Network Economics

A Cautionary Tale on Regulations of Networks

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Outline

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The defining features of two-sided markets

From spot markets to multi-sided markets

(i) spot market (spot transactions) [BC markets)]
(ii) market w/ non simultaneous transactions* [post industrial revolution] **third party enforcement required*
(iii) two-sided markets w/ multiple transactions [post Internet]

Platform markets

1. platform managers (infrastructure)
2. suppliers /producers
3. Individual users (consumers)

CPS as Platforms: Examples

Components of two-sided markets

1. platform managers (infrastructure)
2. suppliers (producers)
3. Individual users (consumers)

Examples: Electricity [E] and Air traffic [Air]

1. RTOs / Distributors (infrastructure) [E]
2. Generators [E]
3. Utilities / Business and residential customers [E]

1. Airports (infrastructure) [Air]
2. Airline carriers [Air]
3. Individual travelers [Air]

Network neutrality: general vs narrow perspective

General perspective

Q1: Neutrality definition?

Q2: Neutrality desirability?

==> No consensus on A1 [definition] and A2 [desirability]

Narrow perspective: Formal game theoretic modeling

- Focus: network neutrality and industry structure
  1. ISPs
  2. CPs
  3. Individual users

Outline

Players and their Objectives

Game G

Long run: Player entry decisions [Industry Structure]

1. Internet Service Providers [ISPs]: N entrants
2. Content Providers [CPs]: M entrants

Short Run: Player (investment & pricing) decisions: the game $G(M, N)$

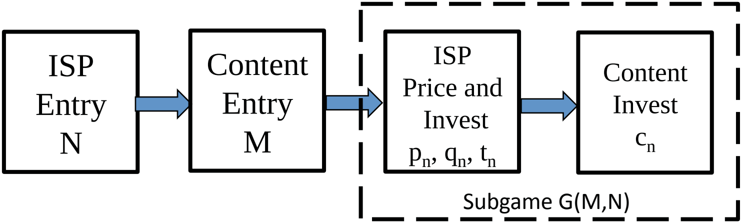
$G(M, N)$ similar to [Musacchio, Schwartz, Walrand (2009)]
$G(M, N)$ is a subgame of G

1. ISPs: capacity investments, price(s)
2. CPs: content investments

Two cases

Neutral: CPs are not charged by ISPs
Non-neutral: CPs are charges by ISPs for access to their users

Timing of the Game



SR Environment: Players (& their choices)

Game $G(M, N)$ – the subgame after M CPs and N ISPs enter

Numbers of providers, their investments, and prices are observable

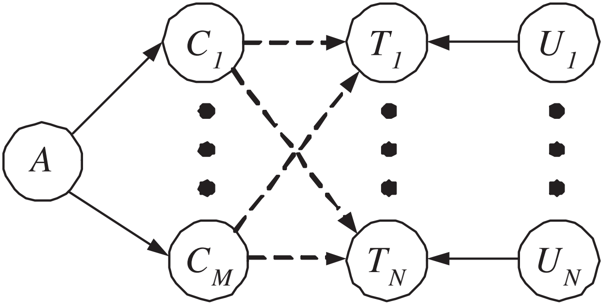
Players

- N internet service providers [ISPs]: T_n, $n = \{1, \dots, N\}$
  Each ISP is a [local] monopolist
- M content providers [CPs]: C_m, $m = \{1, \dots, M\}$
- Users of the n-th ISP: U_n

Player actions

- ISPs: ISP investment t_n, user price p_n, (CP charge q_n)
- CPs: CP investment c_m
- Users: How much to click (network usage)

Players and dollar streams



Environment: User Demand [for ISPs and CPs]

User demand: B_n – click rate of the n-th ISP end-users

$$B_n = \{\mu\eta(c_1^v + \cdots + c_M^v)t_n^w\}\, e^{-p_n/\theta}$$

$$\mu = \frac{(1 - e^{-kM})}{M^{1-v}} \text{ and } \eta = \frac{1}{N^{1-w}}$$

R_{mn} – the n-th ISP end-user demand for the m-th CP C_m

$$R_{mn} = \frac{c_m^v}{c_1^v + \cdots + c_M^v} B_n$$

Parameters characterizing providers

- $v, w \geq 0$, with $v + w < 1$

Parameters characterizing user demand

- $k > 0$ and $\theta > 0$ – preference for variety and demand sensitivity

LR Environment: Provider Objectives

CP and ISP Profits: Π_{Cm} and Π_{Tn}

Provider objective is maximizing profit [revenues net of investments]

$$\Pi_{Cm} = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m - c_e$$

$$\Pi_{Tn} = (p_n + q_n) B_n - \alpha t_n - t_e$$

- a – CPs charge of advertisers for per unit user clicks
- $\beta > 1$ and $\alpha > 1$ – outside options for each CP and ISP
- c_e and t_e – the CP's and ISP's entry cost

Environment: Objectives in Long Run and Short Run

Long Run (LR): CP and ISP Profits

$$\Pi_{Cm} = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m - c_e$$

$$\Pi_{Tn} = (p_n + q_n) B_n - \alpha t_n - t_e.$$

Short Run (SR): CP and ISP Profits in G(N,M)

$$\Pi_{Cm}(N, M) = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m$$

$$\Pi_{Tn}(N, M) = (p_n + q_n) B_n - \alpha t_n.$$

Environment: Summary of Parameters

ISP parameters (α, t_e, w)

$\alpha > 1$ – outside options
$t_e > 0$ – entry cost
$w \geq 0$ – importance of investment

CP parameters (β, c_e, v, a)

$\beta > 1$ – outside option
$c_e > 0$ – entry cost
$v \geq 0$ – importance of investment
$a > 0$ – advertisers' charge

User parameters (k, θ)

$k > 0$ – preference for variety [low k = users value content variety]
$\theta > 0$ – price elasticity [low θ = low user responsiveness to prices]

Environment: Neutral vs Non-neutral

$G(M, N)$ – the subgame of the game G with fixed N and M

One-sided pricing (neutral network)

1. each T_n chooses (t_n, p_n). [Here $q_n = 0$]
2. each C_m chooses c_m.

Two-sided pricing (non-neutral network)

1. each T_n chooses (t_n, p_n, q_n).
2. each C_m chooses c_m.

Non-neutral network: Short Run Equilibrium

TWO-SIDED PRICING (NON-NEUTRAL NETWORK): IN $G(M, N)$

1. each T_n chooses (t_n, p_n, q_n).
2. each C_m chooses c_m.

Proposition 1.

With the two-sided pricing, in all equilibria $t_n = t, p_n = p, q_n = q$ and $c_m = c$.

$$p_n = p^{\ddagger} = \theta - a, \text{ and } q_n = q^{\ddagger} = a - \theta\pi; \tag{1}$$

$$t_n = t^{\ddagger} = \left[(x^{\ddagger})^{1-v} \cdot (y^{\ddagger})^{v} \cdot e^{-(\theta-a)/\theta}\right]^{\frac{1}{(1-w-v)}}; \tag{2}$$

$$c_m = c^{\ddagger} = \left[(x^{\ddagger})^{w} \cdot (y^{\ddagger})^{1-w} \cdot e^{-(\theta-a)/\theta}\right]^{\frac{1}{(1-v-w)}} \times [\mu\eta N]^{\frac{1}{1-v}}; \tag{3}$$

where $x^{\ddagger} = M(\mu\eta)^{\frac{1}{1-v}} \cdot \left(\frac{\theta w}{\alpha}\right) N^{\frac{v}{1-v}}$, $y^{\ddagger} = \frac{\theta v}{\beta}\pi$, and $\pi = \frac{v}{N(1-v)+v}$.

Neutral network: Short Run Equilibrium

ONE-SIDED PRICING (NEUTRAL NETWORK): IN $G(N, M)$

1. each T_n chooses (t_n, p_n). [Here $q_n = 0$]
2. each C_m chooses c_m.

Proposition 2.

With one-sided pricing, in all equilibria $t_n = t, p_n = p, q_n = 0$ and $c_m = c$.

$$p_n = p^{\dagger} = \theta(1 - \pi) \text{ and } q_n = q^{\dagger} = 0; \tag{5}$$

$$t_n = t^{\dagger} = \left[(x^{\dagger})^{1-v}(y^{\dagger})^{v} e^{-p^{\dagger}/\theta}\right]^{\frac{1}{1-v-w}}; \tag{6}$$

$$c_m = c^{\dagger} = \left[(x^{\dagger})^{w}(y^{\dagger})^{1-w} e^{-p^{\dagger}/\theta}\right]^{\frac{1}{1-v-w}} \cdot [\mu\eta N]^{\frac{1}{1-v}}; \tag{7}$$

where $x^{\dagger} := x^{\ddagger}$ and $y^{\dagger} := av/\beta$.

Long Run: Industry Equilibrium

CP and ISP Profits: Π_{Cm} and Π_{Tn}

Provider objective is maximizing profit [revenues net of investments]

$$\Pi_{Cm} = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m - c_e$$

$$\Pi_{Tn} = (p_n + q_n) B_n - \alpha t_n - t_e$$

For Long Run Equilibrium

Necessary conditions for Long Run equilibrium:

$$\Pi_{Cm}(M, N) \geq c_e, \text{ and } \Pi_{Cm}(M+1, N) < c_e.$$

if $M > 0$ otherwise $\Pi_{Cm}(1, N) < c_e$ if $M = 0$.

$$\Pi_{Tn}(M, N) \geq t_e, \text{ and } \Pi_{Tn}(M(N+1), N+1) < t_e$$

User welfare and Social welfare

User welfare [aka consumer surplus]

$$W_U(M,N) = NM^{=}\mu\eta\theta \cdot \left[(x)^w (y)^v\right]^{1/(1-w-v)} e^{-p/[\theta(1-w-v)]}.$$

[The integral of end-user demand from p to infinity]

Social welfare

Sum of User welfare and Provider profits

The Entry Game

Proposition 3

The equilibrium of the game G exists and is unique.

Proposition 4

Consider a game $\tilde{G}$, in which CPs and ISPs enter simultaneously rather than sequentially. Then, a pure strategy Nash equilibrium in $\tilde{G}$, provided it exists, coincides with the equilibrium of G.

Outline

Theoretical Results

LR equilibrium uniqueness: the game G

Unique equilibrium industry structure (N and M are unique).

SR equilibrium uniqueness: the game $G(N, M)$

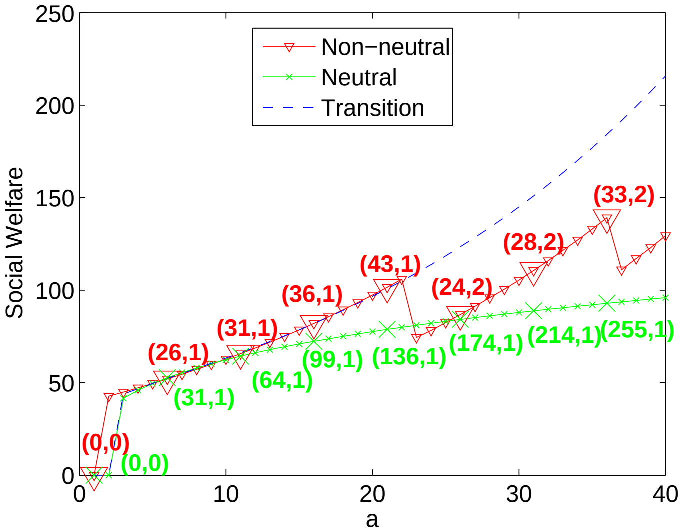
We prove that equilibrium exists and it is symmetric.
[Musacchio, Schwartz, Walrand (2009)] assume symmetry of eq.

Analytical expressions for equilibrium of $G(N, M)$

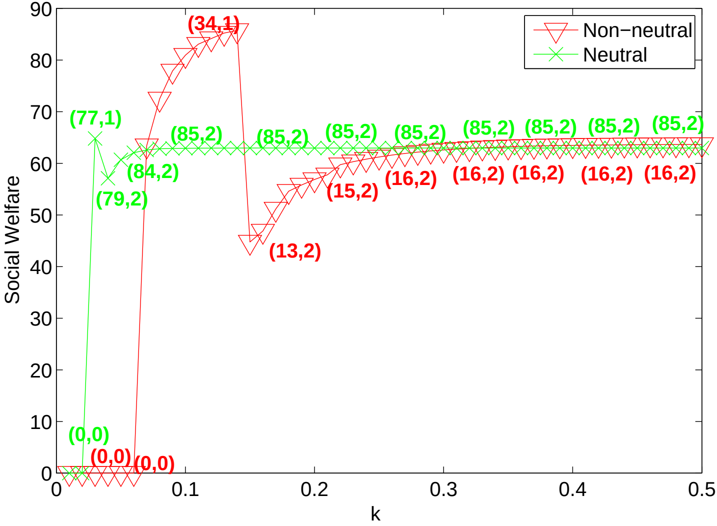
We obtained closed form expressions for equilibrium values in $G(N, M)$ with any given parameters:

- ISP parameters: (α, t_e, w)
- CP parameters: (β, c_e, v, a)
- User parameters: (k, θ)

Numerics: Welfare in SR and LR



Numerics: Equilibrium dependance on parameters



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Industry Structure and Network Regime

The findings

1. Industry structure differs with network regime
   - Neutral: less ISPs, more CPs [lower N, higher M]
   - Non-neutral: more ISPs, less CPs [higher N, lower M]
2. Welfare analysis
   - Transition from Neutral to Non-Neutral: SR and LR effects differ

Trade-offs: Neutral vs Non-Neutral Regime

Non-Neutral Regime tend to be superior when

- a is high
- k is low
- t_e is high
- c_e is low

Superior network regime depends on parameters

A CALL FOR EXTREME CAUTION ABOUT REGULATORY IMPOSITIONS

Connections with literature

References

- Two-sided markets paradigm [review by Rochet and Tirole (2006)]
- Differentiated products [Dixit and Stiglitz (1977)]
- Two-sided markets: investigation of network neutrality problem [Musacchio, Schwartz and Walrand (2009), Njoroge, Ozdaglar, Stier-Moses and Weintraub (2010)]

Two-sided market with endogenous participation

Today's example: model of ISP and CP entry

- Short run [SR] vs Long run [LR]
- Short run = fixed industry structure (fixed ISPs' & CPs' numbers)
- Long run = flexible structure (model ISPs' & CPs' entry choices) [Schwartz, Musacchio, Felegyhazi and Walrand, (2012)])