Platforms with Heterogeneous Externalities

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Motivation

"Soap" operas and American Express

- Literature on "platforms" (endogenous characteristics)
  - Products designed to select among users
  - Literature does not allow this with rich heterogeneity of...
    - Both *preferences* and *contributions*; our purpose
- Key idea is that users play two roles
  1. *Consume* the product as in standard IO
  2. *Produce* endogenous characteristics consumed by others

  $\Longrightarrow$ Must combine with Spence's quality-choosing monopolist
    - Idea comes from my *AER* paper
    - But here add heterogeneity of *contributions*
    - Requires Rotschild-Stiglitz: design product to attract best
- But RS and follow-ons allow only one-D heterogeneity
  - Everything a bang-bang solution, difficult for empirics
- Here general logic based on $\mathrm{Cov}[\mathrm{preference}, \mathrm{contribution}]$

Plan for talk

1. Brief literature review
2. Simple example for main points: three stages
    1. Armstrong's homogeneous model
    2. Preference heterogeneity (my *AER* paper)
    3. Heterogeneous externalities (our contribution)
3. General model: arbitrary charcteristics
4. Applications
    1. Newspapers: classic platforms
    2. Broadcast media: non-transferable utility and soap operas
    3. Credit cards: non-linear pricing and AmEx
    4. Insurance: Rotschild-Stiglitz meets Einav-Finkelstein (?)
5. General results(??)
6. Coordination and insulation(???)
7. Conclusion

Two strands of literature

Our paper tries to unify, simplify and generalize two literatures

1. Platforms
   - Few papers study pricing with heterogenous externalities
     - See Rysman (2009) for overall survey of literature
   - Those that do only measure, don't study pricing
     - Tucker (2008), Cantillon and Yin (2008) and Lee (2010)
   - Except for a few with stylized or one-dimensional models
     - Chandra and Collard-Wexler (09) and Athey et al. (10)
     - Bardey-Rochet (06), Hagiu, Gomes (09), Jeon-Rochet (10)
     - Best of this: Gomes and Pavan (11)
2. Multi-dimensional screening
   - Richer heterogeneity, but mathematically complex
     - Armstrong (1996), Rochet and Choné (1998), etc.
   - Little economic intuition or connection to measurement

Contribution and goals

1. Economic intuition + empirical relevance
2. Rich and general framework connecting literatures

Very recently a few papers come close; most related:

1. Einav et al. (2010) and Einav and Finkelstein (2011)
    - Simple, graphical representation of adverse selection
    - Rich heterogeneity *but all non-price characteristics fixed*
    - Focus here is choice of non-price product characteristics
2. Einav et al. (2011): elasticities for characteristics
    - But does not link to social optimality or to primitives
    - Tough for policy analysis, connection to contract theory
    - Not platform: users don't value endogenous characteristics
3. Weyl and Tirole (2011): multi-D screening and IP
    - Specific application, form, etc., but similar covariances
    - Richer in instruments, endogenous sorting, but less general

Armstrong (2006)'s model

Build from simplest model: Armstrong (2006), linear cost cN

- For simplicity, one-sided model (little lost v. two sides)
- Quasi-linear utility *maintained throughout*
- Homogeneous contributions: users care about total N
- Homogeneous value for characteristic: users value $u(N)$
- Heterogeneous, full support reservation v_i, CDF F
  - Armstrong-Vickers (01): choose utility $\overline{v}$, internalize
    $$\max_{\overline{v}} \left[u\left(F\left(\overline{v}\right)\right) - c - \overline{v}\right] F\left(\overline{v}\right)$$
  - Net social (private) pricing trivial where $N \equiv F\left(\overline{v}\right)$:

$$P = \underbrace{c}_{\text{marginal cost}} - \underbrace{u'N}_{\text{externality}} + \underbrace{\left(\frac{F}{f}\right)}_{\text{inverse hazard/Cournot distortion} \equiv \mu}$$

  - Identical to economies of scale: only Cournot distortion

"A Price Theory of Multi-Sided Platforms"

Let's allow heterogeneity in valuation of externality

- Now general cost $C(N)$, utility from consuming $u(N; \boldsymbol{\theta})$
  - Only assume smoothness, full support, quasi-linearity
  - Maintain dependence on N, so homogeneous contributions
  - RT2006 (RT2003 when $\theta_2 \equiv 0$) special case where $u(N; \boldsymbol{\theta}) = \theta_1 N + \theta_2$
- Timing:
  1. Platform chooses prices
  2. Users decide whether to participate
- Note that there is a potential coordination problem
  - I will ignore this until end of talk...
  - But important contribution was solution concept to solve
  - Just imagine platform can directly choose N
    - This then ties down prices by inverse demand

The Spence distortion

Socially optimal pricing maximizes $V(N) - C(N)$:

$$P = \underbrace{C'}_{\text{private marginal cost}} - \underbrace{\overline{u'}N}_{\text{externality}}$$

- $\overline{u'} \equiv$ average marginal value to participating users
- Just standard Pigou; private optimum sets $MR = MC$

$$\underbrace{P - \mu}_{\text{classical marginal revenue}} + \underbrace{\widetilde{u'}N}_{\text{MR from externalities}} = \underbrace{C'}_{\text{marginal cost}}$$

$\Longrightarrow$ Two distortions from inability to price discriminate

1. Classical Cournot (1838): market power upwards μ
2. Spence (1975): internalize wrong quality preference
   - $\widetilde{u'} \equiv$ average marginal value to *marginal* users
   - Then you were a tourist...

Heterogeneous externalities

Key restriction so far: only *number of* people

- Now we want to allow composition to matter
- $u(E;\theta_i) - P$, $E = \int_{\theta:u(E;\theta)\geq P} e(\theta) f(\theta) d\theta$

$\Longrightarrow$ Hetero. in *generation of* and *valuation for* externalities

- Crucial quantities:
  1. Density of marginal users M
  2. Average marginal contribution $\widetilde{e}$
  3. Average marginal externality of average: $\overline{u'}$
  4. Average marginal externality to marginal: $\widetilde{u'}$
  5. Extent of sorting by E for e, $\sigma \equiv \text{Cov}\left[u', e|u = P\right]$
- We can use these to derive private and social optimum:
  1. $P + \widetilde{e}\overline{u'}N + \widetilde{e}M\sigma\frac{C'-P}{\widetilde{e}} = C'$
     - Direct externality + sorting for those who value quality...
     - Value of the latter is same, so infinite series/implicit
  2. Private optimum same, except for Spence distortion below

Private and social pricing

Rearrangement yields simple rules:

1. Social:

$$S \equiv C' - P = \tilde{e} \frac{\overbrace{\overline{u'}N}^{\text{direct externality}}}{\underbrace{1 - M\sigma}_{\text{infinite series formula}}}$$

2. Private:

$$D \equiv C' + \mu - P = \tilde{e} \frac{\widetilde{u'}N}{1 - M\sigma}$$

- Telemarkets v. shmoozers on the margin
- (A)Symmetry between social and private conditions
- Spence distortion magnified or mitigated
- With no correlation, collapses to above with average

A general model

This example was special because :

1. Only one endogenous characteristic (ec)
2. No instruments other than price
3. Platform cares only about quantity, not other ec's

Fundamental covariance logic applies much more broadly

1. Allow any number instruments $\boldsymbol{\rho}$
   - May or may not ("non-transferable utility") include price
2. Allow any number of ec's $\mathbf{E}$
3. Platform's profit $\pi(\boldsymbol{\rho}, \mathbf{E})$
4. User i's utility is $u(\boldsymbol{\rho}, \mathbf{E}; \boldsymbol{\theta}_i)$
5. Total user surplus is $V(\boldsymbol{\rho}, \mathbf{E}) = \int_{\boldsymbol{\theta}: u(\boldsymbol{\rho}, \mathbf{E}; \boldsymbol{\theta}) \geq 0} u(\boldsymbol{\rho}, \mathbf{E}; \boldsymbol{\theta}) f(\boldsymbol{\theta}) d\boldsymbol{\theta}$
6. $E_i = \int_{\boldsymbol{\theta}: u(\boldsymbol{\rho}, \mathbf{E}; \boldsymbol{\theta}) \geq 0} e_i(\boldsymbol{\theta}, \boldsymbol{\rho}, \mathbf{E}) f(\boldsymbol{\theta}) d\boldsymbol{\theta}$

Start with applications, rather than general solution

Newspapers and classic platforms

Let's start with classic platform: newspapers

- Gentzkow-Shapiro (2010): profit-maximizing media slant
  - Focus: Hotelling model, homogeneous value to advertisers
  - Let's consider a general version of this model
  - Assume income $i^{\mathcal{R}}$ of readers determines value
- Readers $u^{\mathcal{R}}\left(s;\boldsymbol{\theta}^{\mathcal{R}}\right) - P^{\mathcal{R}}$, advertisers $\theta^{\mathcal{A}} I^{\mathcal{R}} - P^{\mathcal{A}}$
- Profits $P^{\mathcal{R}} N^{\mathcal{R}} + P^{\mathcal{A}} N^{\mathcal{A}} - C\left(N^{\mathcal{R}}, N^{\mathcal{A}}, s\right)$
- FOC's for prices as well, but focus on slant:

$$\underbrace{C_s}_{\text{marginal cost of slant}} = \underbrace{N^{\mathcal{R}}\widetilde{u^{\mathcal{R}\prime}}}_{\text{value by marginal reader}} + \underbrace{\frac{N^{\mathcal{A}}P^{\mathcal{A}}}{\mu^{\mathcal{R}}}\sigma^{\mathcal{R}}_{u',i}}_{\text{value of sorting}}$$

- GS ignore second term on right, test for $E\left[C_s|X\right] = 0$
- Ours captures value of sorting (in one robustness check)

Broadcast media and non-transferable utility

Many media platforms don't charge viewers, only advertisers

- Non-transferable utility: broadcast TV, radio, websites
- Advertisers as before, viewers have no price
- Content $m \equiv$ melodrama; power of family purse i
- Viewers also care about nuisance A; cost $C\left(m, N^{\mathcal{A}}, N^{\mathcal{V}}\right)$
- Without transfers, two changes to covariance
  1. *Normalize into utils*: $\sigma^{\mathcal{V}}_{u_A,i} \equiv \mathrm{Cov}\left[\frac{u^{\mathcal{V}}_A}{\widetilde{u^{\mathcal{V}}_A}}, i \middle| u^{\mathcal{V}} = 0\right]$
  2. *Relative covariance* is what matters: $\sigma^{\mathcal{V}}_{u_A-u_m,i}$
- Useful to derive *shadow value* of advertising:

$$\lambda^A = \underbrace{C_m \frac{\widetilde{u^{\mathcal{V}}_A}}{\widetilde{u^{\mathcal{V}}_m}}}_{\text{direct externality}} + \underbrace{\mu^{\mathcal{V}} N^{\mathcal{A}} P^{\mathcal{A}} \widetilde{u^{\mathcal{V}}_A} \sigma^{\mathcal{V}}_{u_A-u_m,i}}_{\text{boomerang sorting externality to advertisers}}$$

Optimal broadcast program design

Profit-maximizing pricing/content provision then simple:

$$P^{\mathcal{A}} = \mu^{\mathcal{A}} + C_{N^{\mathcal{A}}} - \tilde{a}\lambda^{A}$$

$$\underbrace{0}_{\text{Price}} = \underbrace{\frac{C_m}{M^{\mathcal{V}}\widetilde{u_m^{\mathcal{V}}}}}_{\text{quasi-market power}} + \underbrace{C_{N^{\mathcal{V}}}}_{\text{marginal cost}} - \underbrace{\frac{P^{\mathcal{A}}N^{\mathcal{A}}}{I}}_{\text{per-income price for ads}} \left(\underbrace{\widetilde{u_m^{\mathcal{V}}}\sigma^{\mathcal{V}}_{u_m,i}}_{\text{why soap operas}} + \underbrace{\tilde{i}}_{\text{standard externality}} \right)$$

Can also derive socially optimal prices...

- But requires stand on interpersonal comparisons
- No transfers assumption to rely on
- How to measure? Important in many literatures

Credit cards and non-linear pricing

Classic multi-D screening and classic platforms combined:

1. Rochet-Stole (02): non-linear pricing with random exit
2. Rochet-Tirole (03): credit cards (fixed and usage fees)
    - Only Bedre-Defolie and Calvano (2010): very restrictive

We generalize both with rich distributions

- Though only two-part tariff method easy to extend
- Consumers $\mathcal{C}$ and merchants $\mathcal{M}$; random matching
- Platform charges fixed $P^{\mathcal{C}}$, linear $p^{\mathcal{C}}$ and linear $p^{\mathcal{M}}$
- Merchants have net value $\theta^{\mathcal{M}}$ per purchase
    - Accept if $\theta^{\mathcal{M}} \geq p^{\mathcal{M}}$; fraction $N^{\mathcal{M}}$ join
- Consumers choose $q\left(p; \boldsymbol{\theta}^{\mathcal{C}}\right)$ conditional card purchases
    - Envelope: $U^{\mathcal{C}}\left(p; \boldsymbol{\theta}^{\mathcal{C}}\right) = \int_p^{\infty} q\left(\rho; \boldsymbol{\theta}^{\mathcal{C}}\right) d\rho - pq\left(p; \boldsymbol{\theta}^{\mathcal{C}}\right)$
    - Carry card if $U^{\mathcal{C}} N^{\mathcal{M}} \geq P^{\mathcal{C}}$; total fraction of purchases Q
- Cost $cQN^{\mathcal{M}}$

Optimal two-part pricing credit card pricing

Socially optimal merchant price $P^{\mathcal{M}} = \left(c - \overline{U^{\mathcal{C}}} - p\right) Q$

- Profit maximizing: $P^{\mathcal{M}} = \left(c - \frac{P^{\mathcal{C}}}{N^{\mathcal{M}}} - p\right) Q + \mu^{\mathcal{M}}$

Socially optimal fixed fee $P^{\mathcal{C}} = 0$; profit max:

$$P^{\mathcal{C}} = \underbrace{\mu^{\mathcal{C}}}_{\text{market power}} - \underbrace{\tilde{q}\left(p + \frac{P^{\mathcal{M}}}{Q} - c\right)}_{\text{average marginal profits from entrants}}$$

Most interesting is linear, socially optimal $p^{\mathcal{C}} = c - \overline{\theta^{\mathcal{M}}}$

Profit-maximizing linear-part of credit card tariff

$$p^{\mathcal{C}} = c + \underbrace{\frac{P^{\mathcal{M}}}{Q}}_{\text{Spence for merchants}} + \frac{\overbrace{1 - \frac{\widetilde{q}}{\overline{q}}}^{\text{Spence distortion of consumers}}}{\underbrace{\frac{\epsilon_X^{\mathcal{C}}}{p}\frac{\widetilde{\text{Var}}(q)}{\widetilde{q}}}_{\text{Sorting discipline (relaxed by travel)}} + \underbrace{\frac{\overline{\epsilon_q^{\mathcal{C}}}}{p}}_{\text{Wilson-Mussa-Rosen term}}}$$

- $\epsilon_X^{\mathcal{C}} \equiv \frac{\widetilde{q} M^{\mathcal{C}} p}{Q}$, *quantity elasticity from exit*
- $\overline{\epsilon_q^{\mathcal{C}}} \equiv -\frac{E[\epsilon q]}{E[q]}$, *average quantity-weighted unit elasticity*
- When (Bedre-Defolie and Calvano) $\widetilde{q} = \overline{q}$, no $\mathcal{C}$ distortion
- Without platform, exit, simplifies to Wilson: $\frac{p-c}{p} = \frac{1}{\epsilon_q}$
  - Platform in second term, partial Spence in numerator
  - $\widetilde{\text{Var}}(q)$ is sorting as value *and* cost proprotional to q

Adverse selection and insurance

Focus on platforms: consumers care about ec's

- But insurance is classic case of products designed to sort
- Useful to show how our approach works there

Rothschild-Stiglitz=bang-bang because 1-D, undifferentiated

- Bertrand-like outcomes unlikely, insurance differentiated
- We want general measurement for cream-skimming
- Two symmetrically differentiated insurers, 1 and 2
  - Symmetry just for notational simplicity, intuition
  - Easy to extend
- Plans choose coverage level ρ and price P
- Cost of covering $\boldsymbol{\theta}$, $c(\rho, \boldsymbol{\theta})$; again easy to extend
  - Note it is *independent of which plan covers her*
- Insurers play Nash-Bertrand in P and ρ
  - M^X, M^S are *market-expansion* and *switching* margins

A general cream-skimming distortion

Symmetric social optimum:

$$P = \widetilde{c}^X$$
$$\overline{u_\rho} - \overline{c_\rho} = \frac{\sigma^X_{u_\rho,c}}{\mu^X}$$

$\implies$ Even planner worries about sorting *out of the market*

Symmetric equilibrium pricing:

$$P = \overbrace{\frac{1}{\frac{1}{\mu^X} + \frac{1}{\mu^S}}}^{\text{Total Nash-Bertrand market power}} + \overbrace{\widetilde{c}^{X+S}}^{\text{Akerlof (adverse) selection distortion}}$$

$$\underbrace{\widetilde{u_\rho}^{X+S}}_{\text{Spence distortion}} - \overline{c_\rho} = \underbrace{\frac{\sigma^X_{u_\rho,c}}{\mu^X}}_{\text{optimal sorting}} + \underbrace{\frac{\sigma^S_{u_\rho,c}}{\mu^S}}_{\text{Rothschild-Stiglitz cream-skimming distortion}}$$

General analysis

All of these are examples of slightly hairy general formula

- Applies *only if* $\#\boldsymbol{\rho} = \#\mathbf{E}$
- Actually broader than it seems; can always increase E
- Everything in matrix; allow instrument to influence ec's
- All normalizations, notation from non-transferable utility
- Common infinite series multiplier:

$$\gamma = \left[\mathbf{I} - \widetilde{\mathbf{u}_{\mathbf{E}}}\left(M\boldsymbol{\Sigma}_{\mathbf{E}_{-\boldsymbol{\rho}},\mathbf{e}} + N\overline{e_{\mathbf{E}_{-\boldsymbol{\rho}}}}\right)\right]^{-1}$$

- Social and private shadow values of $\mathbf{E}$:

$$\boldsymbol{\lambda}^{\text{social}} = \gamma\left[N\overline{\mathbf{u}_{\mathbf{E}}} + \pi_{\mathbf{E}} - \left(\widetilde{\mathbf{u}_{\boldsymbol{\rho}}}\right)^{-1}\widetilde{\mathbf{u}_{\mathbf{E}}}\left(N\overline{\mathbf{u}_{\boldsymbol{\rho}}} + \pi_{\boldsymbol{\rho}}\right)\right]$$
$$\boldsymbol{\lambda}^{\text{private}} = \gamma\left[\pi_{\mathbf{E}} - \left(\widetilde{\mathbf{u}_{\boldsymbol{\rho}}}\right)^{-1}\widetilde{\mathbf{u}_{\mathbf{E}}}\pi_{\boldsymbol{\rho}}\right]$$

General formulae and challenges

Then socially optimal platform design is

$$\underbrace{-\left(\widetilde{\mathbf{u}_{\boldsymbol{\rho}}}\right)^{-1}\left(N\overline{\mathbf{u}_{\boldsymbol{\rho}}}+\pi_{\boldsymbol{\rho}}\right)}_{\text{subsidy}}=\underbrace{\left(M\left[\boldsymbol{\Sigma}_{\boldsymbol{\rho},\mathbf{e}}+\tilde{\mathbf{e}}\mathbf{1}^{\top}\right]+N\overline{\mathbf{e}_{\rho}}\right)\boldsymbol{\lambda}^{\text{social}}}_{\text{externalities to average users}}$$

Private optimum

$$\underbrace{-\left(\widetilde{\mathbf{u}_{\boldsymbol{\rho}}}\right)^{-1}\pi_{\boldsymbol{\rho}}}_{\text{discount}}=\underbrace{\left(M\left[\boldsymbol{\Sigma}_{\boldsymbol{\rho},\mathbf{e}}+\tilde{\mathbf{e}}\mathbf{1}^{\top}\right]+N\overline{\mathbf{e}_{\rho}}\right)\boldsymbol{\lambda}^{\text{private}}}_{\text{externalities to marginal users}}$$

- Bit tricker when $\#\boldsymbol{\rho}\neq\#\mathbf{E}$, but similar
- We are working on cleaning this all up
  - Eventual goal: show easily how simplifies to each

The coordination problem and allocation approach

Problem with above analysis: ec's determined by users

- Given instruments, may be coordination problem
- Simple example: two sides $\mathcal{A}, \mathcal{B}$ with $u^{\mathcal{S}}\left(N^{-\mathcal{S}}; \boldsymbol{\theta}^{\mathcal{S}}\right)$
- Platform choose prices to each side, users coordinate
- Multiple **N** given **P**, but unique **P** given **N**: $P^{\mathcal{A}}\left(N^{\mathcal{A}}, N^{\mathcal{B}}\right), P^{\mathcal{B}}\left(N^{\mathcal{B}}, N^{\mathcal{A}}\right)$
- Other side ties down distribution of values
- Full support implies smoothly decreasing inverse demand
- If platform *could* choose quantities, easy
    - Unique profit, welfare etc.
- Much like Myerson (1981): easier to solve for allocation
    - Thus the *allocation approach*
- But how to implement, avoid “failure to launch”?
    - My *AER* paper proposes a solution

Insulating tariffs

Condition prices on number of people on other side $P^{\mathcal{S}}\left(N^{-\mathcal{S}}\right)$!

- This is just what Armstrong did: internalize externalities
- But Armstrong's strategy doesn't work here: heterogeneity
- RT2003: prices proportional to number on other side

$\Longrightarrow$ Strategic *insulation*: optimal choice, not utility, independent

- Here heterogeneity too rich, but natural extension:

1. Choose target quantities $\left(\widetilde{N^{\mathcal{A}}}, \widetilde{N^{\mathcal{B}}}\right)$
2. Charge *insulating tariff* $P^{\mathcal{S}}\left(N^{-\mathcal{S}}\right) \equiv P^{\mathcal{S}}\left(\widetilde{N^{\mathcal{S}}}, N^{-\mathcal{S}}\right)$
    - Armstrong, RT2003 both special cases
    - Compensate *average marginal user* for change in other side
    - Marginal users heterogeneous and change with allocation
3. Target achieved uniquely: any other is inconsistent
    - Whatever equilibrium quantity is conjectured, price is right

Insulating platform design

What does this represent? White and Weyl (2011):

- Firms aren't explicitly setting contingent prices
- But most internet companies had low initial prices
  - Made losses initially, but solved chicken-and-egg
- Thus reduced-form for dynamic strategy (Cabral 2011)

Things are a bit more complicated in this paper

1. Many ec's, not just quantities
2. Need not have price instrument

Nonetheless natural analogy: *insulating platform design*:

- Allow *all instruments* to condition on ec's
  - Reduced for dynamic adjustment of platform characteristics
- Allows insulation of all ec's, not just quantity
- Empirical work on dynamic platform strategies
- Technical conditions for possibility complex

General conditions for insulation and challenges

For insulation to be possible, you need enough instruments

1. Both in absolute number...
2. And in separation of effects on ec's
3. Must have this effective power over full range

We are still working on full mathematical statement

- But adds to attractiveness of case when $\#\rho = \#\mathbf{E}$
    - As shown in examples this is often natural
    - In empirical work, pretty easy to adjust to make true

Conclusion

Paper aims to make three contributions:

1. General purpose IO/contract model
2. Use covariance logic to solve in range of applications
3. General formulas from which these can easily be derived

Take away: don't be intimidated by multi-D screening, platforms

- Quite naturally amenable to simple empirical work
- We are also working on more applied theory applications
    1. College admissions and Gale-Shapley matching
    2. Network neutrality and heterogeneous bandwidth demands
- Crucial to combine with competition
    - Heterogeneity endogenous through multihoming
    - Work with Alex White extends *AER* paper to competition
    - Uses insulation; combine with insulating platform design
- Working with Fabinger on general richness of Weyl-Tirole