

Pricing of Bandwidth and Communication on Demand Services



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Issues



- **Bandwidth** is a finite divisible resource.
- Users **compete** for that resource and value it differently.
- Providing end-to-end bandwidth requires a **combination of links** that belong to different operators.
- Communication services differ in **quality**.
- **Signaling** between users and providers cannot be exceedingly complex.
- **Who** should pay? End users or providers or both?

Pricing of Bandwidth and Communication on Demand Services



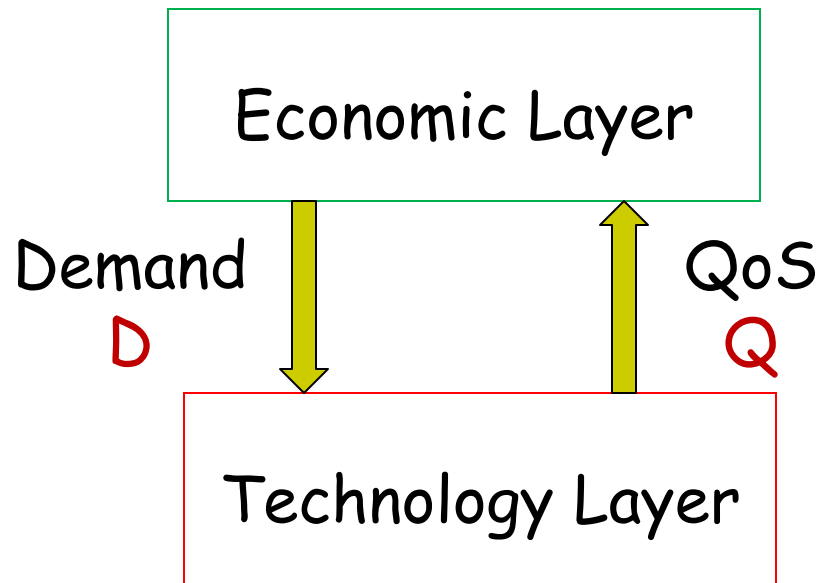
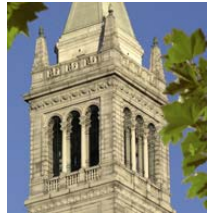
- Issues
- Users & Providers
- General Pricing
- Externality: Congestion Pricing
- Service Differentiation: Paris Metro Pricing
- Competition of Providers
- Pricing QoS
- Uncertainty
- One-Sided Auctions
- Net Neutrality
- References

Pricing of Bandwidth and Communication on Demand Services

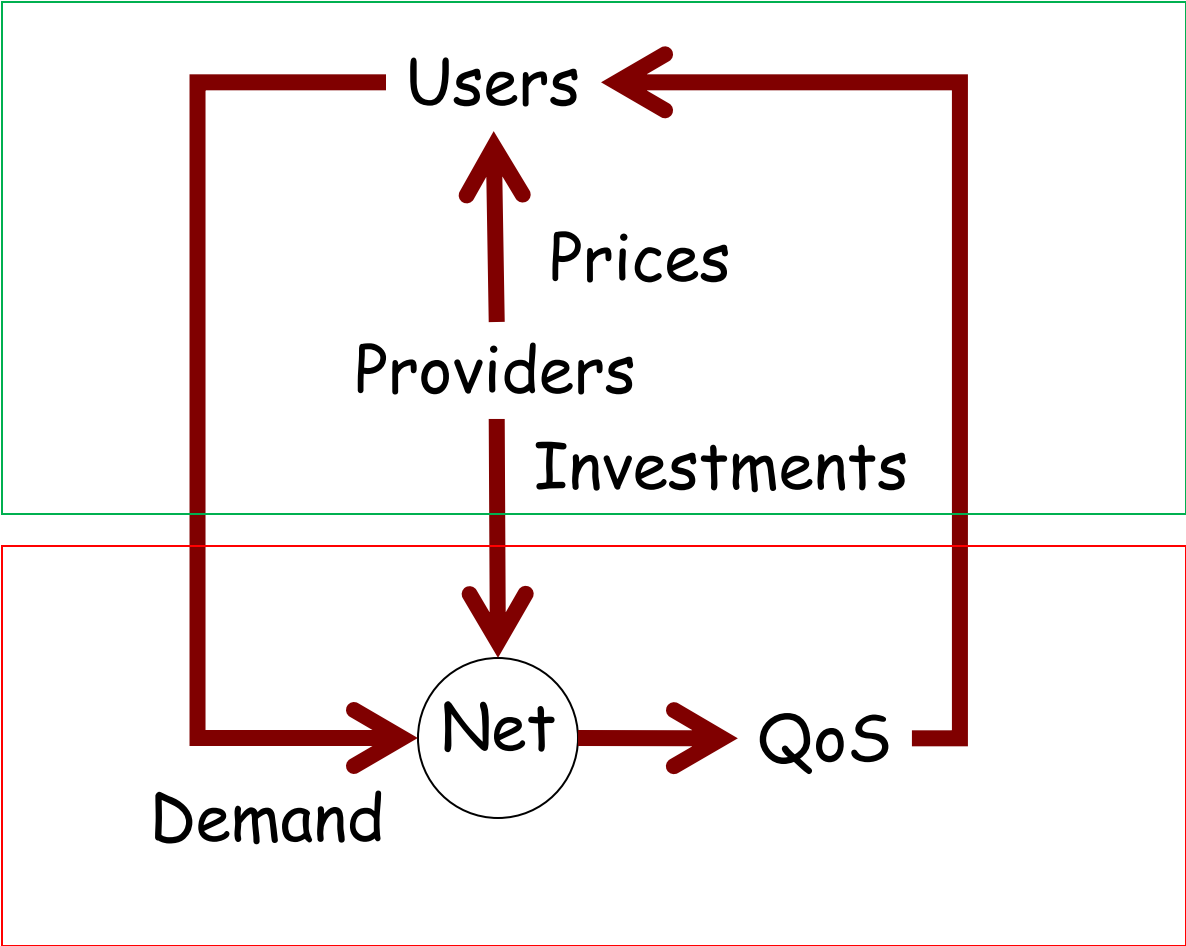
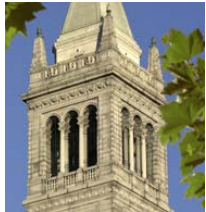


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Users & Providers



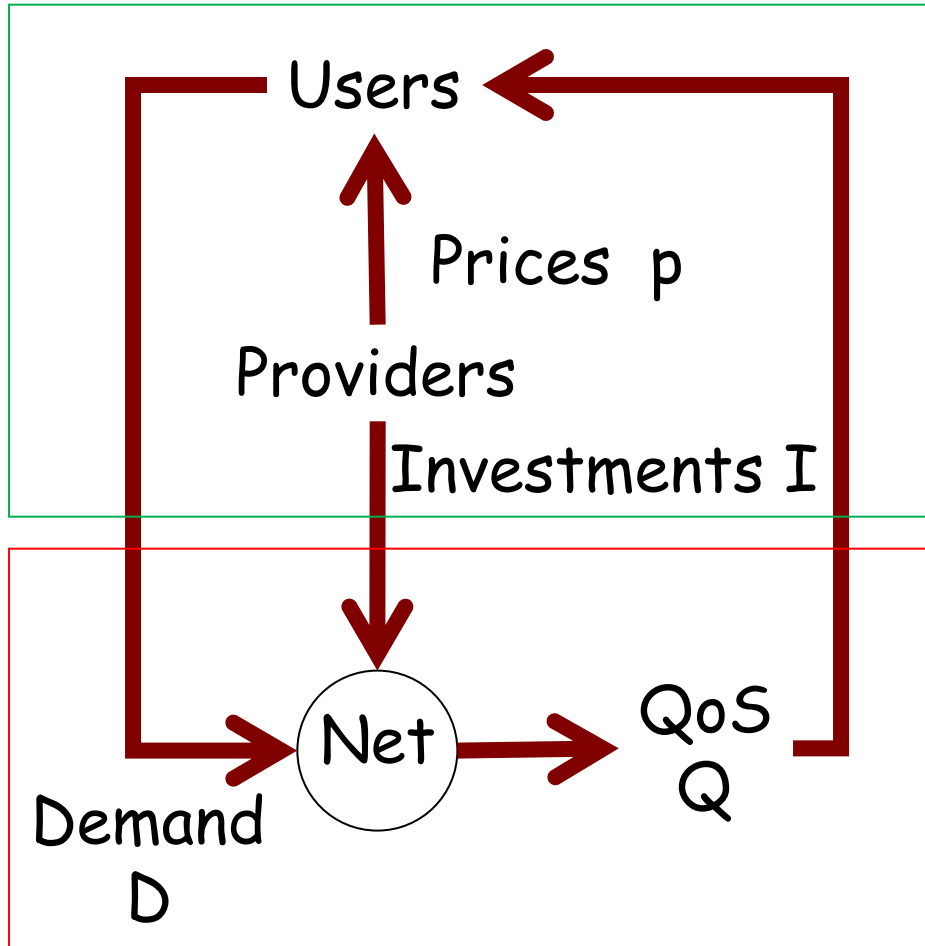
Users & Providers



Economic Layer

Technology Layer

Users & Providers



$$D = \operatorname{argmax} U(D, Q, p)$$

$$(p, I) = \operatorname{argmax} \{p \cdot D - \alpha I\}$$

$$Q = Q(D, I)$$

Note: Protocol choice is another important element

Users & Providers



Strategic Behavior:

Users:

Usage of services: which network, when, how, ...

P2P: What to make available?

Modify "technology": cheat protocol, bigger antenna, ←??

Providers:

Prices

Capacity

Content (more, new, ...)

New technology (WiMax, metro Wi-Fi, 3G, QoS, Vcast, ...)

Users & Providers



General Observations:

Users and Providers interact in a network



In general,

Selfish optimal \neq Social optimal (price of anarchy)

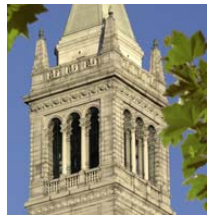
- Selfish users over-consume
- Selfish providers over-price, under-invest



“Internalize the externality”

- Congestion pricing
- Revenue-sharing agreement

Pricing of Bandwidth and Communication on Demand Services

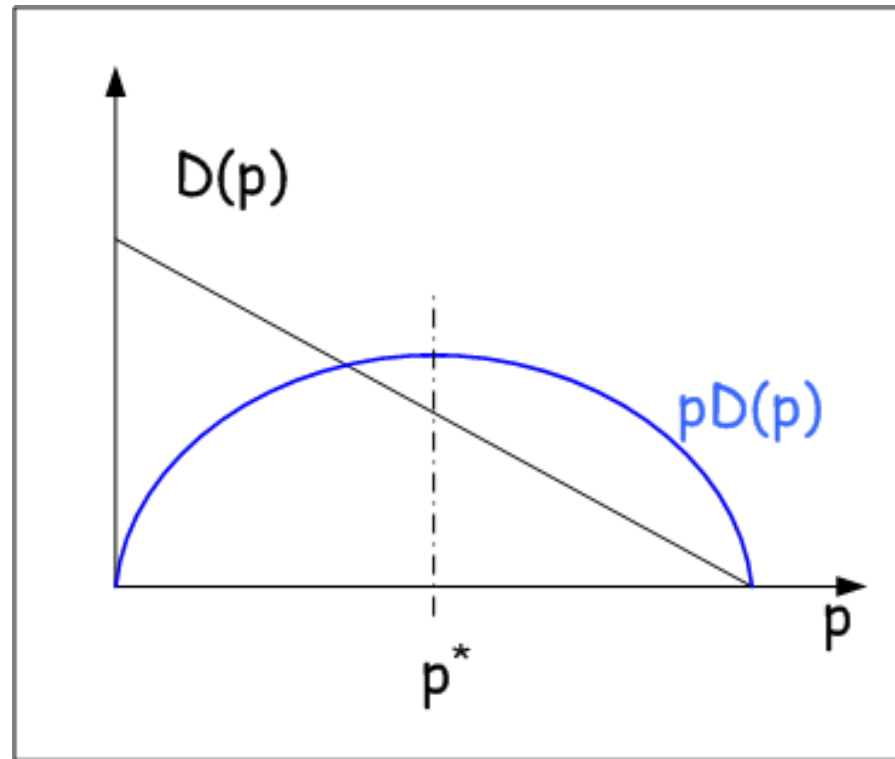


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General Pricing



This is the simplest idea: $\text{Max } pD(p)$



More complete: $\text{Max } pD(p) - C(D(p))$

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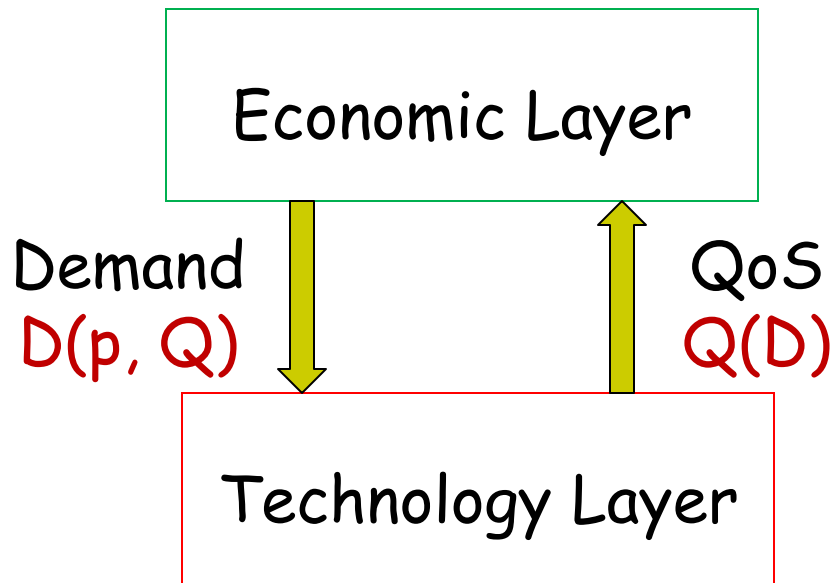


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Externality: Congestion Pricing



In fact, D depends on Q and Q depends on D



The actions of one user affect other users:
externality.

Externality: Congestion Pricing

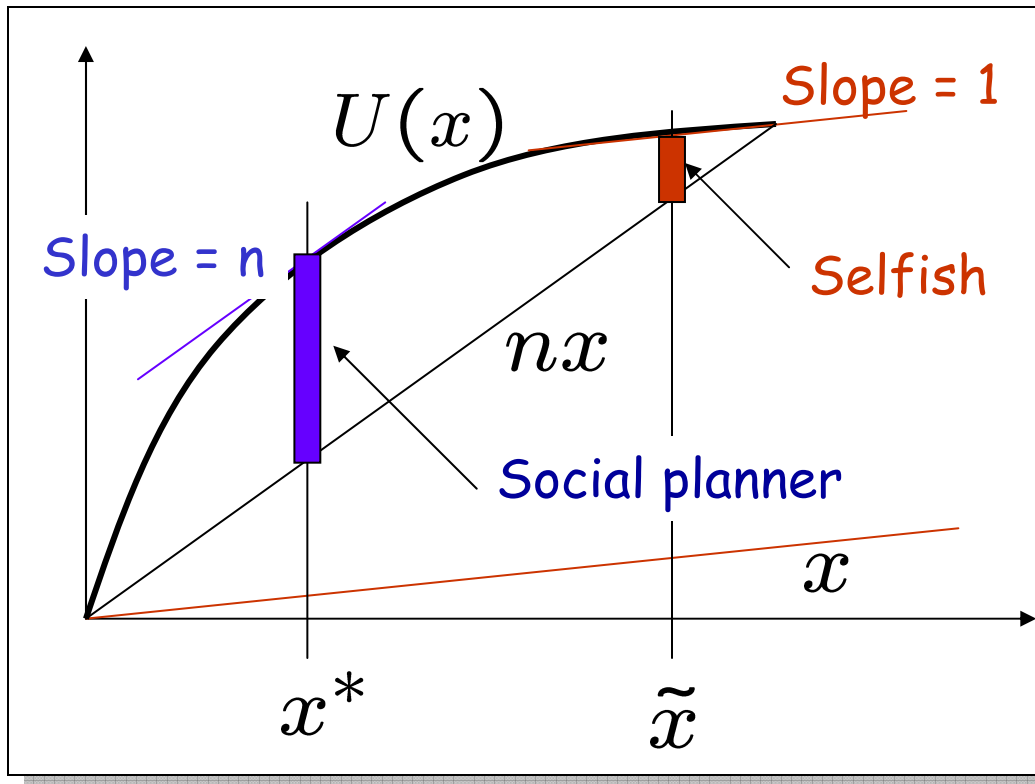
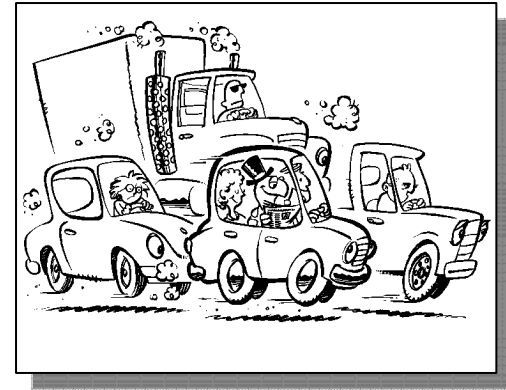


Assume N users share a network.

User i chooses his activity level \tilde{x} to maximize

$$U(x_i) - [x_1 + \dots + x_N]$$

where the sum is the congestion disutility.



A social planner chooses the common activity level $x_i = x^*$ to maximize $U(x) - Nx$.

**Selfish users over-consume:
They neglect their impact
on others.**



Externality: Congestion Pricing

Assume congestion price: $p = (N - 1)x$.

User i chooses his activity level to maximize $U(x_i) - [x_1 + \dots + x_N] - (N - 1)x_i$.

Now, user i chooses the socially optimal x .

The congestion price is the cost imposed by each user on all the other users.

The activity x_i of user i imposes a congestion cost x_i on each of the $N - 1$ other users. The total "externality" cost is $(N - 1)x_i$.

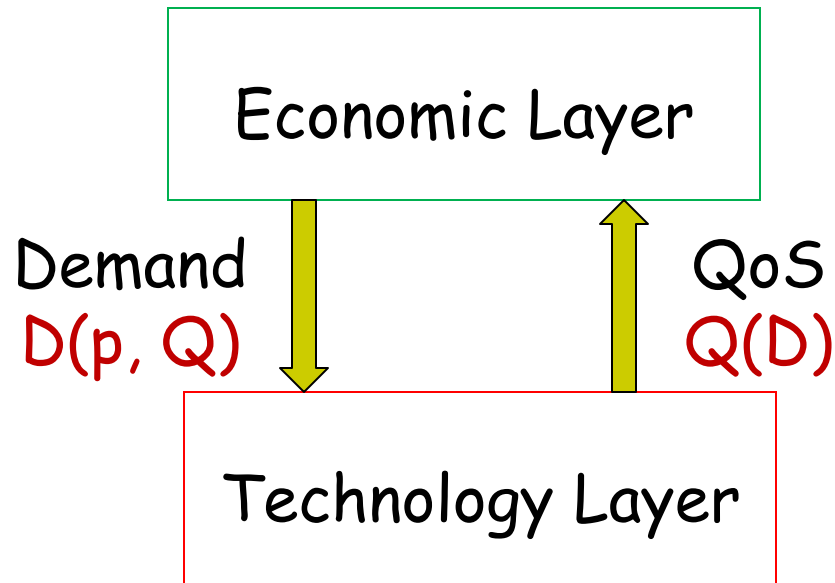
When users face their externality cost, their selfish behaviour is socially optimal.

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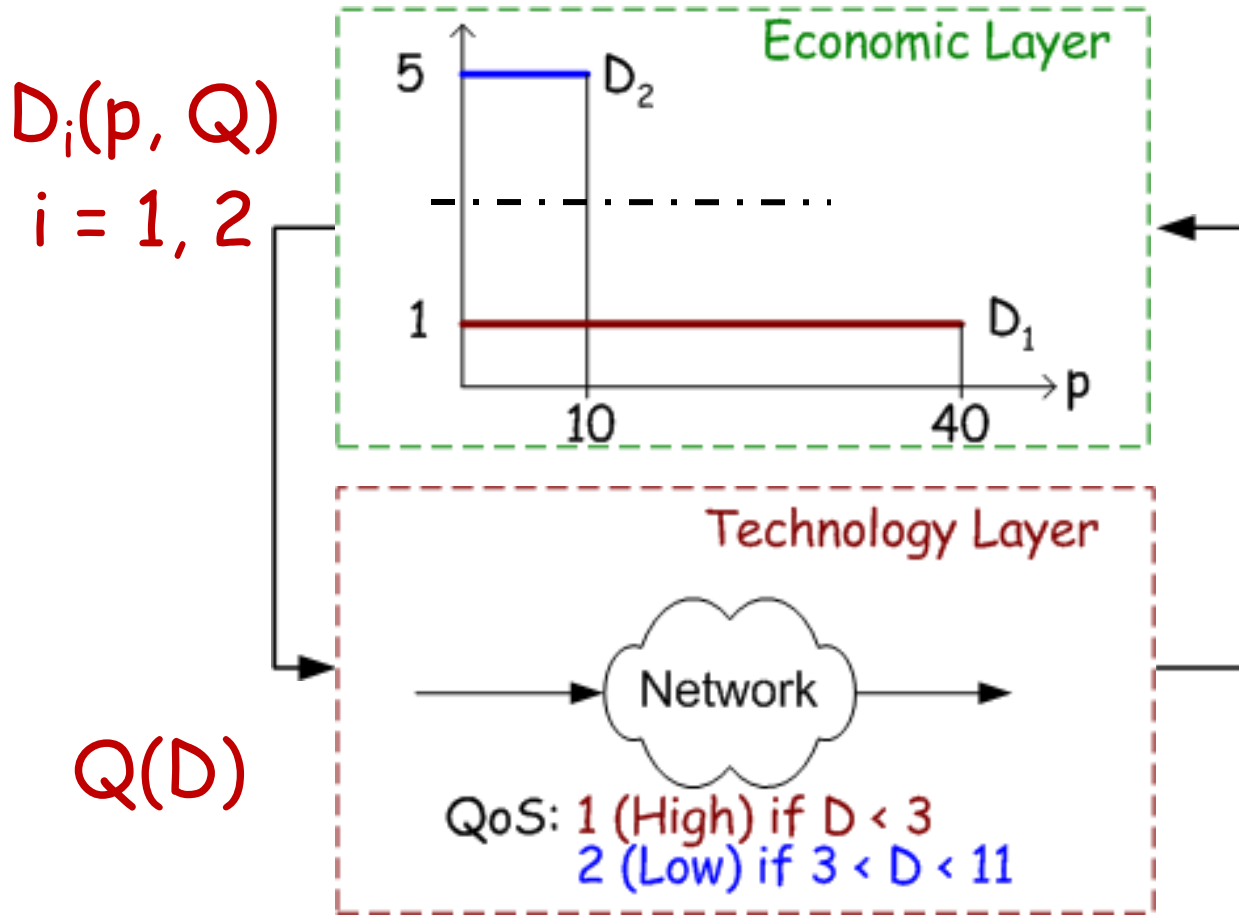
Service Differentiation: Paris Metro Pricing



In fact, services require a different QoS:

$$D_i(p, Q), i = 1, 2, \dots$$

Service Differentiation: Paris Metro Pricing



$p \rightarrow D_1, D_2$
 \rightarrow Revenue

Question:
How to price?

Service Differentiation: Paris Metro Pricing

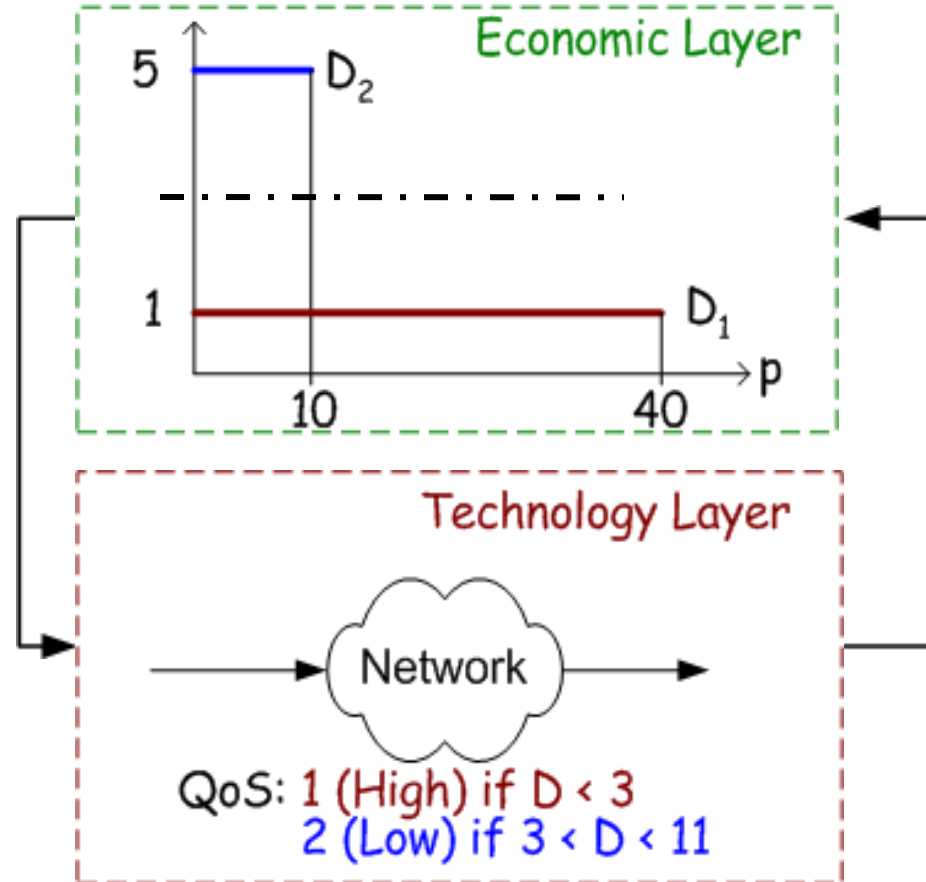


Solution 1:

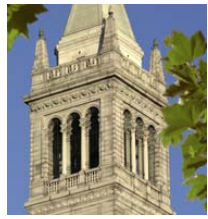
$$p = 10 \rightarrow D_2$$

$$\rightarrow \text{Revenue} = 5 \times 10$$

(Note: $p = 40 \rightarrow D_1 \rightarrow 1 \times 40$)



Service Differentiation: Paris Metro Pricing



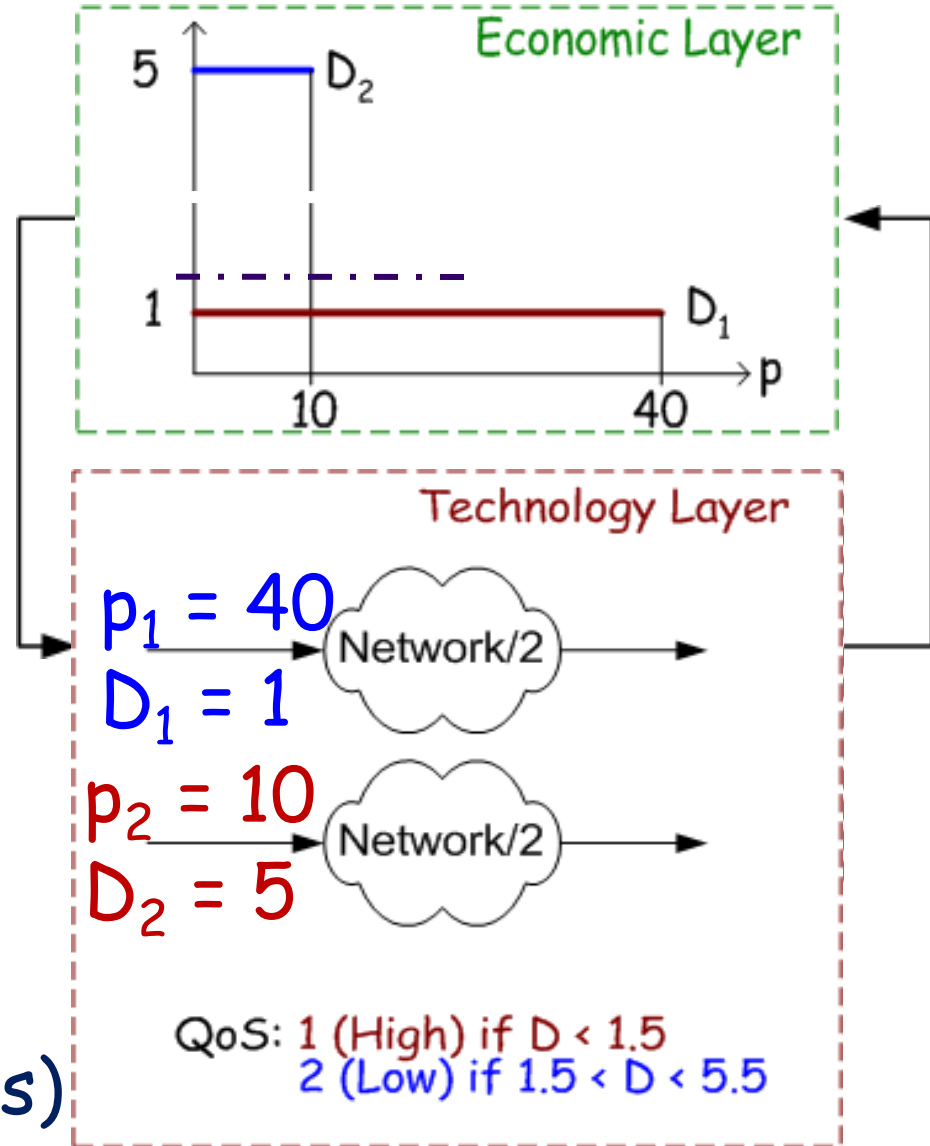
Solution 2:

$p_1 = 40 \rightarrow D_1$
 $\rightarrow \text{Revenue} = 1 \times 40$

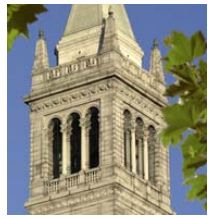
$p_2 = 10 \rightarrow D_2$
 $\rightarrow \text{Revenue} = 5 \times 10$

Total Revenue: 90

Note: QoS achieved
by pricing
(not by QoS mechanisms)



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Competition of Providers

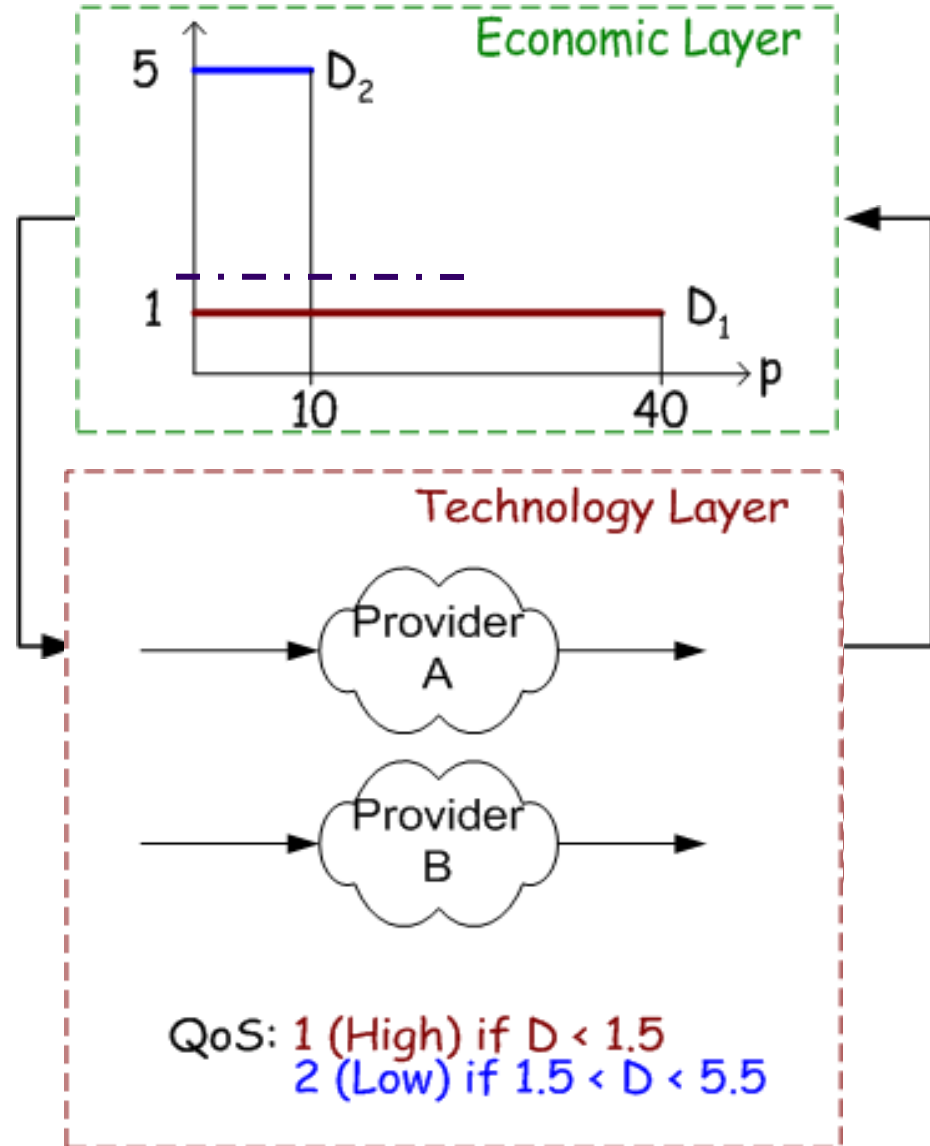


Question:

Will providers
"specialize"
with $D_1 \rightarrow$ Prov. A
 $D_2 \rightarrow$ Prov. B

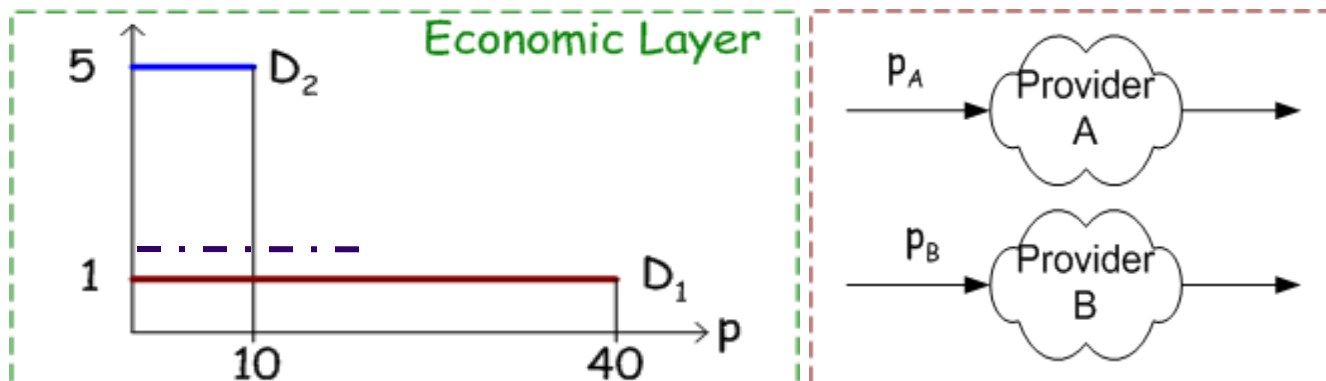
Intuition: No

D_2 brings more revenue
than D_1
 \rightarrow Providers may
compete for it





Competition of Providers



Best Response of A to p_B : (Assume prices must be integers)

Assume $p_B = p$ in $\{0, 1, \dots, 10\}$

If $p_A = p$, then $R_A = 5p/2$

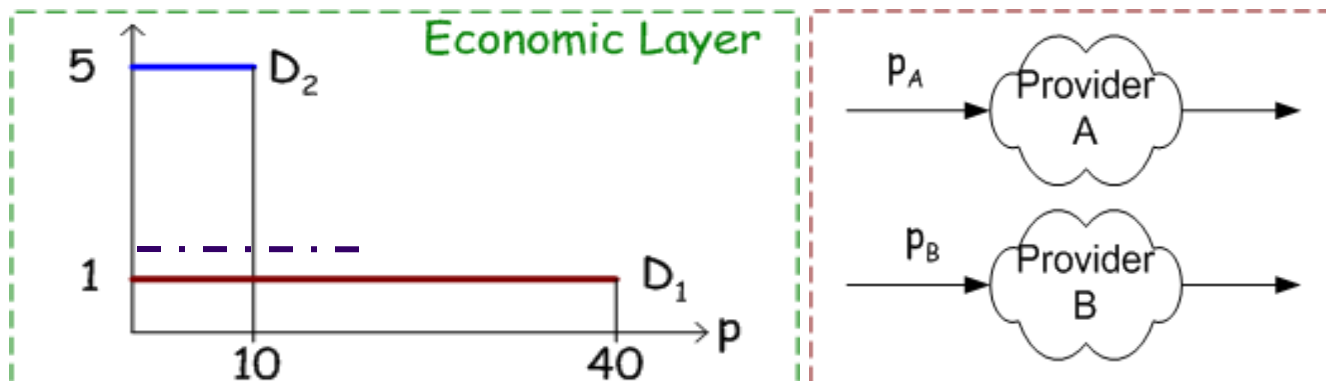
If $p_A = p - 1$, then $R_A = 5(p - 1)$

If $p_A = 40$, then $R_A = 40$

→ Best response is $p_A = 40$ if $p < 9$
 $p - 1$ if $p = 9$ or 10



Competition of Providers



Best Response of A to p_B : (continued)

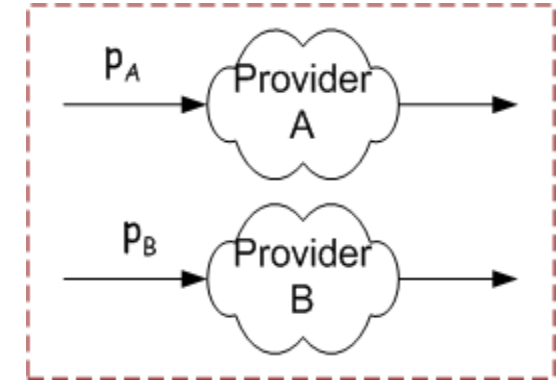
Assume $p_B = p$ in $\{11, 12, \dots, 40\}$

→ Best response is $p_A = 10$

Competition of Providers



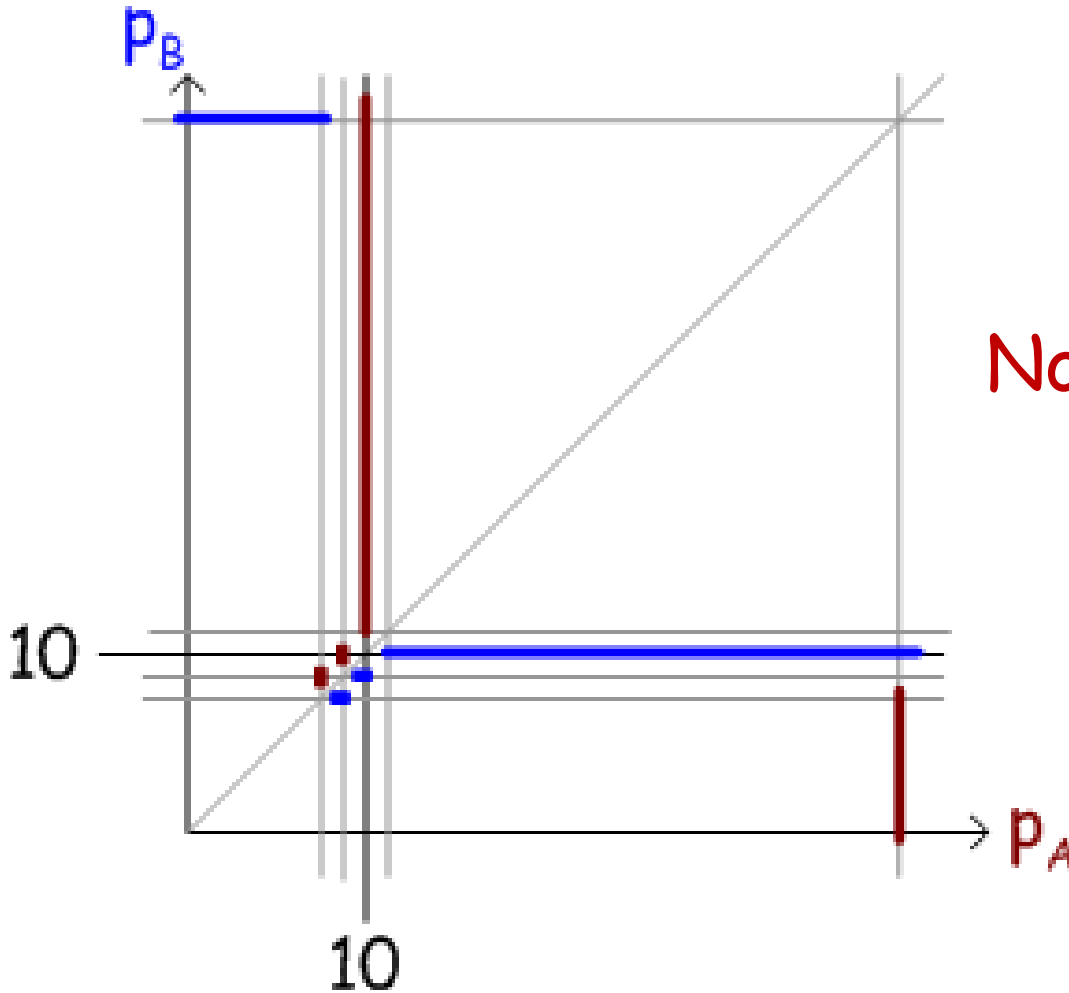
Best Responses: (continued)



No Nash Equilibrium

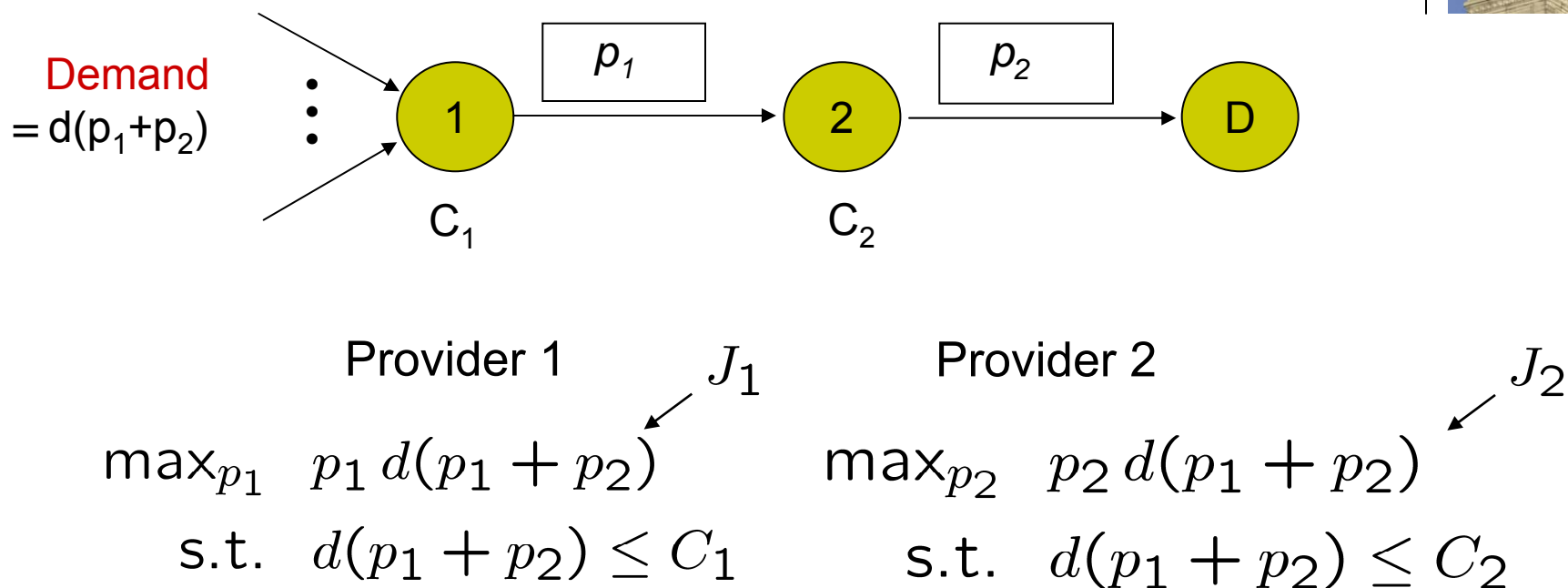
p_A 10 8 10 ...

p_B 40 9 40 9





Competition of Providers



- A game between two providers
- Different solution concepts may apply, depend on actual implementation
- First we consider a **Nash game**

Competition of Providers



Analysis of Nash game shows:

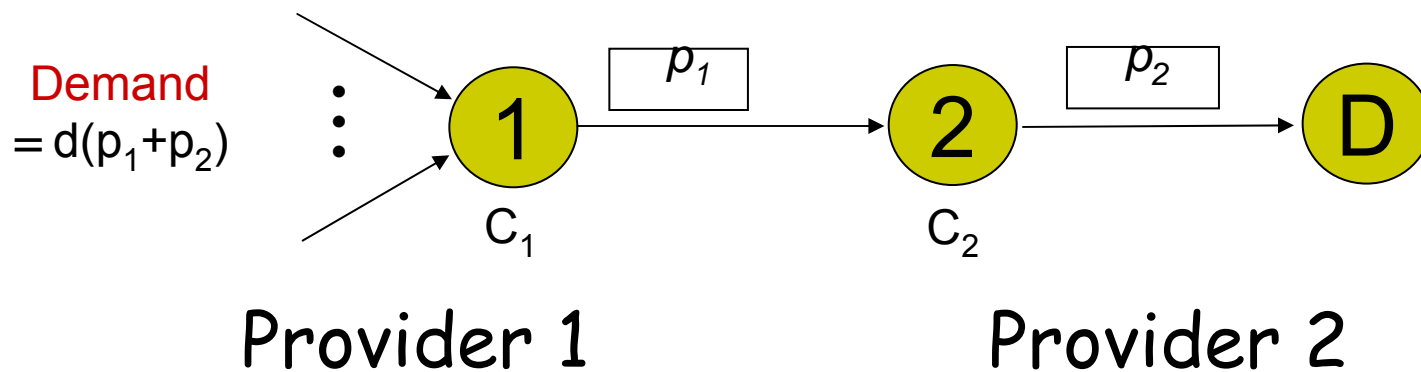
1. Bottleneck providers get more share of revenue than others
2. Bottleneck providers may not have incentive to upgrade
3. Efficiency decreases quickly as network size gets larger (revenues/provider drop with size)

Competition of Providers



Revenue Sharing Game:

Providers agree to share the revenue equally,
but still choose their prices independently



$$\begin{aligned} \max_{p_1} \quad & \frac{1}{2}(p_1 + p_2) d(p_1 + p_2) \\ \text{s.t.} \quad & d(p_1 + p_2) \leq C_1 \end{aligned}$$

$$\begin{aligned} \max_{p_2} \quad & \frac{1}{2}(p_1 + p_2) d(p_1 + p_2) \\ \text{s.t.} \quad & d(p_1 + p_2) \leq C_2 \end{aligned}$$

Competition of Providers



In this revenue-sharing game,

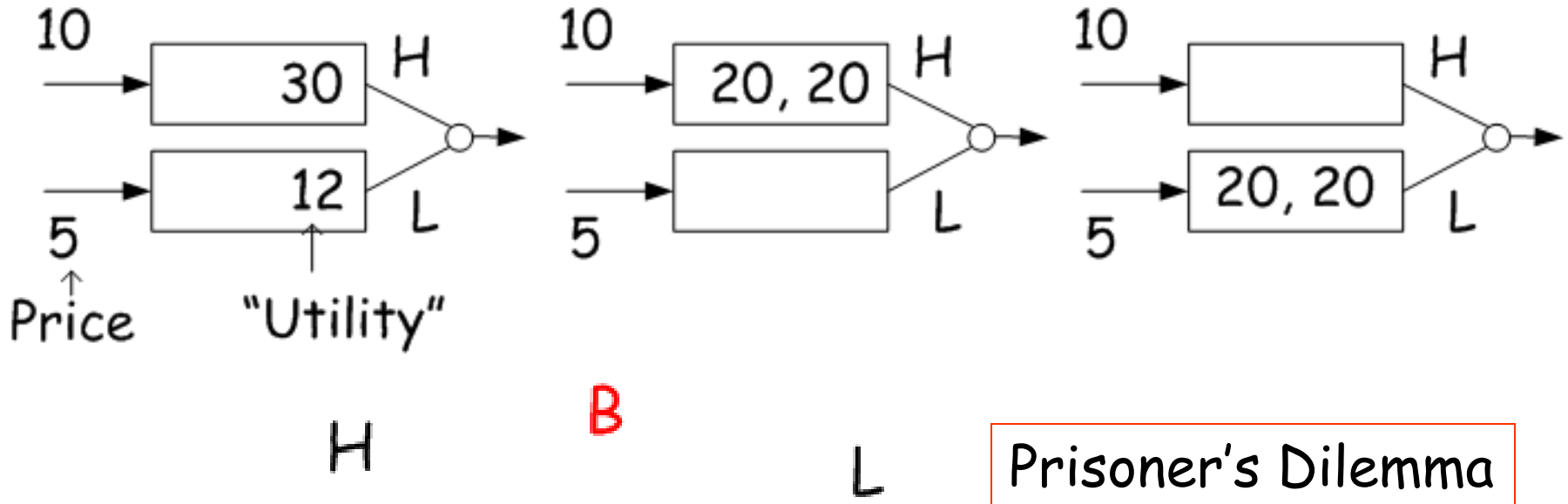
- A Nash Equilibrium always exists
- Incentive to upgrade
 - Upgrade will always increase bottleneck providers' revenue
- Efficient when capacities are adequate
 - It is the same as that in centralized allocation
 - Revenue per provider strictly dominates that in Nash game
- A distributed algorithm exists to compute prices.

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Pricing QoS



Prisoner's Dilemma

	H	$20 - 10 = 10$ $20 - 10 = 10$	$30 - 10 = 20$ $12 - 5 = 7$
A	L	$12 - 5 = 7$ $30 - 10 = 20$	$20 - 5 = 15$ $20 - 5 = 15$

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Uncertainty



Uncertainty may cause missing markets

Market for Lemons

Dealer buy used car for θ uniform in $[0, 1]$.

Buyer values a car that costs θ at 1.5θ .

Dealer asks X for a given used car.

Given X , potential buyer thinks that

θ is uniformly distributed in $[0, X]$.

The expected value of the car to the potential buyer is

$$E[1.5\theta|X] = 1.5 \times 0.5X = 0.75X < X.$$

Hence, the potential buyer does not buy.

If θ were known to the potential buyer, the dealer could ask 1.25θ and both the dealer and the buyer would be happy with the trade.

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Auction – Vickrey



One item. N buyers with valuations v_i .

- Item goes to highest bidder
- Winner pays second highest bid.

Dominant strategy: (Vickrey)
Bid true valuation (\Rightarrow efficient).

Buyer 1's reward is

$$(v_1 - z)1\{b_1 > z\}$$

where z is the second highest bid.

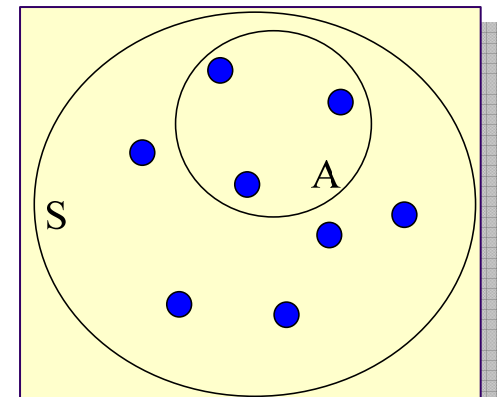
Note that $(v_1 - z)1\{v_1 > z\} \geq (v_1 - z)1\{b_1 > z\}$,
as you see by looking at $v_1 > z$ and $v_1 < z$.

Auction - VCG



Scheme: There is a set S of items. User i has a real utility $v_i(A)$ and declares a utility $b_i(A)$ for every subset $A \subset S$, for $i = 1, \dots, n$. The auctioneer solves **Maximize** $\sum_{i=1}^n b_i(A_i)$ over the possible partitions $(A_1, \dots, A_n, A_{n+1})$ of S . The optimum determines the allocations A_i . To calculate the payments, repeat without agent i and find the optimum allocations B_j^i . The payment of agent i is then

$$\pi_i = \sum_{j \neq i} [b_j(B_j^i) - b_j(A_j)].$$



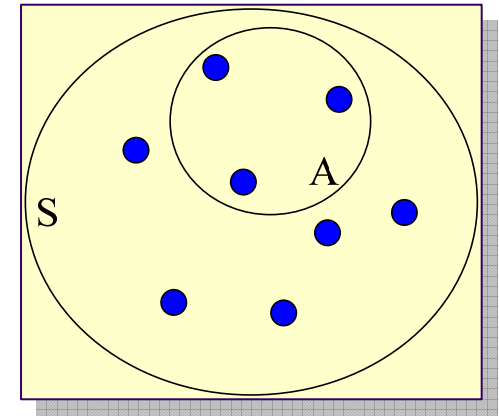
Auction - VCG



The payment of agent i :

$$\pi_i = \sum_{j \neq i} [b_j(B_j^i) - b_j(A_j)].$$

(Externality Price)



Theorem:

A dominant strategy is to declare the true valuations. The resulting NE is efficient since it maximizes the social welfare.

Auction – Bidding for QoS



Model (Shu, Varaiya)

Utility of i in class c : $v_i g_c$ ($g_c = \text{goodput}$)

True valuations:

$\{v_1, \dots, v_N\}$

Actual bids:

$\{x_1, \dots, x_N\}$



Assignments and prices:

$\{p_1, \dots, p_N\}$

g_c
↓

0,9	10	$c = 1$
0,7	10	$c = 2$
0,4	10	$c = 3$
0,2	∞	$c = 4$



Max. # connections

Auction – Bidding for QoS



VCG:

Rank in decreasing order of x_i

Fill up classes 1, 2, ... in that order

Price = reduction of value imposed on others

Say $x_1 \geq x_2 \geq \dots \geq x_{35}$

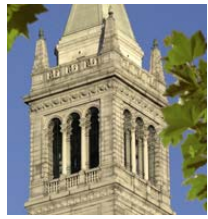
1, ..., 10	0.9	10
11, ..., 20	0.7	10
21, ..., 30	0.4	10
31, ..., 35	0.2	∞

What is p_{13} ?

13 pushes 21 and 31 down

$$\Rightarrow p_{13} = (0.4 - 0.2)x_{31} + (0.7 - 0.4)x_{21}$$

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Neutrality: Issues



- Contentious Debate



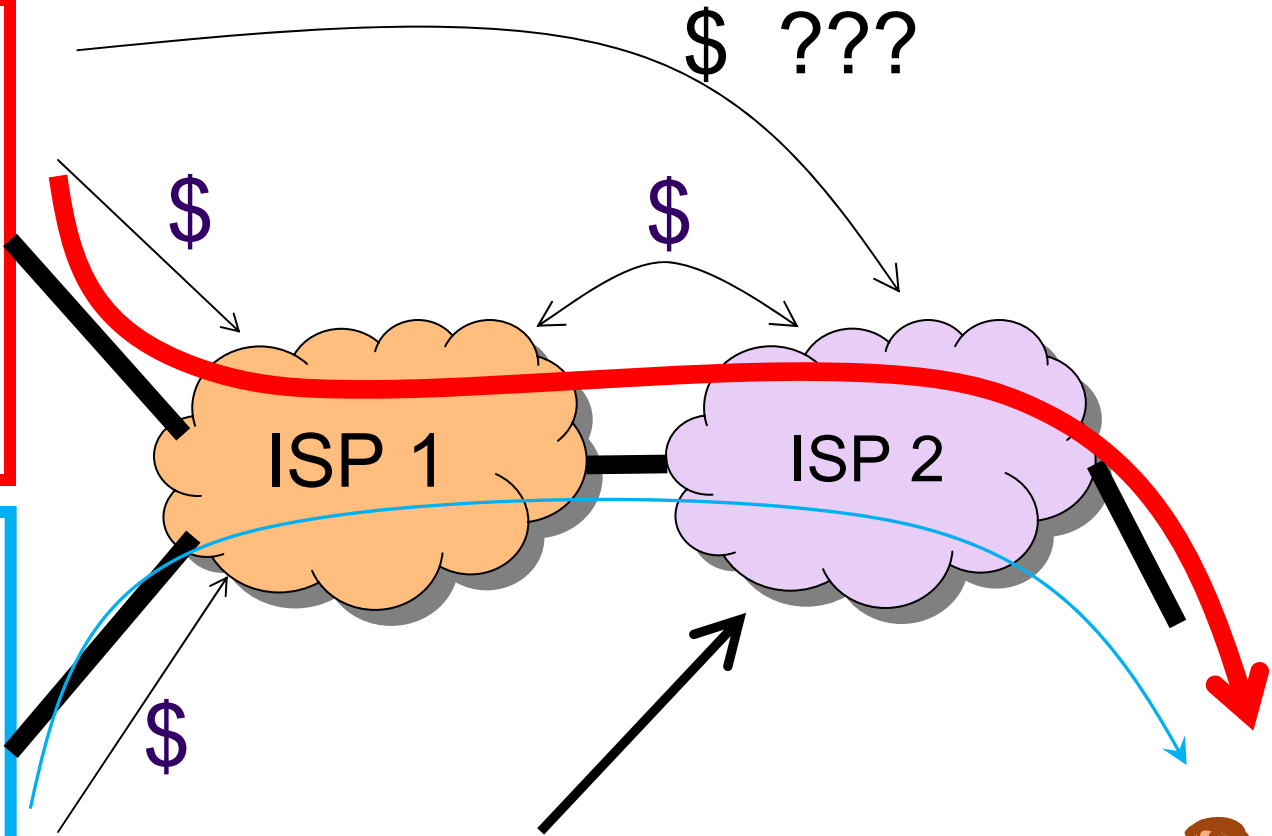
- But, what (if any) bearing should the issues have on the future network architecture?
- Does future architecture need features for
 - Revenue sharing between content and transit providers?

Neutrality: Issues



Content Provider A

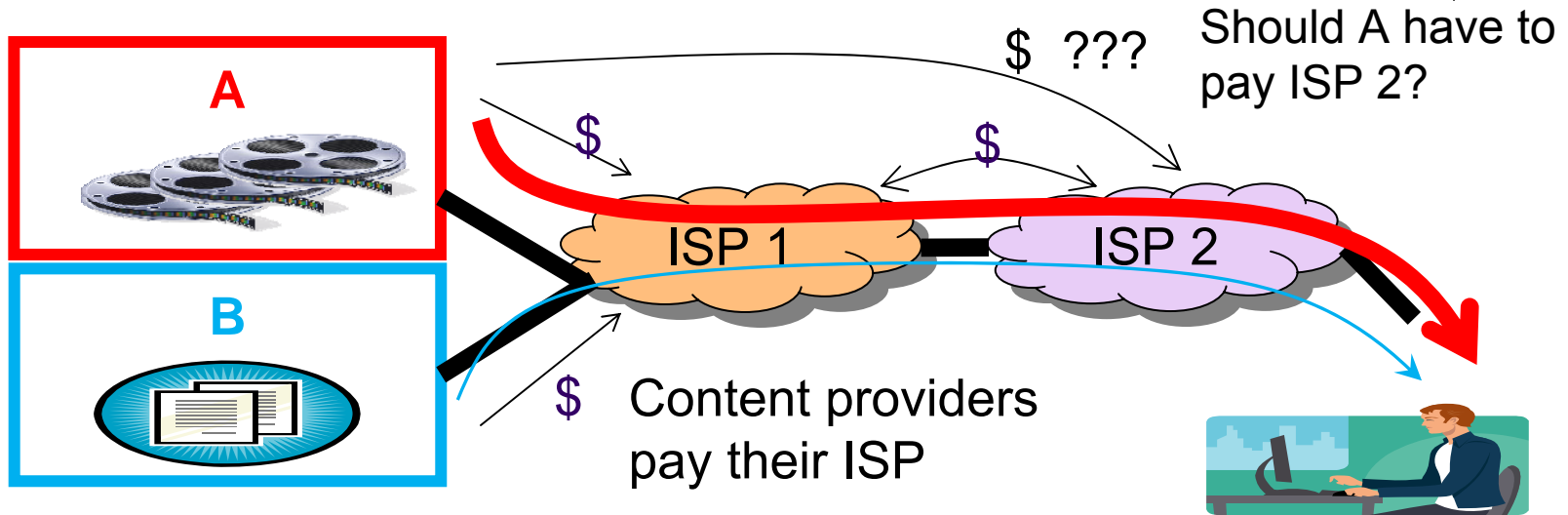
Content Provider B



ISP 2 needs to invest
To enable A's service



Neutrality: Issues



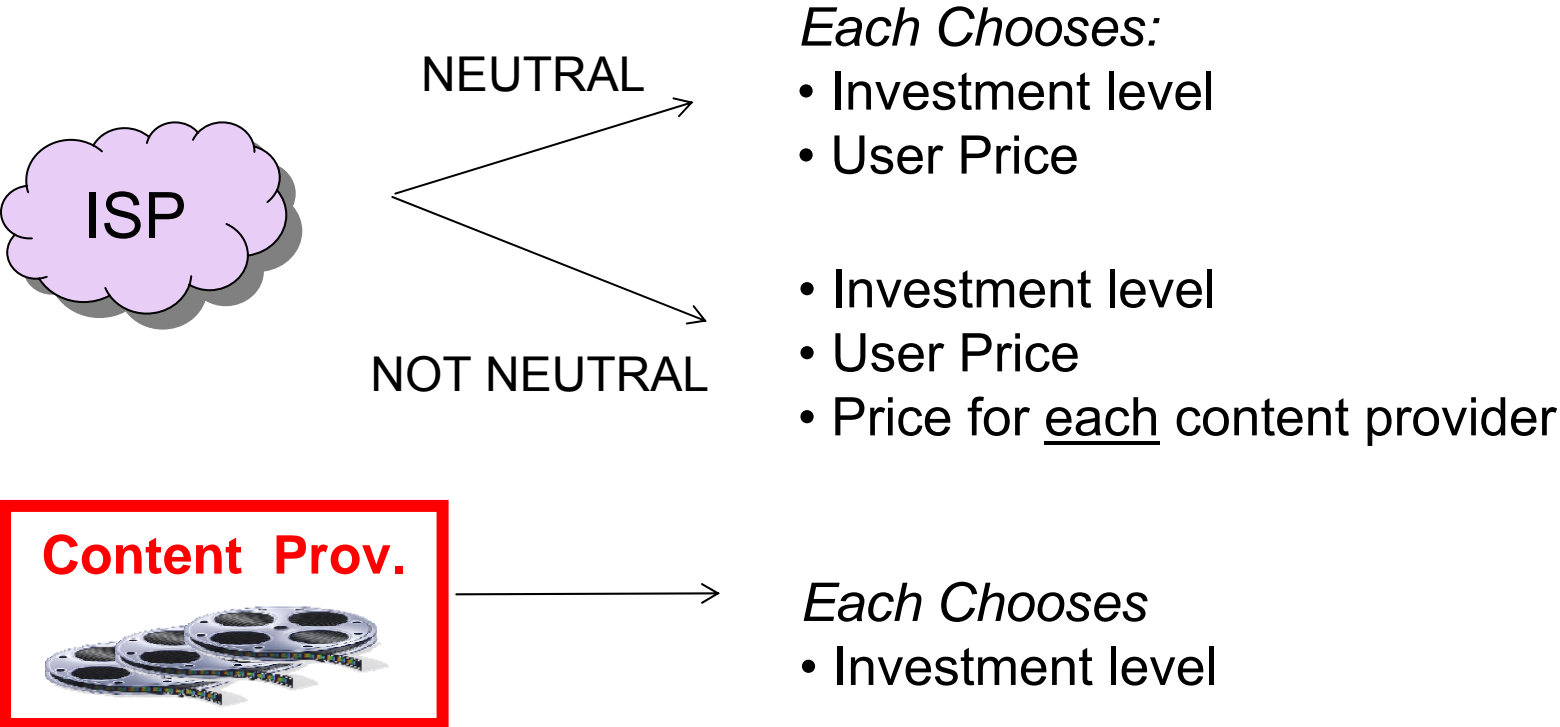
- Would allowing 2 to charge A
 - encourage 2 to invest?
 - discourage A to invest?
- What revenue sharing mechanisms should new Internet have?



Neutrality: Model

(Content Investment, ISP Investment) → Usage

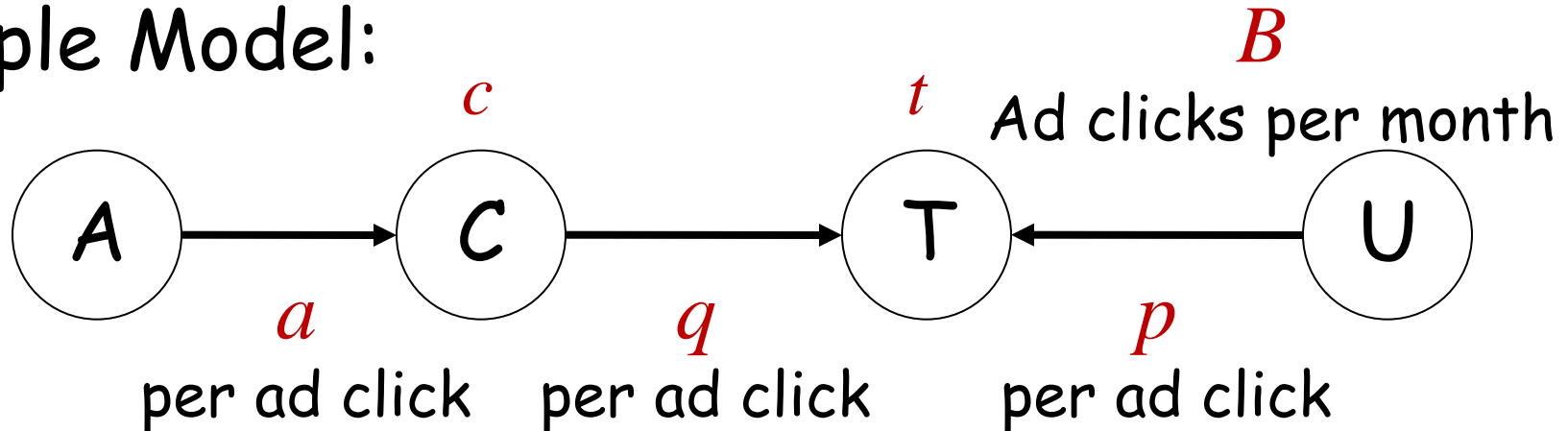
Usage → (Ad Revenue to Content, User Revenue to ISPs)



Neutrality: Model



Simple Model:



$$B = c^v t^w e^{-p/\theta} \quad 0 < v, w; v + w < 1$$

$$R_C = (a - q)B - \alpha c$$

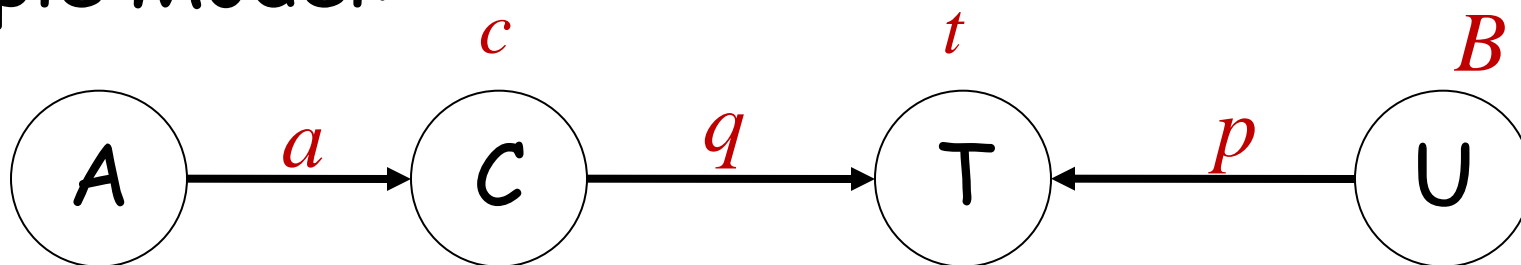
$$R_T = (q + p)B - \beta t$$

A = advertisers
C = content provider
T = transport provider
U = regular users

Neutrality: Model



Simple Model:



$$B = c^v t^w e^{-p/\theta} \quad 0 < v, w; v + w < 1$$

$$R_C = (a - q)B - \alpha c$$

$$R_T = (q + p)B - \beta t$$

Question:

$$q \uparrow \Rightarrow R_T \uparrow$$

or

$$q \uparrow \Rightarrow R_C \downarrow \Rightarrow c \downarrow \Rightarrow B \downarrow \Rightarrow R_T \downarrow$$

Neutrality: Model



Simple Model:

$$B = c^v t^w e^{-p/\theta} \quad 0 < v, w; v + w < 1$$

$$R_C = (a - q)B - \alpha c$$

$$R_T = (q + p)B - \beta t$$

Assume T chooses (t, p, q) . Then C chooses c to max

$$R_C = (a - q)c^c t^w e^{-p/\theta} - \alpha c$$

Given this $c(t, p, q)$, T then chooses (t, p, q) to max

$$R_B = (p + q)c^c t^w e^{-p/\theta} - \beta t$$

Neutrality: Model



Simple Model:

$$B = c^v t^w e^{-p/\theta} \quad 0 < v, w; v + w < 1$$

$$R_C = (a - q)B - \alpha c$$

$$R_T = (q + p)B - \beta t$$

In the neutral case, T chooses $(t, p, q = 0)$. Then C chooses c to max

$$R_C = a c^c t^w e^{-p/\theta} - \alpha c$$

Given this $c(t, p, 0)$, T then chooses $(t, p, 0)$ to max

$$R_B = p c^c t^w e^{-p/\theta} - \beta t$$

Neutrality: Results



Result 1:

The revenues per click and ROIs are the same under both regimes for content and transport providers.

Result 2:

The size of the market is larger in the neutral case only if a/θ is neither very large nor very small.

Neutrality: Results



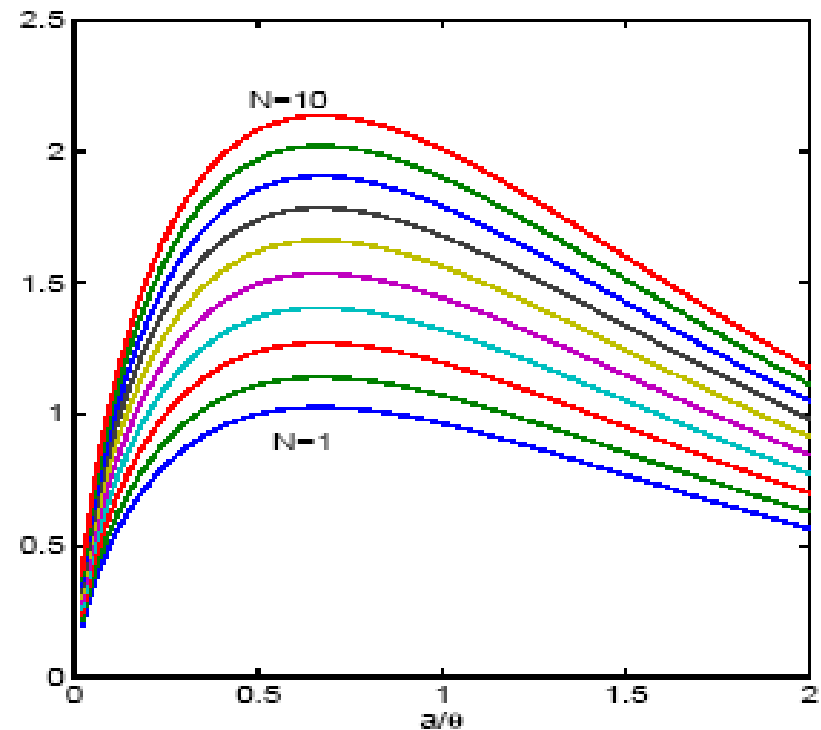
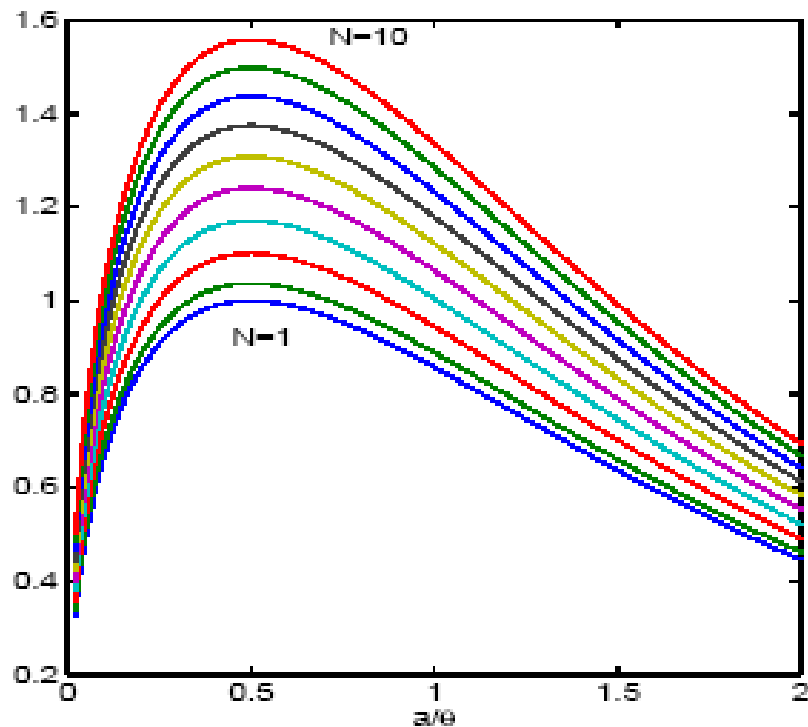
$$\left(\frac{B(\text{neutral})}{B(\text{non-neutral})} \right)^{1-v-w}$$

$$\left(\frac{t(\text{neutral})}{t(\text{non-neutral})} \right)^{1-v-w}$$

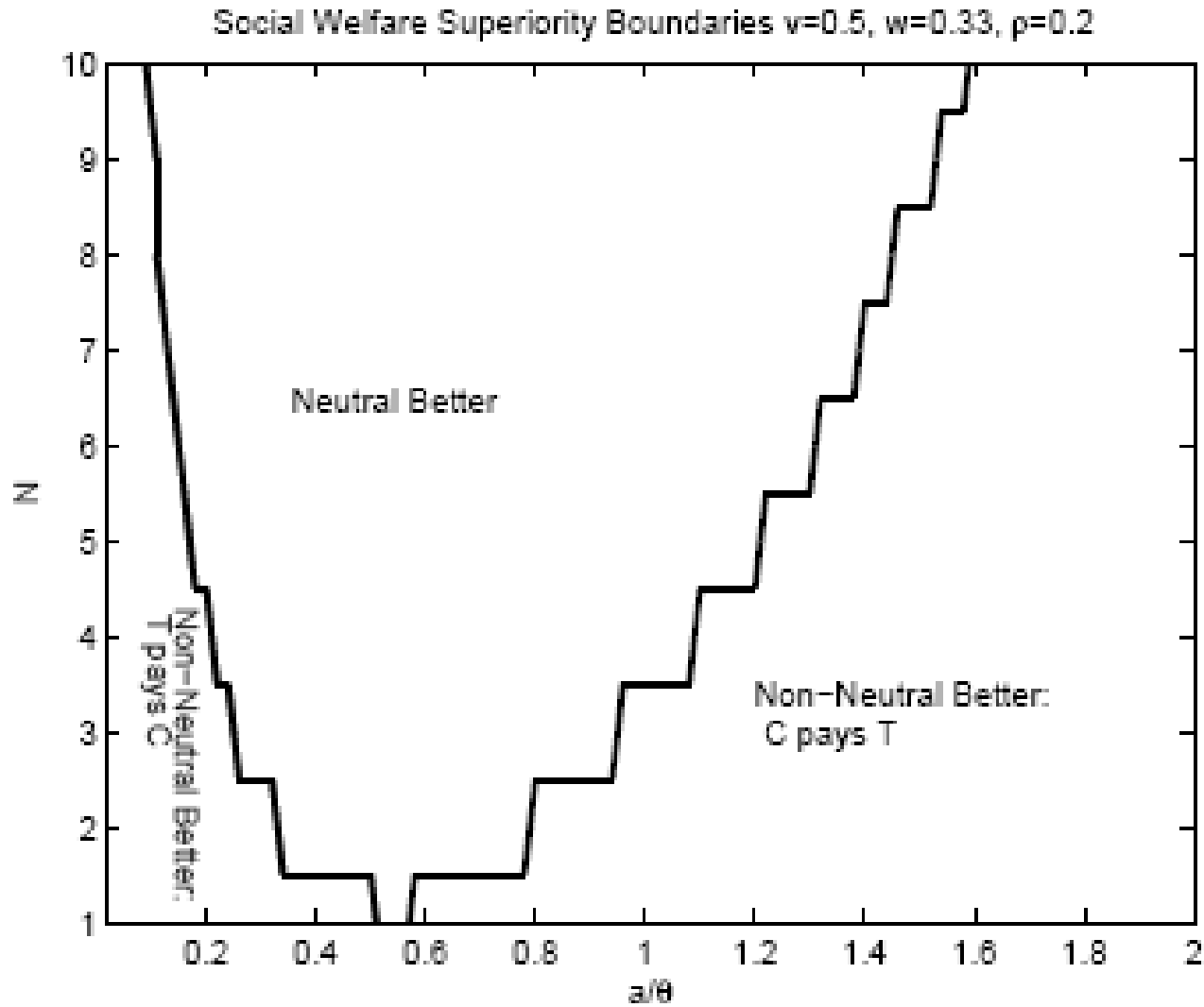
$$\left(\frac{R_T(\text{neutral})}{R_T(\text{non-neutral})} \right)^{1-v-w}$$

$$\left(\frac{c(\text{neutral})}{c(\text{non-neutral})} \right)^{1-v-w}$$

$$\left(\frac{R_C(\text{neutral})}{R_C(\text{non-neutral})} \right)^{1-v-w}$$



Neutrality: Results



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References



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