Nonlinear pricing with network effects

Arun Sundararajan
Leonard N. Stern School of Business
New York University

Motivation

Some examples of network goods and their drivers of network effects

- Microsoft Windows
  - File compatibility
  - Applications software
- Ability to trade on eBay
  - Liquidity
  - Supporting marketplace services
- Oracle Database
  - Software tools
  - Qualified database administrators

Motivation

- In standard models of network goods
  - Each customer buys one unit
  - Network value depends on adoption = #of customers
  - Network value is constant across customers
- In reality, the usage of many network goods varies across different customers
  - Number of OS licenses (Windows)
  - Trading frequency (eBay)
- Moreover, the network value of these goods
  - Depends on total usage across customers, and not merely the number of customers
  - May also depend on individual usage
  - May vary across customers, even at the same levels of individual and total usage

Research agenda

- Model monopoly nonlinear pricing of network goods
  - Network value depends on total usage
  - Network value for each customer may depend on their individual usage
  - Marginal network value may vary across customers
- Characterize optimal pricing schedules
  - Existence of fulfilled-expectations contract
  - Uniqueness of optimal contract
  - Variation in properties with network value
- Analyze welfare properties of contracts
  - Surplus division between firm/customers
  - Surplus distribution across customers
- Study effects of entry deterrence
  - Changes in pricing
  - Changes in welfare properties

Some related work

- Monopoly models of network goods
  - Rohlfs (1974), Oren and Smith (1981), Oren, Smith and Wilson (1982), Economides (1996), Cabral, Salant and Woroch (1999), Fudenberg and Tirole (2000)
- Single-dimensional monopoly price screening
  - Maskin and Riley (1984), Jullien (2000)
- Empirical estimates of network effects
  - Databases (Gandal 1994, 1995)
  - Spreadsheets (Gandal 1995, Brynjolfsson and Kemerer 1996)
  - Word processing software (Grohn 1999)
  - Networking equipment (Forman 2001)

Model

- Monopoly seller of a network good
- Continuum of heterogeneous customers, indexed by type θ distributed as $F(\theta)$ with $f(\theta)>0$, $\frac{1-F(\boldsymbol{\theta})}{f(\boldsymbol{\theta})}$ nondecreasing
- Utility functions of customer type θ: $W(q,\boldsymbol{\theta},Q)-p$
  - q: individual usage of customer
  - Q: gross usage across all customers
- Key properties of $W(q,\theta,Q)$
  - Individual usage: $W_{11}(q,\boldsymbol{\theta},Q)<0$, $W_2(q,\boldsymbol{\theta},Q)>0$, $W_{12}(q,\boldsymbol{\theta},Q)>0$
  - Gross usage: $W_3(q,\boldsymbol{\theta},Q)\geq 0$, $W_{13}(q,\boldsymbol{\theta},Q)\geq 0$, $W_{23}(q,\boldsymbol{\theta},Q)>0$
- Intrinsic value function: $U(q,\boldsymbol{\theta})=W(q,\boldsymbol{\theta},0)$
- Network value: $W(q,\boldsymbol{\theta},Q)-U(q,\boldsymbol{\theta})$

Model

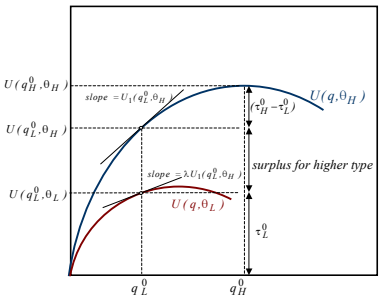
Contracts: quantity-price pairs $q(\theta)$, $\tau(\theta)$

- Feasible: IC and IR
- Optimal: Given expectation of gross consumption Q, maximizes profits among all feasible contracts
- Optimal fulfilled-expectation: Optimal contract for Q under which actual consumption $\int q(\theta)dF(\theta) = Q$

Sequence of events

- Seller posts contract
- Customers form expectation Q of gross consumption
- Based on type q and expectation Q, each customer chooses individual consumption q to maximize surplus
- Seller, customers get payoffs

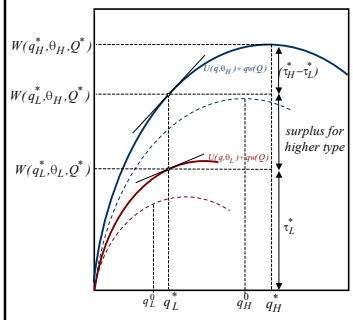
Base case: $W(q,\theta,Q) = U(q,\theta)$



Base case contract $q^0(\theta)$, $\tau^0(\theta)$ is unique

All results illustrated for two types, for better intuition

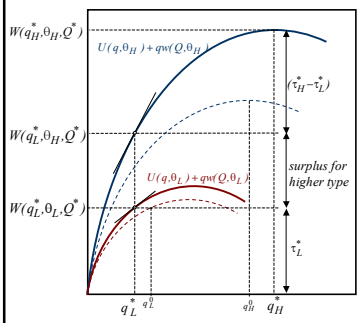
Solution: $W(q,\theta,Q) = U(q,\theta) + qw(Q)$



- Optimal FE contract exists if w(Q) is bounded, is unique if $w_1(Q) < -U_{11}(q,\theta)$
- Consumption q(θ) increases for all customers
- Monopolist captures direct surplus increases
- Customers and monopolist share indirect surplus increase

- Trade-off between price discrimination and value creation

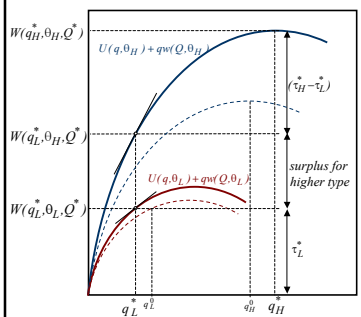
Solution: $W(q,\theta,Q) = U(q,\theta) + qw(Q,\theta)$



- Optimal FE contract exists if w(Q) is bounded, is unique if $w_1(Q) < -U_{11}(q,\theta)$
- Consumption q(θ) increases for a positive fraction of types, may decrease for lower types
- Surplus distribution is skewed towards higher customer types

- Further accentuates the tradeoff between price discrimination and value creation

Solution: $W(q,\theta,Q) = U(q,\theta) + qw(Q,\theta)$



If $\frac{U_1(q^*(\underline{\theta}),\underline{\theta})}{U_{12}(q^*(\underline{\theta}),\underline{\theta})} < \frac{w(Q^*,\underline{\theta})}{w_2(Q^*,\underline{\theta})}$

then $q^*(\theta) > q^0(\theta)$

for all θ

If $\frac{U_1(q^*(\underline{\theta}),\underline{\theta})}{U_{12}(q^*(\underline{\theta}),\underline{\theta})} > \frac{w(Q^*,\underline{\theta})}{w_2(Q^*,\underline{\theta})}$

then $q^*(\theta) < q^0(\theta)$

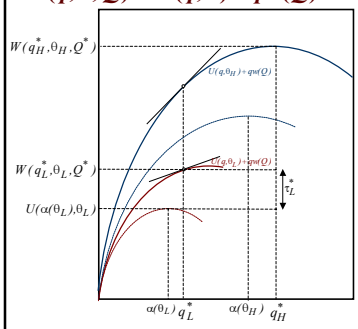
for a subset of lower θ

Entry deterrence

- Incumbent monopolist
  - Customers get both intrinsic value and network value from incumbent product
- One or more potential entrants
  - Entry cost = 0
  - If entry occurs, customers who purchase get just intrinsic value from product
  - Collapses some 'dynamic' aspects of an incumbent's advantage into a static model
- Monopolist prices to deter entry, by assumption
- Problem reduces to monopoly pricing with type-dependent participation constraints

Entry-deterring solution:

$W(q,\theta,Q) = U(q,\theta) + qw(Q)$



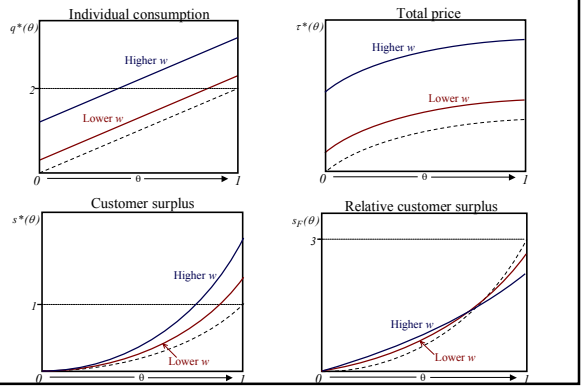
- With an entry threat, usage $q^*(\theta)$ is either
  - exactly the same as it was without, or
  - adjusted upwards for a subset of lower types
- Monopolist profits fall, customer surplus increases
- Outcome is not efficient
  - inefficiently low usage by all types
  - ...but potentially higher total surplus than if entry actually occurs

- For constant network effects, entry deterring solution involves fixed price, is socially optimal

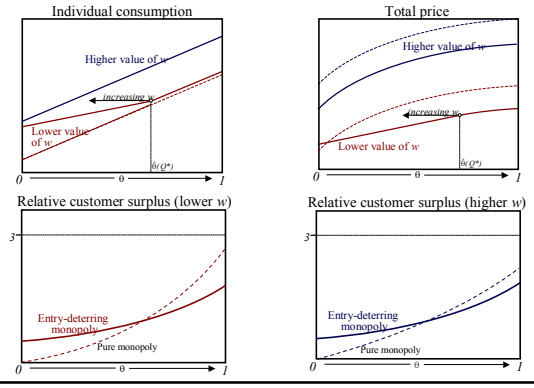
Example

$W(q,\theta,Q) = (\theta+1)q - \frac{1}{2}q^2 + wqQ$

$\theta \sim U[0,1]$



Example with entry deterrence



Summary

- Existence, uniqueness conditions for nonlinear pricing with network effects
- Changes in usage induced by different network effects
  - Just Q: No changes in usage
  - Both Q and q: Increase in usage across all types
  - Q, q and customer type: Potential further downward distortion of usage of lower types, below levels in absence of network effects
- Further changes in usage induced a costless entry threat
  - May increases usage for lower types, does not affect usage for a subset of higher types, mitigates downward distortion
- Network effects (and/or an entry threat) generally improve equity in surplus distribution across different customer types
- Threat of entry can result in socially superior outcomes than actual entry, socially efficient outcome in special cases