Network Neutrality and Provider Investment Incentives

WANG Qian & WANG Yongzhi

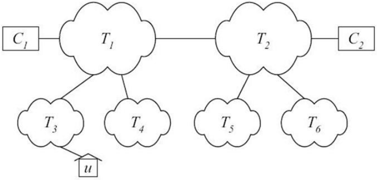
May 15, 2008

Outline

- Introduction
- Model Description
- Neutrality vs. Non-neutrality
- Problems and Extensions
- Conclusion

Introduction

- Network neutrality
  - User discrimination: Pricing users differently for the same service
  - Service differentiation: Handling packets differently
- This paper mainly focus on user discrimination
  - Neutral: Prohibit user discrimination
  - Non-neutral: Allow user discrimination



Introduction

- Two arguments:

	Against Neutrality	For Neutrality
Supporter	Transport providers	Content providers
Reason	The income of transport providers cannot balance their costs	Give the transport providers too much market power
Outcome	No incentive to invest on network capacity reduce the network quality	No incentive to invest on content provision reduce the content quality

Model Description

- M content providers (C_m), N transport providers (T_n).
- T_n is attached to "end" users U_n and charges them p_n per click.
- T_n charges C_m q_n per click.
- C_m invests c_m, T_n invests t_n.
- Assumption 1: The numbers of transport and content providers are fixed.
- Assumption 2: Each transit provider has 1/N of the entire market.

Model Description

- The rate B_n of clicks of end users U_n

$$B_n = \{\frac{1}{N^{1-w}}(c_1^v + \cdots + c_M^v)[(1-\rho)t_n^w + \frac{\rho}{N}(t_1^w + \cdots + t_N^w)]\}e^{-p_n/\theta}$$

- $\rho \in (0,1)$, $\theta > 0$, $v, w > 0$ with $v + w < 1$
- $c_1^v + \cdots + c_M^v$ is the value of the content providers, and is concave, which means end users prefer variety of content.
- $[(1-\rho)t_n^w + (\rho/N)(t_1^w + \cdots + t_N^w)]$ is the value of the transport provider investments.
- The faction $1/N^{1-w}$ is a convenient normalization.

Model Description

- The rate R_{mn} of clicks from end users U_n to C_m is given by

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

- The total rate of clicks for content provider C_m is

$$D_m = \sum_n R_{mn}$$

- Assumption 3: Content providers charge a fixed amount a per click to the advertisers.
- Content provider's profit is

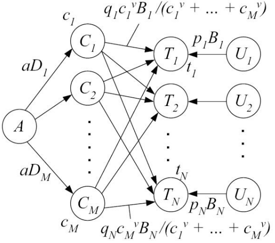
$$R_{C_m} = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m$$

- Transport provider T_n's profit is

$$R_{T_n} = (p_n + q_n) B_n - \alpha t_n$$

Model Description

- Objective: To find symmetric equilibria in both the neutral and non-neutral cases.
- Assumption 4:
  - Neutral Case: In stage 1 each T_n simultaneously chooses (t_n, p_n, q_n). In stage 2 each C_m chooses which transit provider to connect to and also chooses c_m.
  - Non-neutral Case: In stage 1 each T_n simultaneously chooses (t_n, p_n, q_n). In stage 2 each C_m chooses c_m.



In the neutral case, the Bertrand competition between the transit providers forces q_n to be zero.

Neutrality vs. Non-neutrality

- How to compute the optimal (t, p, q, c)?
  - In Non-neutrality case:
    - First, we study how C chooses the optimal c for a given (t,p,q)
    - Second, we substitute the value of c in the expression for R_T and optimize for (t, p, q)
  - In neutrality case:
    - It is similar to the non-neutral case, except that $q_n = 0$. Then, we do the same thing as in non-neutral case.

Neutrality vs. Non-neutrality

- Compute the optimal c for given (t, p, q)
    - Recall that the profit of content provider C_m is :

$$
\begin{aligned}
R_{Cm} &= aD_m - \sum_n q_n R_{mn} - \beta c_m \\
&= N^{w-1} c_m^v [\sum_n (a - q_n)((1-\rho) t_n^w + \frac{\rho}{N}(t_1^w + \cdots + t_N^w)) e^{-p_n/\theta}] - \beta c_m.
\end{aligned}
$$

    - Note that, the profit is independent on investments of other content providers. Therefore, we maximize it, set its deviation equal to zero and get the c, which is same for all content provider.

Neutrality vs. Non-neutrality

- Compute optimal (t, p, q)
  - Based this c, Recall the profit of transport provider is :

    $$R_{T_n} = (p_n + q_n)B_n - \alpha t_n$$

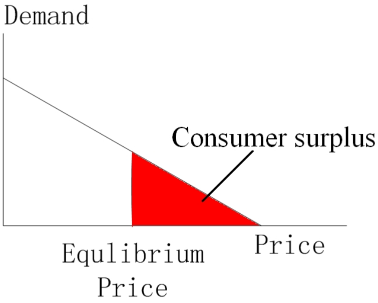
    In this equation, substitute c by (t, p, q) and note that the profit of T_n also depends on others' investment and prices $(t_k, p_k, q_k), k \neq n$.
  - We find the symmetric Nash equilibrium by setting the three corresponding partial derivatives of R_{T_n} equal to zero, and then finding the symmetric intersection point of the best response functions.

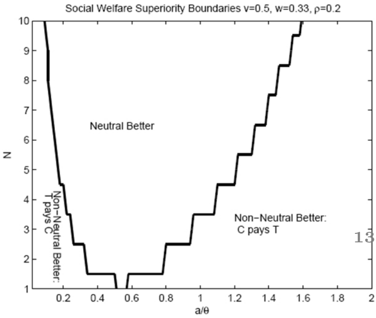
Neutrality vs. Non-neutrality

- After this computation, in both cases, we get the following solutions:
  - $p_n = p$: price for end user;
  - $q_n = q$: price for content provider;
  - $t_n = t$: investment of transport provider;
  - $R_{Cm} = R_C$: profit of content provider;
  - $R_{Tn} = R_T$: profit of transport provider;
  - R_C/c: the rate of return on investments of the content provider;
  - R_T/t: the rate of return on investments of the transport provider;
  - $B = \sum_n B_n$: the total click rate;
- We compare the Nash equilibrium of the two cases and list three interesting results.

Neutrality vs. Non-neutrality

- Comparison: User Welfare and Social Welfare
  - We use the consumer surplus as a measure of end user welfare and compute the consumer surplus by taking the integral of the the demand function from the equilibrium price to infinity.
  - We use the sum of the end user welfare and the profit of transport and content provider as the social welfare, and we are interested at the ratio of the social welfare in the neutral vs. non-neutral cases.





Neutrality vs. Non-neutrality

- Comparison: Return on Investment
  - First, $p + q = p_0$, which means the total revenue per click of the transit providers is the same in both regimes.
  - Second, $R_C/c = R_{C_0}/c_0, R_T/t = R_{T_0}/t_0$, which means the return on investments of the content and transit providers is the same too.

Neutrality vs. Non-neutrality

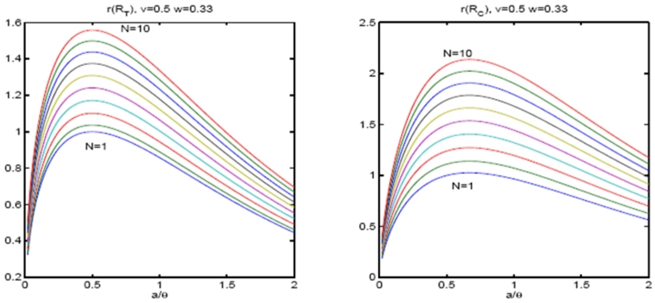
- Comparison: Investment incentive
  - Even though the return on investment in both cases is same, the investment might be quite different because the two regimes provide different incentive to investment. We define the ratio such as

$$r(R_C) = (\frac{R_C(neutral)}{R_C(non - neutral)})^{1-v-w}$$

    Meanwhile, we define $r(R_T)$ similarly.
  - Because the return of investment is same, we prefer the case which provides more incentive to transit and content provider. For example, when $r(R_C) > 1$ we prefer the neutral case.

Neutrality vs. Non-neutrality

- Comparison: Investment incentive
  - When a/θ is small, the non-neutral regime is preferable to both content and transit providers.
  - When a/θ is large, the non-neutral regime is also preferable.
  - When a/θ is in the middle area, the neutral regime is preferable.
  - When a/θ is fixed and we increase N, the neutral regime becomes more preferable.



Problems and Extensions

- Neutral and non-neutral cases should have different expressions of content providers' profit and transport providers' profit.
- Neutral case:

$$R_{C_m} = \sum_{n=1}^{N} (a - q_{n_m}) R_{mn} - \beta c_m,$$

in which n_m is the index of the transport provider that C_m is connected to.

$$R_{T_n} = p_n B_n + \sum_{\tilde{m}} q_n D_{\tilde{m}} - \alpha t_n,$$

in which $\tilde{m}$ is the index of the content providers which are connected to T_n directly.

Problems and Extensions

- Non-neutral case:

$$R_{C_m} = \sum_{n, n \neq n_m} (a - q_n) R_{mn} + a R_{mn_m} - \sum_{n} q_{n_m} R_{mn} - \beta c_m,$$

$$R_{T_n} = p_n B_n + \sum_{\tilde{m}} q_n D_{\tilde{m}} + \sum_{m \neq \tilde{m}} q_n R_{mn} - \alpha t_n$$

in which n_m is the index of the transport provider that C_m is connecting, $\tilde{m}$ is the index of the content providers which is connected to T_n directly.

Conclusions

- Network regime affects investment incentives.
- $\frac{a}{\theta}$ is crucial.
- Transit providers would over charge at equilibrium in a non-neutral regime.