中国科学技术大学
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Transparency and Control in Platforms for Networked Markets

John Pang, Weixuan Lin, Hu Fu, Jack Kleeman, Eilyan Bitar, Adam Wierman

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Paper Information

Crosscutting Areas

Transparency and Control in Platforms for Networked Markets

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- Authors: John Pang,a,* Weixuan Lin,b Hu Fu,c Jack Kleeman,d Eilyan Bitar,b Adam Wiermana

John Zhen Fu Pang

- Education
  - California Institute of Technology (*Pasadena, CA September 2014-July 2019*)
    - PhD in Computing and Mathematical Sciences
    - Thesis: Online Platforms in Network Markets: Transparency, Anticipation and Demand Management.
  - Nanyang Technological University(*Singapore September 2010-December 2013*)
    - Bachelor of Science in Mathematical Sciences
- Publication
  - Operations Research
  - 21st Power Systems Computation Conference (PSCC)
  - ACM Sigmetrics
  - IEEE Transactions on Power Systems
- Work Experience
  - Institute for High Performance Computing, A*STAR (*Singapore October 2020-Present*)
    - Research Scientist
    - Model and analyze critical systems under various national targets for vehicular electrification
  - Software Technology and Innovation Center, Schlumberger (*Menlo Park, CA, USA July 2019-August 2020*)
    - Proof-of-Concept Machine Learning Projects for Oil and Gas Industry
  - Software Technology and Innovation Center, Schlumberger (*Menlo Park, CA, USA Summer 2017,2018*)
    - Data Science/Machine Learning Intern

Weixuan Lin

Applied Scientist, Amazon.com

■ Education

- Cornell University (*Ithaca, NY, USA*)
  - PhD in electrical and computer engineering
  - Research interests: stochastic control, algorithmic game theory and online algorithms
  - Thesis: Decentralized Control of Constrained Linear Systems via Convex Optimization Methods
- Tsinghua University(*Beijing, China*)
  - Bachelor of Science in electrical engineering

■ Publication

- Operations Research
- IEEE Transactions on Sustainable Energy
- IEEE Transactions on Power Systems
- IEEE Transactions on Sustainable Energy
- IEEE Transactions on Automatic Control

Hu Fu

- Education
  - Cornell University (*Ithaca, NY, USA*)
    - PhD in Computer Science
- Publication
  - Operations Research
  - Games and Economic Behavior
  - Mathematics of Operations Research
  - Proceedings of the 55th Annual ACM Symposium on Theory of Computing
  - International Conference on Web and Internet Economics
  - Symposium on Simplicity in Algorithms
  - Proceedings of the AAAI Conference on Artificial Intelligence
- Work Experience
  - Postdoc at Microsoft Research, New England Lab
  - Postdoc at Caltech, Computing and Mathematical Sciences
  - Assistant professor in the Department of Computer Science of the University of British Columbia (*2016-2020*)
  - Associate professor in the Institute for Theoretical Computer Science at Shanghai University of Finance and Economics

Jack Kleeman

- Work Experience
  - *2021*- Partner at Index Ventures, investing in developer tools, infrastructure and security.
  - *2020-2021* Site Reliability Engineer in Apple's Cloud Infrastructure org. Led a team managing petabytescale distributed storage on Kubernetes.
  - *2017* Five weeks as a Backend Engineering intern for Monzo, building fraud detection tools using Go microservices and Cassandra, as well as front end work in React.
  - *2017* Two months as an Undergraduate Research Fellow at **Caltech** in the Social and Information Sciences Laboratory**,** studying **algorithmic game theory**. I completed a project on search costs in decentralised markets.

- Education
  - St Catharine's College, Cambridge – Economics (*2015-2018*)
  - First class, ranked 9th/151

Eilyan Bitar

- Education
  - UC Berkeley(*2011*)
    - PhD
  - UC Berkeley(*2006*)
    - Bachelor
- Work Experience
  - Postdoctoral Fellow at the California Institute of Technology(Hosted by Adam Wierman and Steven Low,*2012*)
  - Invited Visiting Scientist at the Simons Institute for the Theory of Computing as part of a research program on Algorithms and Uncertainty(*2016*)
  - Visiting Academic at Amazon(*Currently*)
  - Associate Professor in the School of Electrical and Computer Engineering at Cornell University
- Publications
  - Proceedings of the IEEE Conference on Decision and Control
  - IEEE Transactions on Automatic Control,
  - Proceedings of the American Control Conference
  - IEEE Transactions on Power Systems
  - Proceedings of the 55th IEEE Conference on Decision and Control
- Research Interests
  - robust and stochastic optimization, control

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Adam Wierman

Education

- Carnegie Mellon University
  - Ph.D. (*2007*) Computer Science
  - M.Sc. (*2004*) Computer Science
  - B.Sc. *(2001)* Computer Science with an additional major in Mathematics

Work Experience

- Assistant Professor of Computer Science, California Institute of Technology (*2007-2012*)
- Professor of Computer Science, California Institute of Technology(*2012-2015*)
- Director of Information Science and Technology (*2016-pres*), California Institute of Technology
- Executive officer (a.k.a. Department Chair) (*2015-2020*),California Institute of Technology

Publications

- Operations Research
- ACM Sigmetrics 2022
- Journal of Electric Power Systems Research
- IEEE ACC 2022
- IEEE/ACM Transactions on Networking

Research Interests

- Sustainable computing; Network economics; Power systems; Online algorithms; Scheduling and resource allocation;Distributed Systems; Stochastic Networks

Scenario

- Platforms **match** producers to consumers and **set prices** algorithmically.

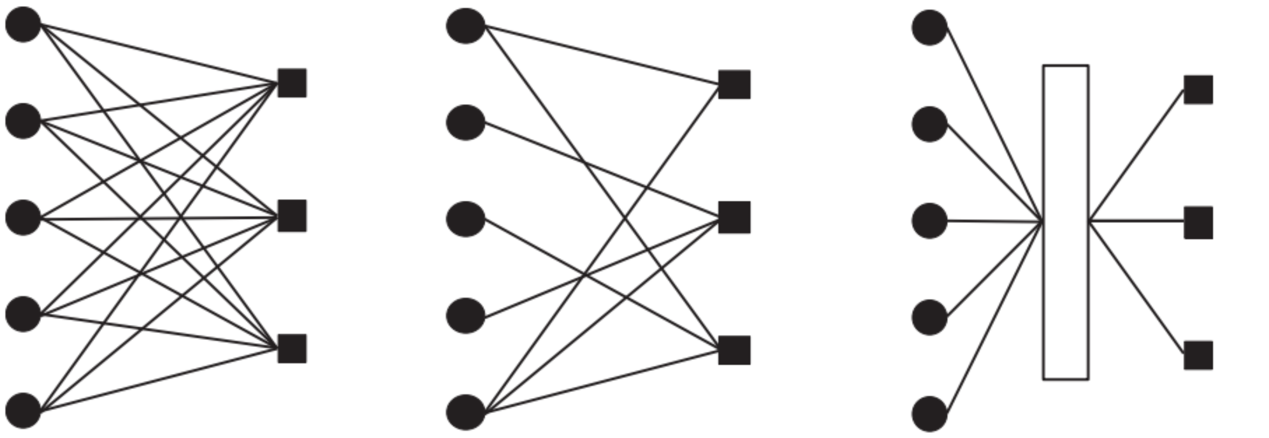
- Many other platforms connect producers to consumers in innovative ways to improve both the **provisioning of supply** and **fulfillment of demand.**

- This paper investigates the trade-off between **transparency** and **control** that arises in the **design of access and allocation control** mechanisms in platforms, using **networked Cournot competition**.

Problem

- Three designs:
  - *Open access design*. Displays the offers from all produces to all customers.
  - *Controlled allocation design*. It only allows drivers to accept or decline the ride that is assigned from the platform.
  - *Discriminatory access design*. Directs customers to preselected BuyBox producers.
- Research Problems:
  - *What is the worst-case efficiency loss of platforms under these designs?*
  - *What is the impact of allocation control on worst-case efficiency loss?*
  - *Is there a sweet spot between open access and controlled allocation mechanism?*

(a) Open Access (b) Discriminatory Access (c) Controlled Allocation



Literature Review

Related area	Published research	Research content	Gap
Platform Design and Operation	Rochet and Tirole(2003);Evans and Schmalensee (2005);Armstrong(2006);	**Earlier** works introduce different models of two-sided platform markets; **Recent** research focus on identifying design features that are common to successful platforms	Understand the impact of different **access and allocation control** mechanisms on the **efficiency** of two-sided platforms
Open Access, Controlled Allocation and Discriminatory Platforms and Design Factors	Hui et al. (2016); Alijani et al. (2017) Chen (2017); Liang et al. (2017);	Benefits of different designs. **Pricing and allocation policies** that might limit price manipulation from suppliers. The effect of **algorithmic pricing on the efficiency** of the discriminatory access platform. The impacts of **different aspects of platform**.	Examine the reduction in **worst-case efficiency loss** (relative to open access designs) that can be attained through discriminatory access.
Networked Competition	Ilkilic (2009); Xu et al. (2017); Bimpikis et al. (2019b)	Capture the effects of **network constraints** on strategic interactions between firms.	Extend on **worst-case efficiency loss** of **Cournot games** to the **network setting**

Open Access Model

- Quantity produced by firm i in market j: q_{ij}
- $q_i = (q_{i1}, \dots, q_{im}) \in \mathbb{R}_+^m$
- Aggregate quantity by firm i: $s_i \coloneqq \sum_{j=1}^m q_{ij}$
- Demand Model: $p_j(d_j) \coloneqq \alpha_j - \beta_j d_j$
- Social welfare:

$$SW(q, C) \coloneqq \sum_j^m \int_0^{d_j} p_j(z)dz - \sum_i^n C_i(s_i)$$

- Efficient social welfare given edge set $F \times M$

$$SW^*(F \times M, C) \coloneqq \sup_{q \in Q(F \times M)} SW(q, C)$$

Controlled Allocation Model

- Objective of platform:

$$\max \mathrm{OBJ}(d; \lambda) \coloneqq \lambda \cdot \mathrm{CS}(d) + (1 - \lambda) \cdot \mathrm{REV}(d) \quad (4)$$

$$\text{subject to} \sum_{j=1}^m d_j = Q$$

- Products provided by firms: $Q = \sum_{i=1}^n s_i$
- Consumer surplus:

$$\mathrm{CS}(d) \coloneqq \sum_{j=1}^m \int_0^{d_j} p_j(z)dz - d_j p_j(d_j)$$

$$\mathrm{REV}(d) \coloneqq \sum_{j=1}^m d_j p_j(d_j)$$

- Price paid to firms: $p(d) \coloneqq \frac{\sum_j^m d_j p_j(d_j)}{\sum_j^m d_j}$
- Solution to (4): $A_\lambda: \mathbb{R}_+ \to \mathbb{R}_+^m$

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Competition under open access and discriminatory access platforms

- The competition is described by networked Cournot game.
- Payoff function of firm i:

$$\pi_i(q_i, q_{-i}) := \sum_{j=1}^{m} q_{ij} p_j(d_j) - C_i(s_i)$$

- Feasible supply profiles associated with firm i

$$Q_i(\mathcal{E}) := \left\{x \in \mathbb{R}_+^m \middle| x_j = 0, \forall (i,j) \notin \mathcal{E}\right\}$$

- Triple $(F, Q(\mathcal{E}), \pi)$ defines a normal-form game
- Nash equilibrium quantity $q^{NE}(\mathcal{E}) \in Q(\mathcal{E})$
- Definition 2 (Price of Anarchy).

$$\rho(\mathcal{E}, C) := \frac{SW^*(F \times M, C)}{SW(q^{NE}(\mathcal{E}), C)}$$

Competition under controlled allocation platforms

- The competition is described by a multi-leader, single-follower Stackelberg game.
- Payoff function of firm i:

$$\pi_i(s_i, s_{-i}; \lambda) := s_i p\left(A_\lambda\left(\sum_{i=1}^{n} s_i\right)\right) - C_i(s_i)$$

- Definition 4. The price of anarchy $\rho(\lambda, M)$ associated with the networked Stackelberg game with platform objective function determined by λ and a set of markets M is defined as:

$$\rho(\lambda. M) := \sup_{s \in SE} \frac{SW^*(F \times M, C)}{SW(s, \lambda)}$$

Results about Open Access Platforms

- Tight bounds on the worst-case efficiency loss in open access platforms

Theorem 1. The worst-case efficiency loss associated with a cost function profile C and the corresponding open access networked Cournot game $(F, Q(F \times M), \pi)$ is upper bounded by

$$\rho(F \times M, C) \leq \frac{3}{2}\left(1 - \frac{1}{3n+6}\right)$$

Proposition 1. At each Nash equilibrium, the demand fulfilled in each market $j \in M$ is at least half of the demand fulfilled at the socially efficient production profile

- Symmetric Cost Profiles

Proposition 2. Assume that $C_1 = C_2 = \cdots = C_n$. The price of anarchy associated with the corresponding networked Cournot game $(F, Q(F \times M), \pi)$ is upper bounded by

$$\rho(F \times M, C) \leq 1 + \frac{1}{(n+1)^2 - 1}$$

Additionally, this bound is tight.

Results about Controlled Allocation Platforms

- The price of anarchy of the controlled allocation platform that maximizes social welfare grows at least linearly in the number of markets.

Theorem 2. The price of anarchy of a controlled allocation platform that maximizes social welfare $\mathrm{OBJ}(d; 1/2)$ grows at least linearly in the number of markets. That is, there exists a family of inverse demand functions and cost profiles such that

$$\rho(1/2, M) \geq \frac{8m}{9}$$

- Lower bounds on the PoA

Theorem 3. Assume that there are at least $m \geq 2$ markets. The price of anarchy $\rho(\lambda, M)$ in controlled allocation platforms satisfies:

$$\rho(\lambda, M) \geq \begin{cases} \max\left\{\frac{3}{2}, \frac{2}{3}\left(1+\sqrt{1+\frac{\lambda^2}{(2\lambda-1)(\lambda-1)}}\right)\right\}, & \lambda \in \left[0, \frac{1}{2}\right) \\ \frac{8m}{9}, & \lambda \in \left[\frac{1}{2}, \frac{2}{3}\right) \\ \infty, & \lambda \in \left[\frac{2}{3}, 1\right] \end{cases}$$

Results about Discriminatory Access Platforms

- The bound on the PoA

Theorem 4. Let $C \in \mathcal{L}^n(c_{min}, c_{max})$ and assume that $c_{min} < \max_{j\in M} \alpha_j$. Additionally, let $\mathcal{E}^* \subseteq F \times M$ denote the network structure that maximizes the social welfare derived under discriminatory access platforms at Nash equilibrium according to Problem (12). The efficient social welfare associated with the edge set $\mathcal{E}^*$ satisfies:

$$SW^*(\mathcal{E}^*, C) = SW^{\&}(F \times M, C)$$

Moreover, the price of anarchy of the corresponding networked Cournot game $(F, Q(\mathcal{E}^*), \pi)$ is upper bounded by

$$\rho(\mathcal{E}^*, C) \leq \frac{\sum_j^m \frac{\left(\left(\alpha_j - c_{min}\right)^*\right)^2}{\beta_j}}{\sum_j^m \max_{k\in\{1,\dots,n\}} \left\{\frac{2k+4}{3k+5} + \delta(\gamma_j, k)\right\} \frac{\left(\left(\alpha_j - c_{min}\right)^*\right)^2}{\beta_j}}$$

The bound is tight if $\alpha_1 = \alpha_2 = \cdots = \alpha_m$

Approach

Central planner's perspective	*What is the **worst-case efficiency loss** of platforms under three designs?*		
Three designs	Open Access	Controlled Allocation	Discriminatory
Model and Analysis	**Networked Cournot Game**	**Networked Stackelberg Game**	**Networked Cournot Game**
	Upper bound on efficiency loss	Lower bound on efficiency loss	Upper bound on efficiency loss
	Symmetric and Asymmetric cost profile	Lower bound for different weights	Greedy algorithm for optimal network design problem
Conclusion	At least 2/3 of the efficient social welfare	Worst case efficiency loss is unbounded	At least 4/3 of the efficient social welfare

Thank you for listening!

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