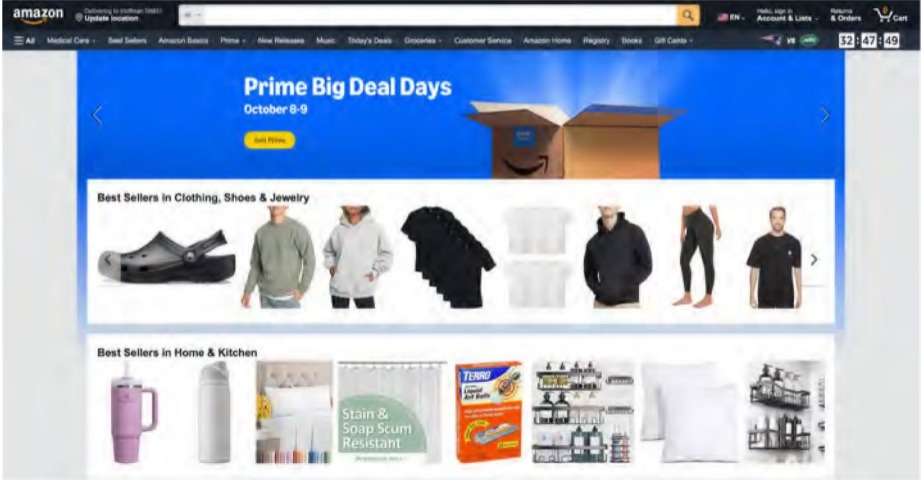
Hangcheng Zhao and Ron Berman

The Wharton School, University of Pennsylvania

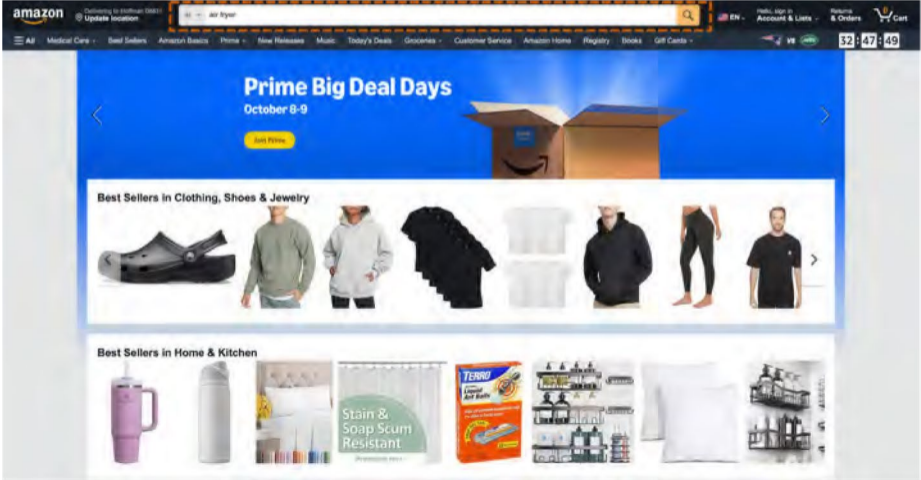
October 2024



Motivating Example




Motivating Example





Motivating Example


Motivating Example

Results
Check each product page for other buying options.

 **CrispMAX Multifunctional Digital Air Fryer** • Reheat, Bake, Dehydrate, Convection Oven, 11 Touch Screen Presets Fry, Roast, Dehydrate, Bake, XL 10L Family Size, Auto Shutoff, Large Easy-View Window, Black
★★★★☆ (3,142)
It's bought in past month
\$99⁰⁰ was \$109.99
- [Shop Now](#)
FREE delivery Sat, May 28
Or fastest delivery Thu, May 23
[Add to Cart](#)

 **Emeril Lagasse 26 QT Extra Large Air Fryer, Convection Toaster Oven with French Doors, Stainless Steel**
★★★★☆ (9,071)
It's bought in past month
\$151⁰⁰ was \$169.99
- [Shop Now](#)
FREE delivery Sat, May 28
Or fastest delivery Thu, May 23
[Add to Cart](#)


 **Ninja AF101 Air Fryer** that Crisps, Roasts, Reheats, & Dehydrates, for Quick, Easy Meals, 4 Quart Capacity, & High Gloss Finish, Gray
★★★★☆ (12,312)
It's bought in past month
\$79⁰⁰ was \$89.99
- [Shop Now](#)
FREE delivery Sat, May 28
Or fastest delivery Thu, May 23
[Add to Cart](#)


 **Ninja Air Fryer Pro 4-in-1** with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air-Crisp Technology with 400F for hot, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF161
★★★★☆ (144)
It's bought in past month
\$119⁰⁰
- [Shop Now](#)
FREE delivery Sat, May 28
Or fastest delivery Thu, May 23
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Motivating Example


Motivating Example

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★★★★☆ (144)
It's brought in past month
\$119⁹⁹
- [Shop Now](#)
FREE delivery Sat, May 28
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Motivating Example

- Firms need to make **pricing** and **advertising** decisions.
- Firms use ML/AI **algorithms** to price and bid.

Motivating Example



SELLER SNAP

Features Pricing Resources About Us [Start Your Free Trial](#) Login

**The most advanced AI Amazon repricer
and business intelligence software on
the market.**

Save time. **Avoid price wars**. Maximize profits.

[Learn more](#)

The image shows a screenshot of the Seller Snap website. The top navigation bar includes the Seller Snap logo, menu items for Features, Pricing, Resources, and About Us, a prominent orange 'Start Your Free Trial' button, and a 'Login' link. The main content area has a dark blue background with white text. The headline reads 'The most advanced AI Amazon repricer and business intelligence software on the market.' Below this, a sub-headline says 'Save time. Avoid price wars. Maximize profits.' The phrase 'Avoid price wars' is enclosed in a white rectangular box. At the bottom of the main content area is a green 'Learn more' button.

Background



[Home](#) / [Business Guidance](#) / [Business Blog](#)

[Business Blog](#)

Price fixing by algorithm is still price fixing

By: Hannah Garden-Monheit and Ken Merber

March 1, 2024



Landlords and property managers can't collude on rental pricing. Using new technology to do it doesn't change that antitrust fundamental. Regardless of the industry you're in, if your business uses an algorithm to determine prices, a brief filed by the FTC and the Department of Justice offers a helpful guideline for antitrust compliance: your algorithm can't do anything that would be illegal if done by a real person.

Today, the FTC and Department of Justice took action to fight algorithmic collusion in the residential housing market. The agencies filed a [joint legal brief](#) explaining that price fixing through an algorithm is still price fixing. The brief highlights key aspects of competition law important for businesses in every industry: (1) you can't use an algorithm to evade the law banning price-fixing agreements, and (2) an agreement to use shared pricing recommendations, lists, calculations, or

Background

Justice Department Sues RealPage for Algorithmic Pricing Scheme that Harms Millions of American Renters

Friday, August 23, 2024



For Immediate Release

Office of Public Affairs

RealPage's Pricing Algorithm Violates Antitrust Laws

The Justice Department, together with the Attorneys General of North Carolina, California, Colorado, Connecticut, Minnesota, Oregon, Tennessee, and Washington, filed a civil antitrust lawsuit today against RealPage Inc. for its unlawful scheme to decrease competition among landlords in apartment pricing and to monopolize the market for commercial revenue management software that landlords use to price apartments. RealPage's alleged conduct deprives renters of the benefits of competition on apartment leasing terms and harms millions of Americans. The lawsuit was filed today in the U.S. District Court for the Middle District of North Carolina and alleges that RealPage violated Sections 1 and 2 of the Sherman Act.

The [complaint](#) alleges that RealPage contracts with competing landlords who agree to share with RealPage nonpublic, competitively sensitive information about their apartment rental rates and other lease terms to train and run RealPage's algorithmic pricing software. This software then generates recommendations, including on apartment rental pricing and other terms, for participating landlords based on their and their rivals' competitively sensitive information. The complaint further alleges that in a free market, these landlords would otherwise be competing independently to attract renters based on pricing, discounts, concessions, lease terms, and other dimensions of apartment leasing. RealPage also uses this scheme, and its substantial data base, to maintain a monopoly in the market for commercial revenue management software. The

Research Questions:

1. How does reinforcement learning (RL) algorithms influence competition bids, prices, and profits?
2. When can algorithmic pricing be beneficial for consumers? Is there any supporting empirical evidence?

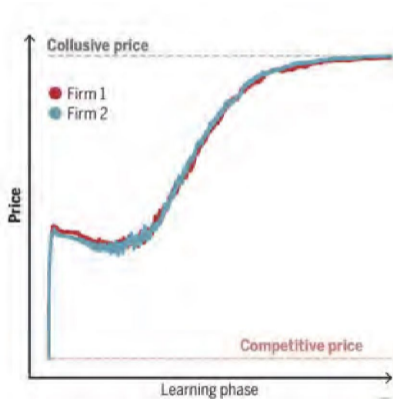
Overview

- Part 1: Contributions and Intuition
- Part 2: Conditions for Beneficial Algorithmic Pricing
 - Theoretical Model Setup
 - Reinforcement Learning Simulation of Pricing and Bidding
- Part 3: Empirical Analysis: Beneficial Algorithmic Pricing on Amazon.com

- Conclusion and Managerial Implications

Contributions

- Recent research:
- *Calvano et al., 2020; Hansen et al., 2021; Johnson et al., 2023; Wang et al., 2023* - Competing algorithms learn to tacitly collude on higher prices.



Calvano et al. (2020) Protecting consumers from collusive prices due to AI. *Science*

Contributions

- Algorithms still collude when pricing and bidding.
- However, algorithmic prices can be lower when consumers consider fewer products.
- Empirically estimate using Amazon data:
- Negative interaction of consumer consideration size and algorithms on prices.

- In 52% of Electronics keyword markets, algorithms can generate lower prices.

ModelSetup

Digital Platform Setting

- Platform displays products in
- sponsored positions
- and organic positions

The screenshot displays Amazon search results for air fryers. It is divided into two main sections: 'Sponsored' and 'Organic'. The 'Sponsored' section includes three listings with orange callouts and a bracket on the right. The 'Organic' section includes two listings with a black bracket on the right.

Results
Check out product ads for other buying options.

Sponsored

- ORFMAN Multifunctional Digital Air Fryer** - Wellness, Dehydration, Convection Oven, 13 Touch Screen Presets Fry, Roast, Dehydrate, Bake, XL 12L Family Size, Auto ShutOff, Large Easy-View Window, Black
4.7 (4,347)
\$179 (4,347)
Free delivery Sat, May 23
In transit delivery Thu, May 21
[Add to cart](#)
- Emerit's Signature 35-Qt Extra Large Air Fryer, Convection Toaster Oven with French Doors, Stainless Steel**
4.5 (2,011)
\$151 (2,011)
Free delivery Sat, May 23
In transit delivery Thu, May 21
[Add to cart](#)

Organic

- Ninja AF101 Air Fryer that Crisps, Roasts, Reheats, & Dehydrates, for Quick, Easy Meals, 4 Quart Capacity, High-Gloss Finish, Grey**
4.7 (43,011)
\$79 (43,011)
Free delivery Sat, May 23
In transit delivery Thu, May 21
[Add to cart](#)
- Ninja Air Fryer Pro 4-in-1 with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air Crisp Technology with ADFP for fast, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF141**
4.7 (14,000)
\$119 (14,000)
Free delivery Sat, May 23
In transit delivery Thu, May 21
[Add to cart](#)

Digital Platform Setting

- Platform displays products in
- sponsored positions
- and organic positions
- Sellers price and bid
- similar products within the same keyword
- different ASINs
- Platform displays products in


The screenshot displays a search results page for air fryers. It is divided into two main sections: 'Sponsored' and 'Organic'. The 'Sponsored' section at the top features three listings with orange 'Sponsored' labels. The first listing is a 'COSORI Multifunctional Digital Air Fryer' priced at \$99. The second is an 'Emeril Lagasse 36-Qt Extra Large Air Fryer' priced at \$151. The 'Organic' section below features three listings with black 'Organic' labels. The first is a 'Ninja AF101 Air Fryer' priced at \$79. The second is a 'Ninja Air Fryer Pro 4-in-1' priced at \$119. Each listing includes a product image, a title, a price, and a 'Add to Cart' button.

Digital Platform Setting

- sponsored positions
- and organic positions
- **Sellers** price and bid
- similar products within the same keyword
- different ASINs

Results

Check out product pages for other buying options.



CHERMAIN Multifunctional Digital Air Fryer + Rotisserie, Dehydrator, Convection Oven, 17 Touch Screen Presets Fry, Roast, Dehydrate, Bake, XL 10L Family Size Auto ShutOff, Large Easy-View Window, Black

4.5 (1,230)
See how it compares to other models


\$99⁹⁹ (List: \$199.99)

Shipping

FREE delivery Sat, May 25
Or fastest delivery Thu, May 23

ADD TO CART

Consideration Set



Essential Lagasse 26 QT Extra Large Air Fryer, Convection Toaster Oven with French Doors, Stainless Steel


4.5 (1,231)
See how it compares to other models

\$151⁹⁹ (List: \$199.99)

Shipping

FREE delivery Sat, May 25
Or fastest delivery Thu, May 23

ADD TO CART



Ninja AF101 Air Fryer that Crisps, Roasts, Reheats, & Dehydrates, for Quick, Easy Meals, 4 Quart Capacity & High-Gloss Finish, Grey

4.5 (1,232)
See how it compares to other models

\$79⁹⁹ (List: \$99.99)

Shipping


FREE delivery Sat, May 25
Or fastest delivery Thu, May 23

ADD TO CART

Save on Ninja

Save \$2.00 on Ninja

\$55.99 (1) used & new offers



Ninja Air Fryer Pro 4-in-1 with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air Crisp Technology with 400F for hot, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF161

4.5 (1,233)
See how it compares to other models

\$119⁹⁹

Shipping

FREE delivery Sat, May 25
Or fastest delivery Thu, May 23

ADD TO CART

Digital Platform Setting


- Heterogeneous consumers
 - consider different numbers of products
 - Platform displays products in
 - sponsored positions
 - and organic positions
 - Sellers price and bid

Digital Platform Setting

- similar products within the same keyword
- different ASINs
- **Heterogeneous consumers**
- consider different numbers of products
- **Platform** displays products in
- sponsored positions

Results

View 4 more products to see all other results options.



CHERMAIN Multifunctional Digital Air Fryer + Rotisserie, Dehydrator, Convection Oven, 17 Touch Screen Presets Fry, Roast, Dehydrate, Bake, 8L, 10L, Family Size, Auto ShutOff, Large Easy-View Window, Black

4.5 (1,234) | 100% (100)


\$99.99 (was \$199.99)

100% (100)

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART

Consideration Set



Emeril Lagasse 28 QT Extra Large Air Fryer, Convection Toaster Oven with French Doors, Stainless Steel


4.5 (1,234) | 100% (100)

\$151.99 (was \$199.99)

100% (100)

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART



Ninja AF101 Air Fryer that Crisps, Roasts, Reheats, & Dehydrates, for Quick, Easy Meals, 4 Quart Capacity, & High-Gloss Finish, Ergo


4.5 (1,234) | 100% (100)

\$79.99 (was \$99.99)

100% (100)

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART



Ninja Air Fryer Pro 4-in-1 with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air Crisp Technology with 400F for hot, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF161

4.5 (1,234) | 100% (100)

\$119.99 (was \$149.99)

100% (100)

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20


ADD TO CART

Digital Platform Setting

- and organic positions
- Sellers price and bid
- similar products within the same keyword
- different ASINs

Results

View a multi-product page for other buying options.



CHEFMAN Multifunctional Digital Air Fryer • Rotisserie, Dehydrator, Convection Oven, 17 Touch Screen Presets Fry, Roast, Bake, Dehydrate, Bake, XL 10L Family Size Auto ShutOff, Large Easy-View Window, Black

4.5 (1,230)

See how it compares to other models


\$99⁰⁰ (List: \$139.99)

Shipping

FREE delivery Sat, May 25

Or fastest delivery Thu, May 23

ADD TO CART



Emeril Lagasse 26 QT Extra Large Air Fryer • Convection Toaster Oven with French Doors, Stainless Steel

4.5 (1,231)

See how it compares to other models


\$151⁰⁰ (List: \$189.99)

Shipping

FREE delivery Sat, May 25

Or fastest delivery Thu, May 23

ADD TO CART



Ninja AF101 Air Fryer that Crisps, Roasts, Reheats, & Dehydrates, for Quick, Easy Meals, 4 Quart Capacity & High-Gloss Finish, Grey

4.5 (1,232)

See how it compares to other models


\$79⁰⁰ (List: \$99.99)

Shipping

FREE delivery Sat, May 25

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ADD TO CART



Ninja Air Fryer Pro 4-in-1 with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air Crisp Technology with 400F for hot, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF141

4.5 (1,233)

See how it compares to other models

\$119⁰⁰

Shipping

FREE delivery Sat, May 25

Or fastest delivery Thu, May 23

ADD TO CART

Consideration Set

Digital Platform Setting


- Heterogeneous consumers
 - consider different numbers of products
 - Platform displays products in
 - sponsored positions
 - and organic positions
 - Sellers price and bid

Digital Platform Setting

- similar products within the same keyword
- different ASINs
- **Heterogeneous consumers**
- consider different numbers of products

Results

View & search results for other keywords.



CHEFMAN Multifunctional Digital Air Fryer • Rotisserie, Dehydrator, Convection Oven, 17 Touch Screen Presets Fry, Roast, Dehydrate, Bake, XL 10L Family Size Auto Shutoff, Large Easy-View Window, Black

4.5 (1,234)


See how to save money

\$99 ^{MSRP \$199.99}

Yelp

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART



Emeril Lagasse 2B-QT Extra Large Air Fryer • Convection Toaster Oven with French Doors, Stainless Steel

4.5 (1,234)


See how to save money

\$151 ^{MSRP \$199.99}

Yelp

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART



Ninja AF101 Air Fryer that Crisps, Roasts, Bakes, & Dehydrates for Quick, Easy Meals, 4 Quart Capacity & High-Gloss Finish, Grey

4.5 (1,234)


See how to save money

\$79 ^{MSRP \$99.99}

Yelp

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

ADD TO CART



Ninja Air Fryer Pro 4-in-1 with 5 QT Capacity, Air Fry, Roast, Reheat, Dehydrate, Air Crisp Technology with ADFC for hot, crispy results in just minutes, Nonstick Basket & Crisper Plate, Grey, AF161

4.5 (1,234)

See how to save money

\$119 ^{MSRP \$149.99}

Yelp

FREE delivery Sat, May 21
Or fastest delivery Thu, May 20

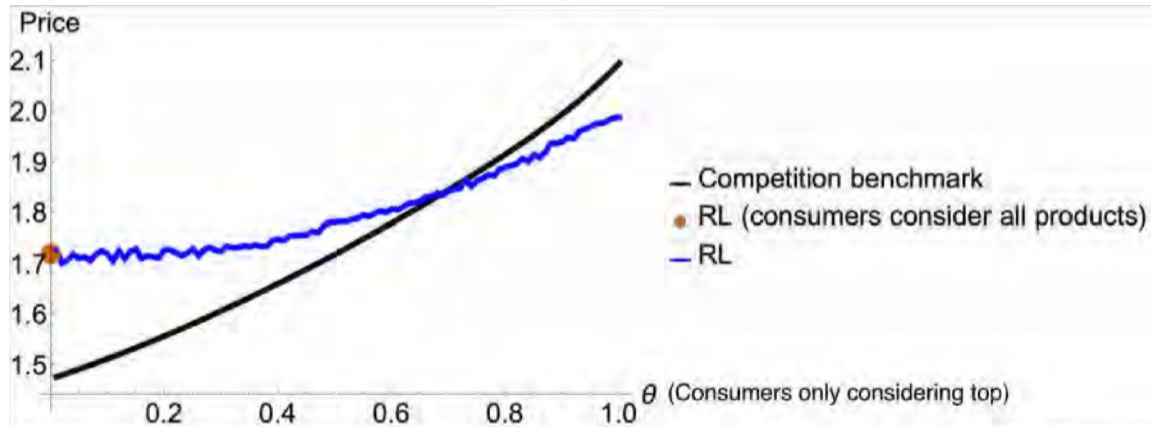
ADD TO CART

Consideration Set

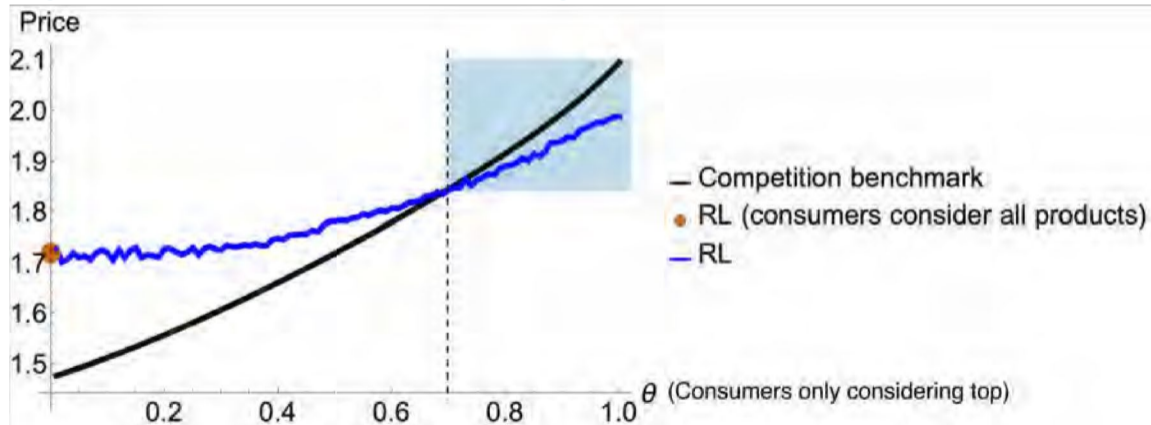
Algorithmic Pricing and Bidding

Reinforcement learning (RL) algorithms learn to **maximize profits** via dynamic **exploration/exploitation** of **prices and advertising bids** .

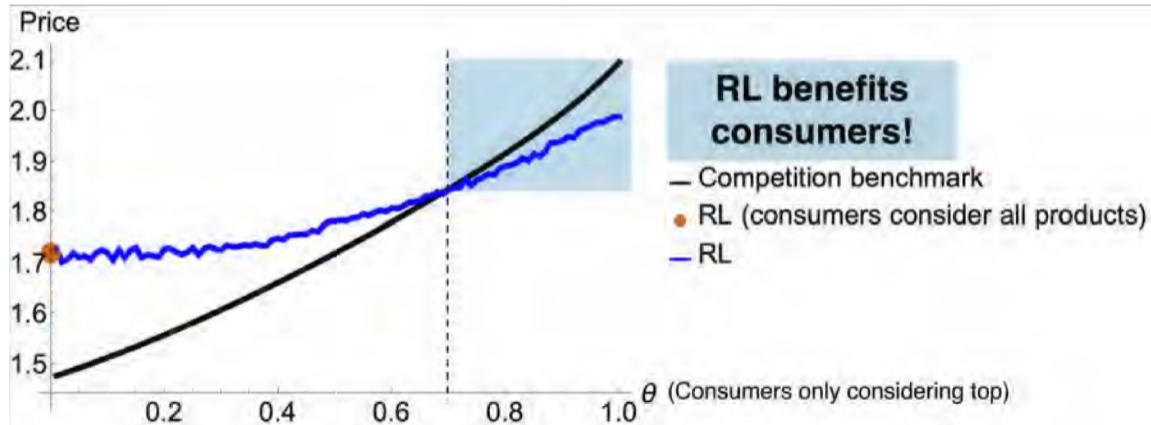
Algorithmic Decision-Making vs Competition Benchmark



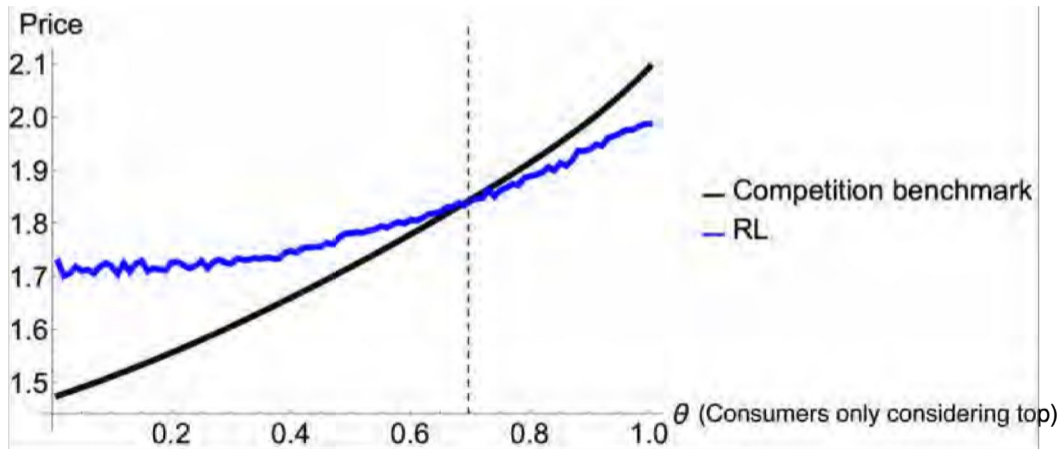
Algorithmic Decision-Making vs Competition Benchmark



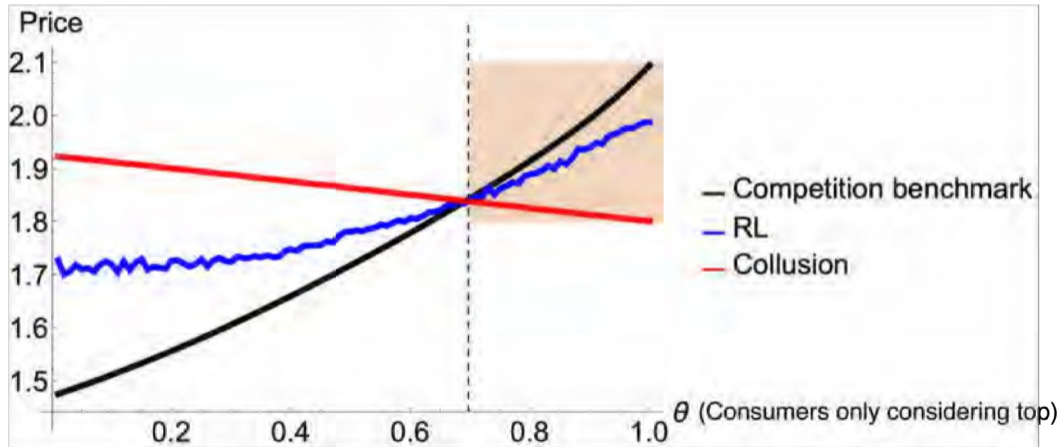
Algorithmic Decision-Making vs Competition Benchmark



Will the Results Generalize to Different Algorithms? YES!



Will the Results Generalize to Different Algorithms? YES!

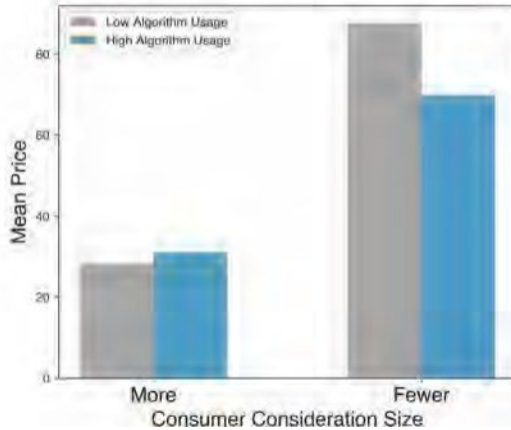


EmpiricalAnalyses:

ConsumerConsiderationSize \times AlgorithmUsage

Algorithms and Consideration Size Interaction

- **Negative** interaction of consideration size and algorithm usage on pricing.
- Algorithm index is imputed from pricing correlation (*Chen et al., 2016*).



▸ Contribution

▸ ByCategoryAlgorithmUsageIndex

Summary

- Algorithmic pricing can **benefit** consumers when the consideration set is small.
- The results of beneficial algorithmic pricing can **generalize** to different algorithms with an exploration feature.

- We find **empirical evidence** for these benefits on Amazon.com.
- We consider the **platform's strategic response** and find that algorithms can create a win-win-win scenario for consumers, sellers, and the platform itself.

Thank You

Email: zhaohc@wharton.upenn.edu

ronber@wharton.upenn.edu



Stylized Model of Two Ex-ante Symmetric Sellers

- In period t , seller i sets price p_i^t and bid b_i^t , and gets profit:

$$\pi_{it}(p_t, b_t) = \vartheta \cdot \Pr(b_i^t > b_j^t)$$

Consumers
 11111111111111111111111111111111 11111111111111111111111111111111 ¶

Prob i only con-
 sidering
 first
 product

Wins
 Auction

+ (1 - θ)

· $s_i(p_{it}, a_i)$

Consumers
Considering
Everything

$$- \gamma_i \cdot \mathbf{E}[b_{it} | b_{it} > b_{jt}] \cdot (1 - \tau) \cdot p_{it} - c_i$$

Logit Demand vs an Outside Good

Profit Margin

Ad costs per sale

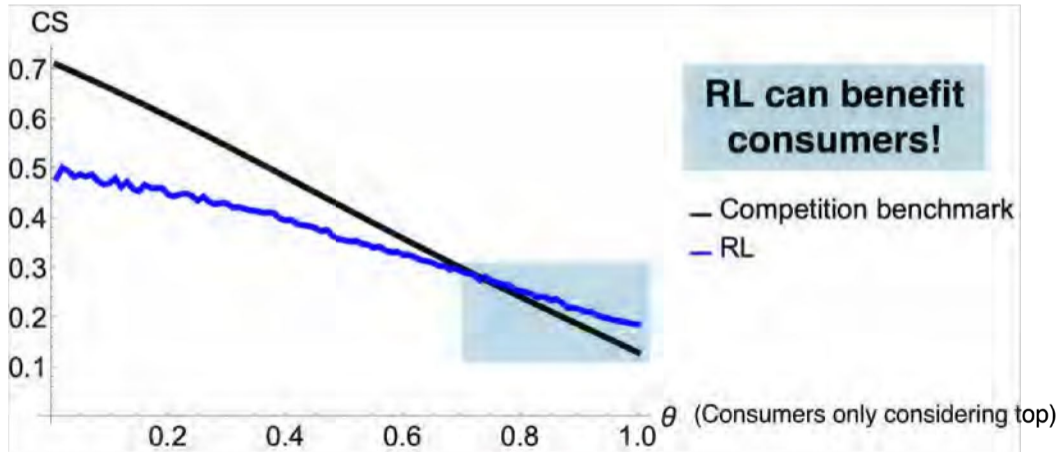
$$S_i(p_{it}, p_{jt}, a_i, a_j) \cdot ((1 - \tau) \cdot p_i^t - c_i)$$

Profit Margin vs an Outside Good

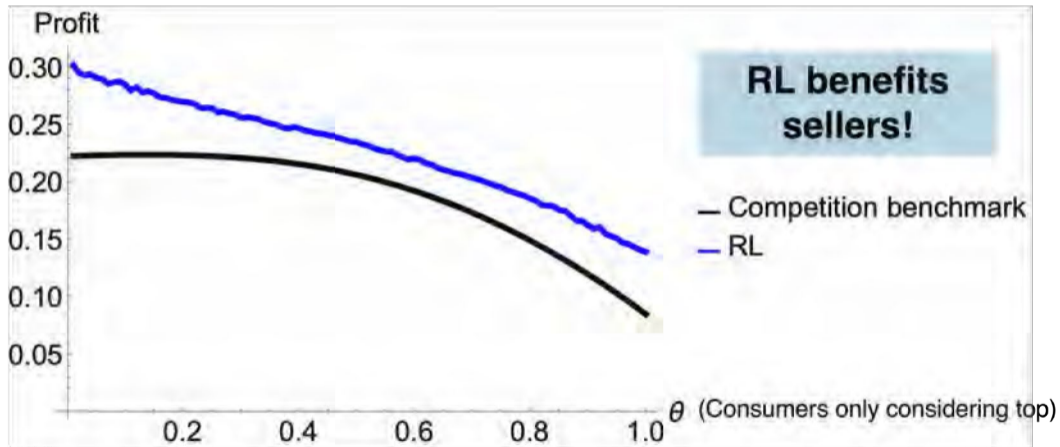
τ : commission rate, c production cost

- [▶ Micro foundation](#)
- [▶ Asymmetric sellers](#)
- [▶ Back](#)

RL Can Benefit Consumers

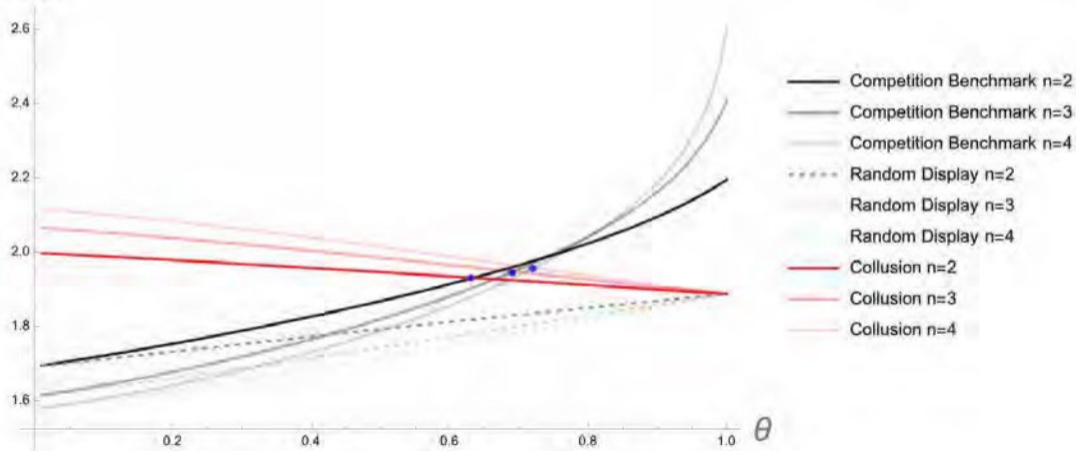


RL Benefits Sellers



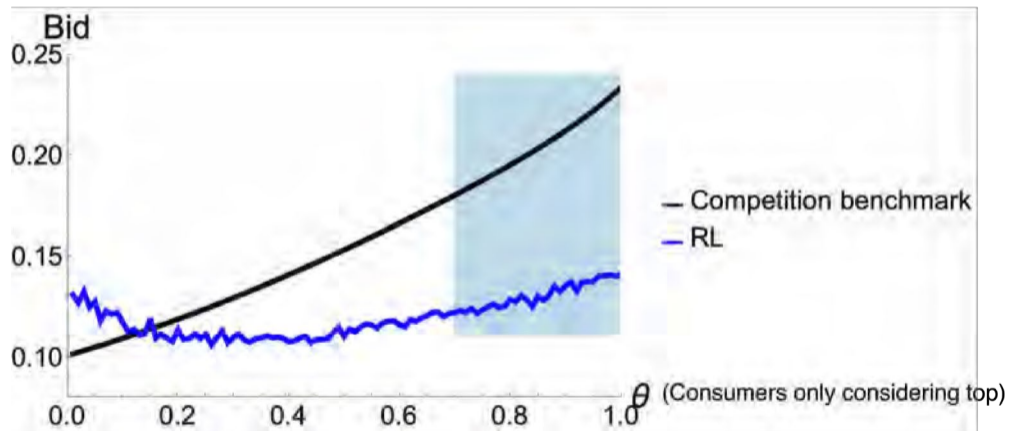
Would RL Always Lead to Lower Prices? YES!

Price



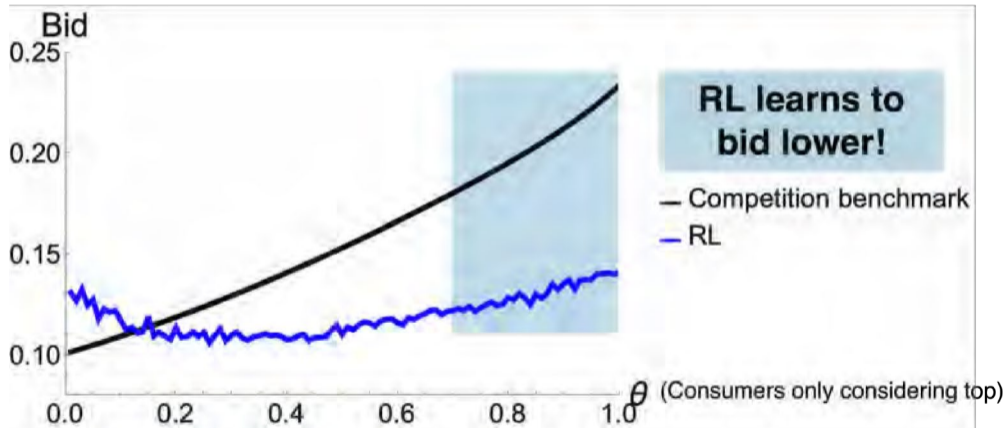
Mechanism: Bid Coordination

- RL can coordinate on lower bids, reducing costs and lowering prices.



Mechanism: Bid Coordination

- RL can coordinate on lower bids, reducing costs and lowering prices.



Algorithms Learn to Price and Bid

$$\begin{aligned}
 & \left\| \begin{matrix} Q_{t+1}(s,a) \\ \max_{a \in A} Q_t(s,a) \end{matrix} \right\| = (1 - \alpha) Q_t(s,a) + \alpha \left(\begin{matrix} r_t \\ \pi_t(s,a) \end{matrix} + \epsilon \right) + \delta \left\| \begin{matrix} Q_t(s,a) \\ a \in A \end{matrix} \right\|
 \end{aligned}$$

State-Action

Learning

Discount

Value

Rate

Factor

Function

- With a probability of $1 - \epsilon_t$, the algorithms **exploit**.

- With a probability of $\epsilon_t = e^{-\beta t}$, the algorithms **explore**, where $\beta > 0$ is the experimentation parameter

Micro Foundation of ϑ

- At each position, consumers compare

- the expected incremental utility of continuing their search to the next position, - and the cost s .
- Consumers search the first position but not the second

$$\log(1 + \delta_1) - 0 > s > \log(1 + \delta_1 + E[\delta^2 | \delta_1]) - \log(1 + \delta_1)$$

- Consumers search the second

$$\log (1 + \delta_1 + E [\delta^{\wedge}_2 | \delta_1]) - \log (1 + \delta_1) > s$$

Micro Foundation of ϑ

- Then ϑ and $1 - \vartheta$ can be expressed as

$$F_s (\log (1 + E [\delta^{\wedge}_1])) - F_s (\log (1 + \delta_1 + E [\delta^{\wedge}_2 | \delta_1]) - \log (1 + \delta_1)) \vartheta =$$

$$F_s(\log(1 + E[\hat{\delta}_1]))$$

$$1 - \vartheta = \frac{F_s(\log(1 + \delta_1 + E[\hat{\delta}_2 | \delta_1]) - \log(1 + \delta_1))}{F_s(\log(1 + E[\hat{\delta}_1]))}$$



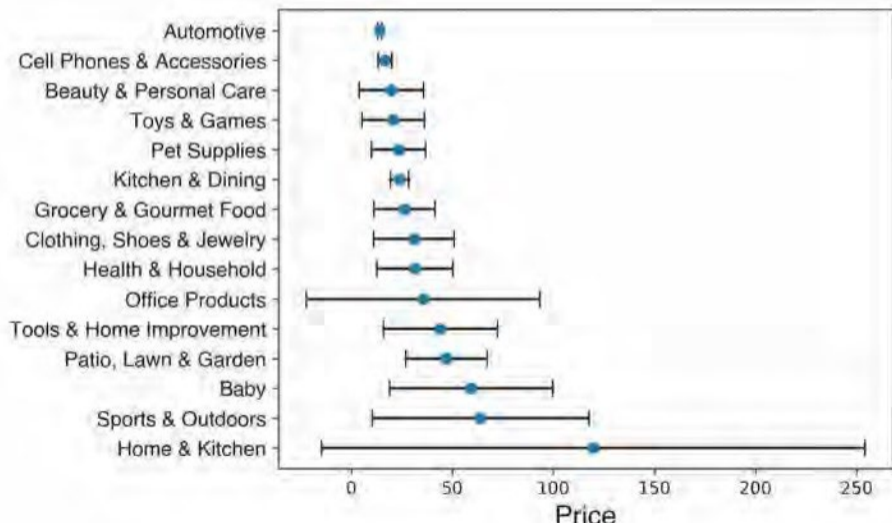
Model Details

- Identification:
- Unobserved quality follows AR(1), $\xi_{jt} = \eta_{jt} + \rho \cdot \xi_{jt-1}$.
- Contemporaneous shock of the unobserved quality is uncorrelated with previous period organic rank r_{jt-1}

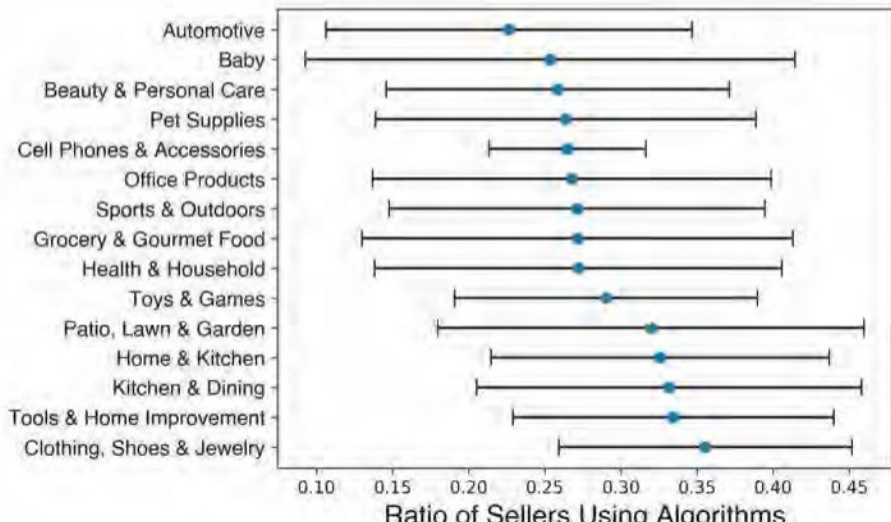
E

$$\begin{pmatrix} \eta_{jt} \cdot \tilde{\zeta}_{jt-1} \\ \eta_{jt} \cdot r_{jt-1} \end{pmatrix} = 0$$

By Category Price



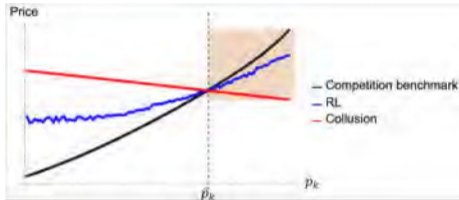
By Category Algorithm Usage Index



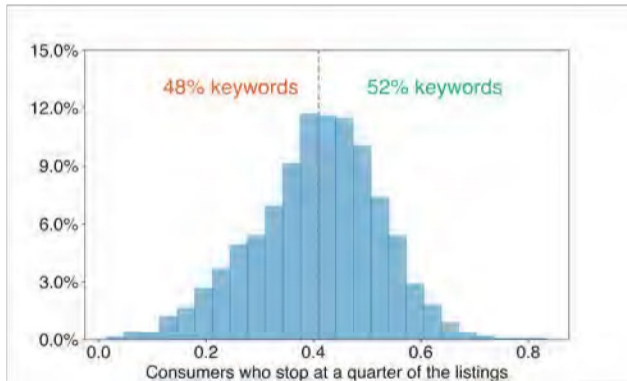
Compute RL Crossing Condition

- For every keyword k , estimate consumer consideration size \hat{p}_k .

- Use demand estimates from keyword k and the RL simulation to find the crossing condition p_k^- .
- If $p_k^{\hat{}} > p_k^-$, then algorithms can be beneficial in keyword market k .

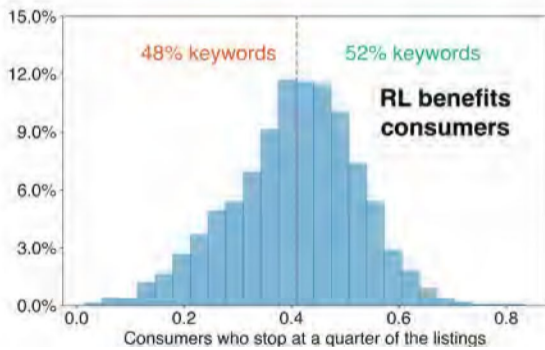


Compare Estimates With RL Crossing Condition



- Algorithms can lead to beneficial outcomes in 52% of Electronics markets.
- Regulation can be useful in markets with consumers considering more products. [▶ back](#) [▶ Summary](#)

Compare Estimates With RL Crossing Condition



- Algorithms can lead to beneficial outcomes in 52% of Electronics markets.
- Regulation can be useful in markets with consumers considering more products. [▶ back](#) [▶ Summary](#)

Platform's Strategic Response

- The platform has two revenue channels:



Platform's Strategic Response

- We consider two incentive-based instruments for the platform:



Platform's Strategic Response



[CommissionRate](#)

[ReservePrice](#)

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Platform's Strategic Response

- The platform should adjust **commission rate**, not adjust **auction reserve price**.



Platform's Strategic Response



[CommissionRate](#)

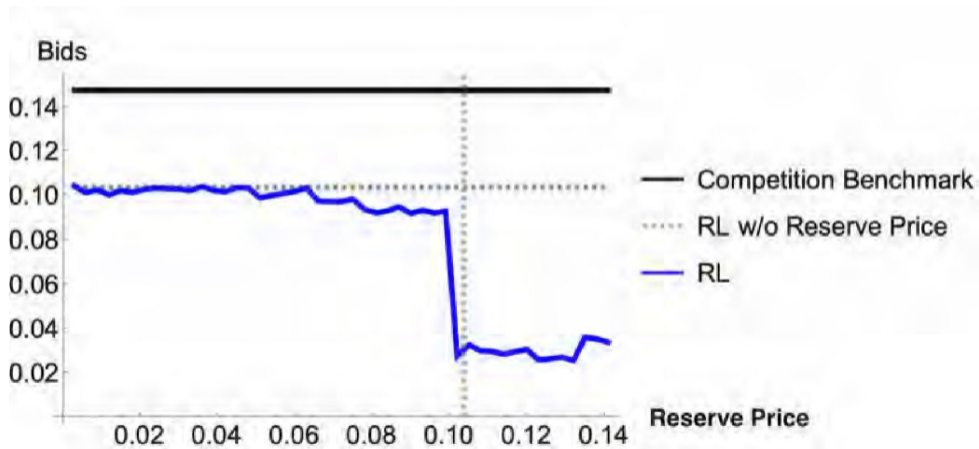
[ReservePrice](#)

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Reserve Price

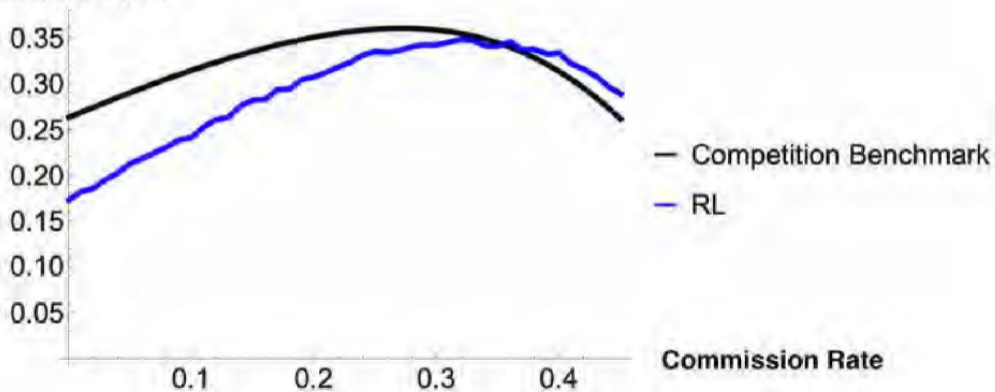
- Adjusting **auction reserve price** leads algorithms to coordinate on lower bids.



Commission Rate

- Adjusting **commission rate** recoups ad revenue from commissions.

Platform's Profit



Total Surplus

- When consumer search costs are high, algorithms increase total welfare.

