# MOT Seminar
# Applications of Game Theory: Neutrality, Security, and Congestion

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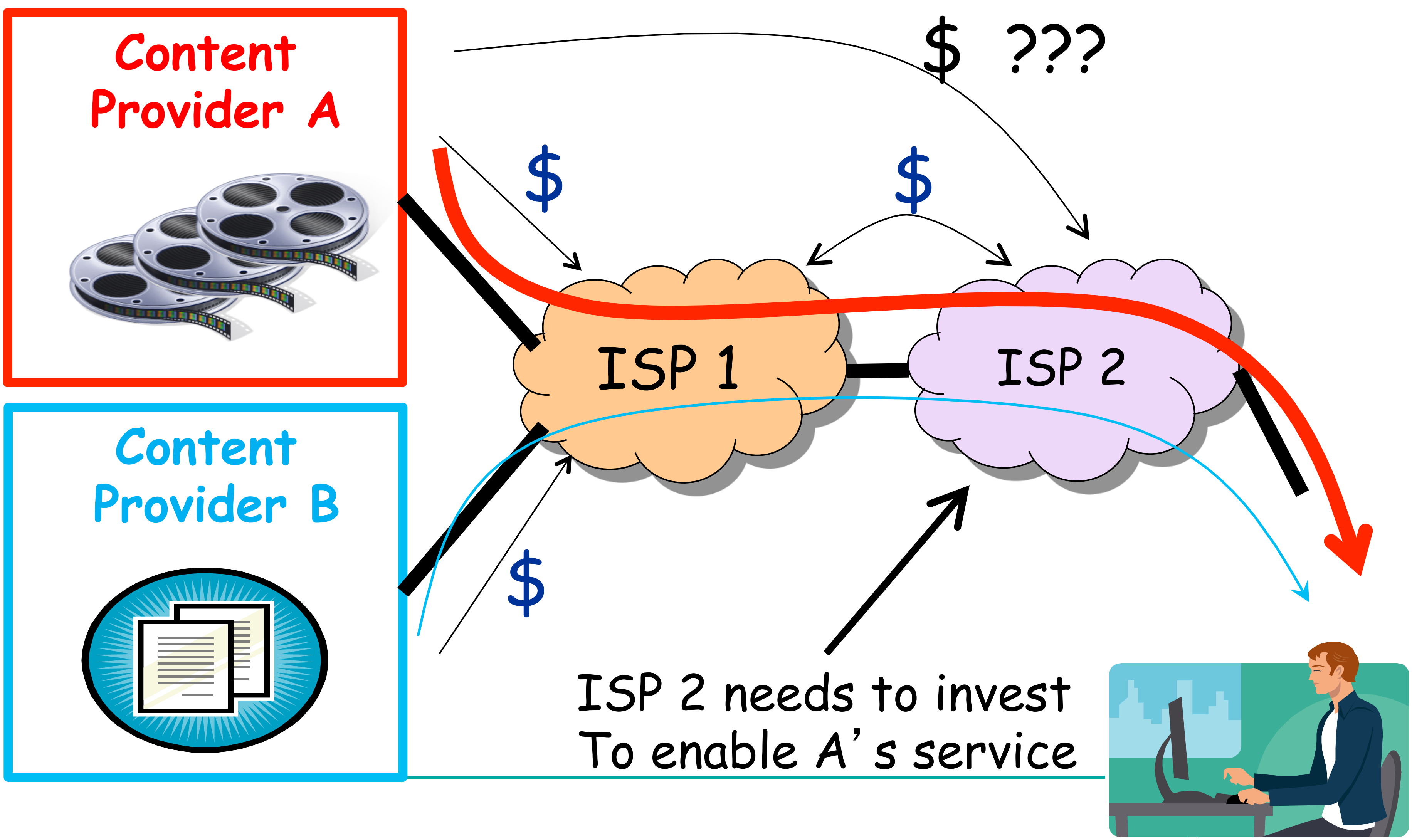
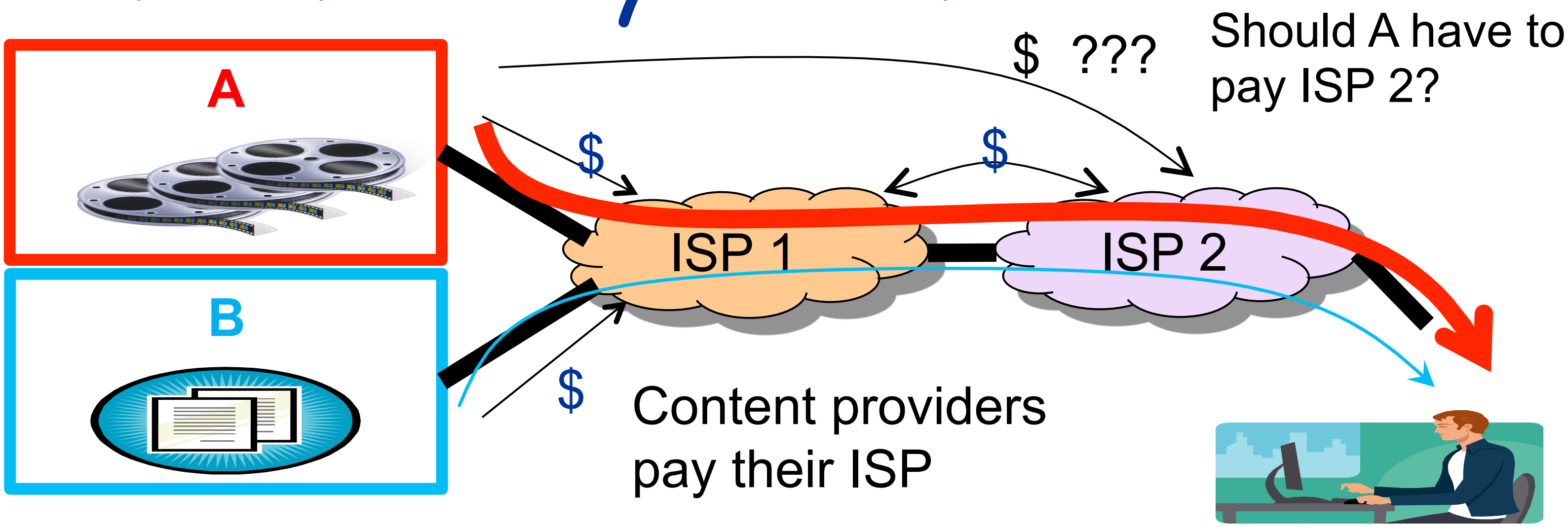
4/19/18

# User Discrimination: Good or Bad?



# Net Neutrality: Issues

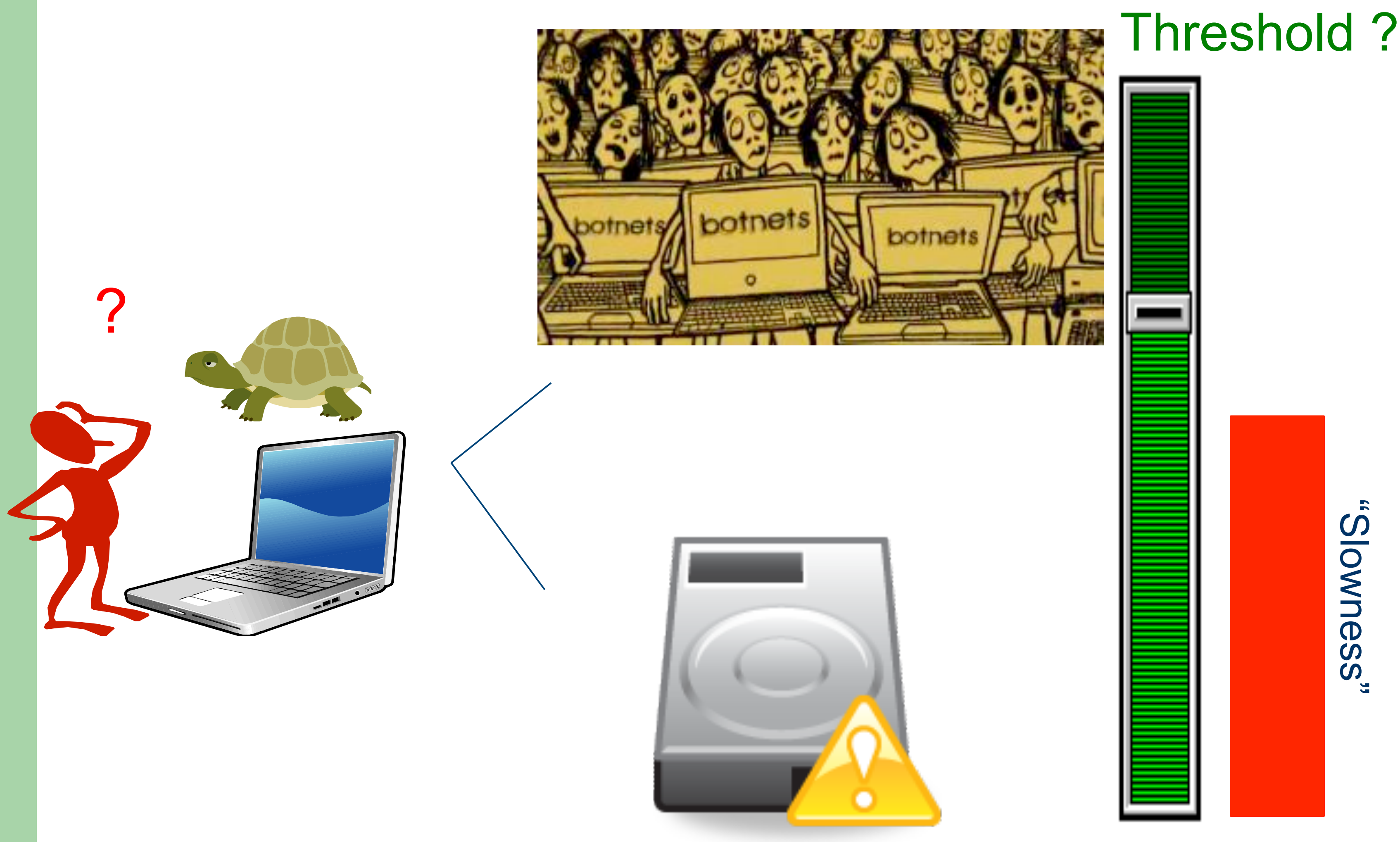



Would allowing 2 to charge A

- encourage 2 to invest?
- discourage A to invest?

What revenue sharing mechanisms should new Internet have?

# Do I have a botnet?





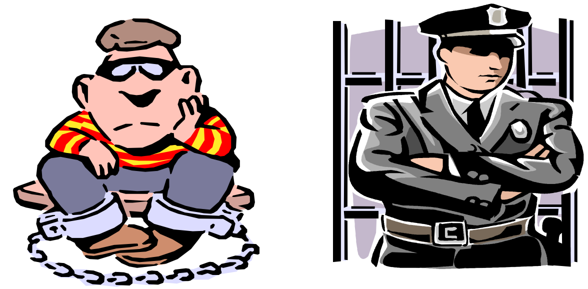

UC SANTA CRUZ
John Musacchio

# What is Game Theory?

- Study of interacting strategic agents.
- Used frequently in economics and other sciences.
  - Competition between firms.
  - Auction Design.
  - International Policy.
  - Evolution of Species.
  - And many more…

# Classic Example: Prisoner's Dilemma

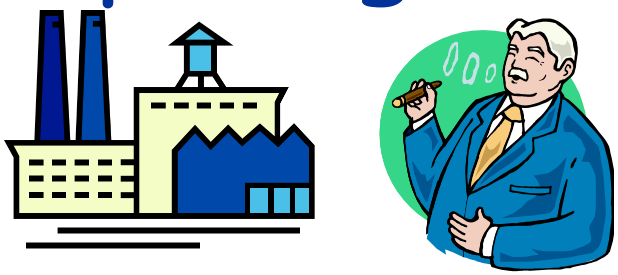
Prisoner A



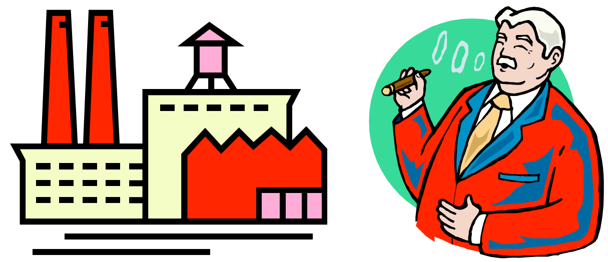
Prisoner B

| | Silent | Betray |
|---|---|---|
| Silent | (-1 [redacted] | (-4, [redacted] |
| Betray | (0, [redacted] | (-3, [redacted] |

# Competing Firms



Firm A



Firm B

| | Stagnate | Innovate |
|---|---|---|
| Stagnate | (2, [redacted] | (-1, [redacted] |
| Innovate | (3, [redacted] | (0, [redacted] |

# Elements of a Game

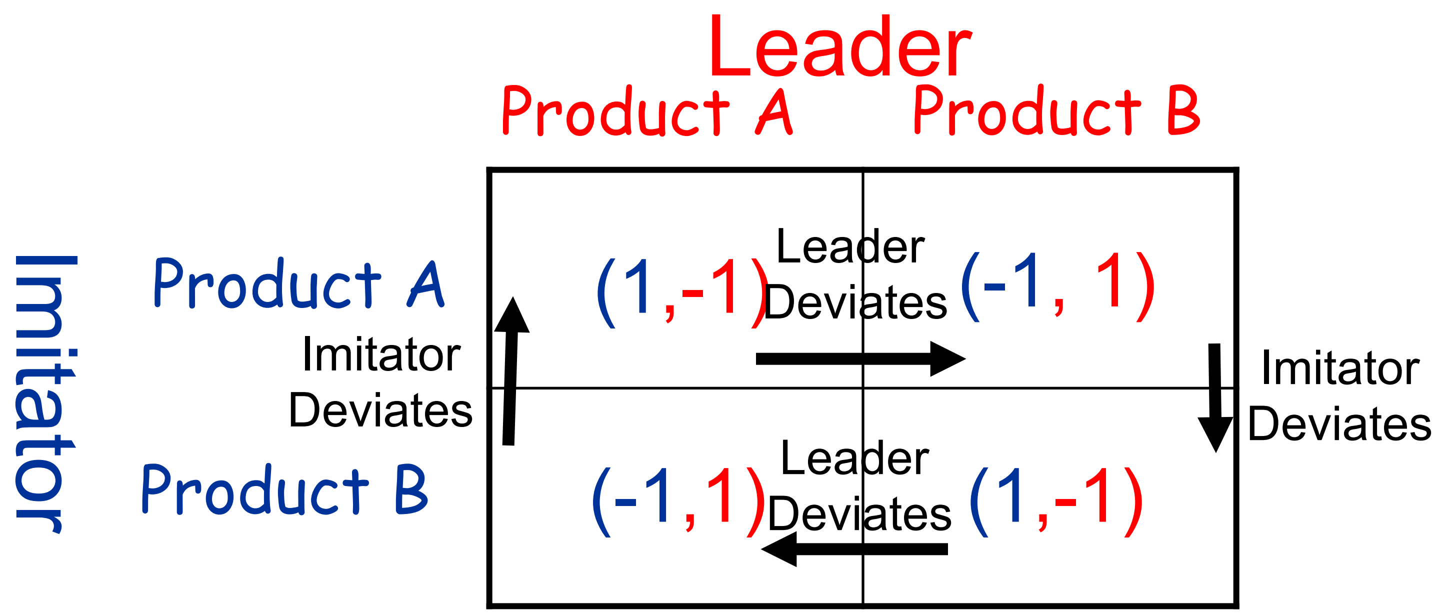
- Players
- Strategy
  - Player's actions
    - Innovate or Stagnate
  - Strategy Space – Set of all possible strategies
  - Strategy Profile – Particular combination of player strategies.
- Payoff
    - A mapping from player strategy profile to player rewards
      - Example: U( (I, I) ) = (0,0)

# Solution Concept

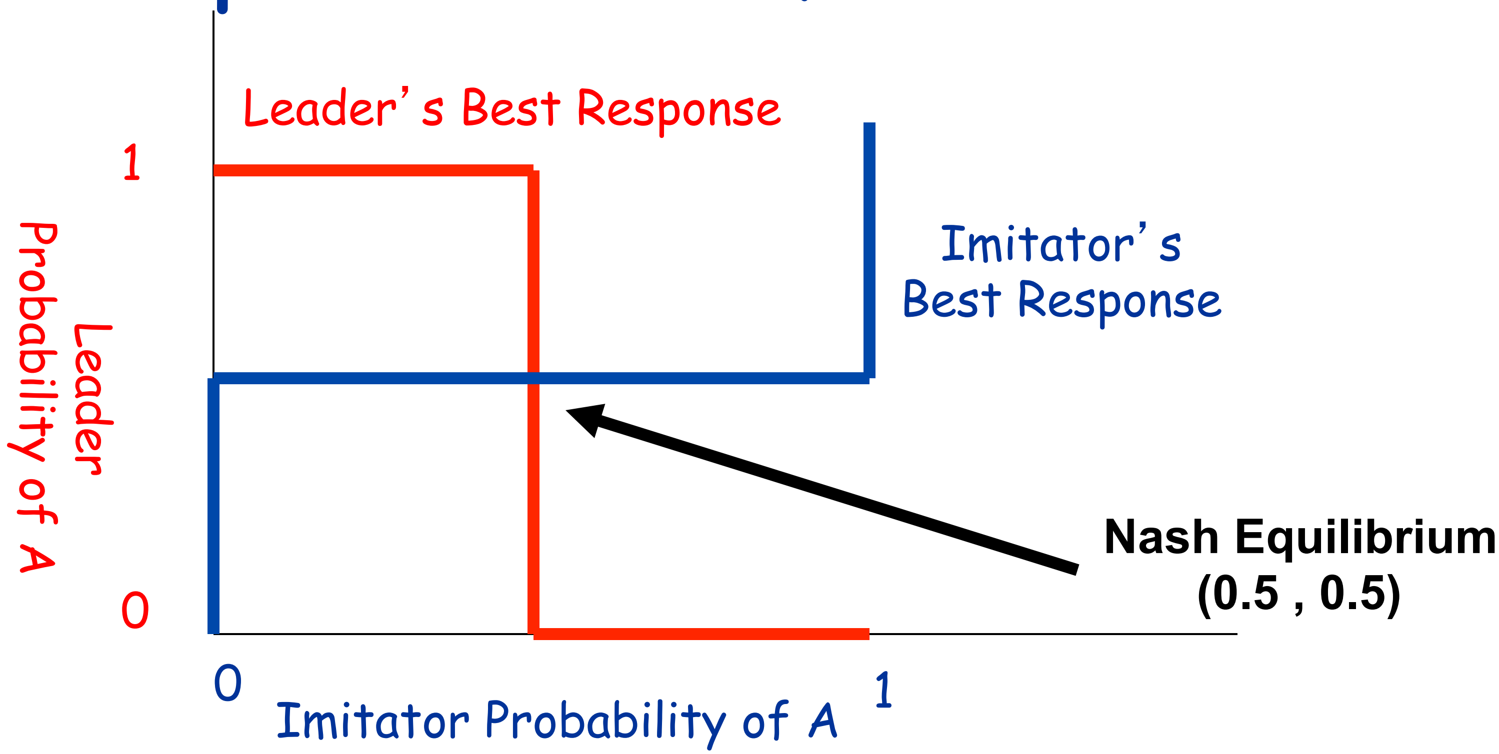
- Nash Equilibrium
  - A strategy profile from which no player has an incentive to deviate unilaterally
    - Example (I,I) is a NE
      - $U_A(I, I) > U_A(S, I)$ Firm A cannot do better by deviating
      - $U_B(I, I) > U_B(I, S)$ Firm B cannot do better by deviating
    - (I, I) is a **Nash Equilibrium**.
- Do all games have a Nash Equilibrium?

# Example: Leader, Imitator (matching pennies)

- Idea: Player 1 (Imitator) wants a match, Player 2 (Leader) doesn't.
- What is the Nash Equilibrium?
- Expand strategy space to allow randomized or "mixed" strategies.



# Example: Leader, Imitator




- NE is not strict in this case.
  - (At NE, players are indifferent to switching)
  - Such an NE is said to be not *strict*

# Nash Existence

- Finite Strategy Space (J.F. Nash 1950)
  - Every n-player game has at least one Nash Equilibrium (possibly mixed).

# Static vs. Multi Stage

- Static Games
  - Players choose strategies simultaneously, without knowing what the others do.
- Multi-Stage
  - Game is played in multiple rounds.
  - Players may see how others played in previous rounds.
    - That information helps choose how to play in the next round.
  - A strategy is a full specification of what actions to take in each stage, as a function of the observations from previous stages

# Congestion Externalities

Externality: An actor's choice effects other's utility

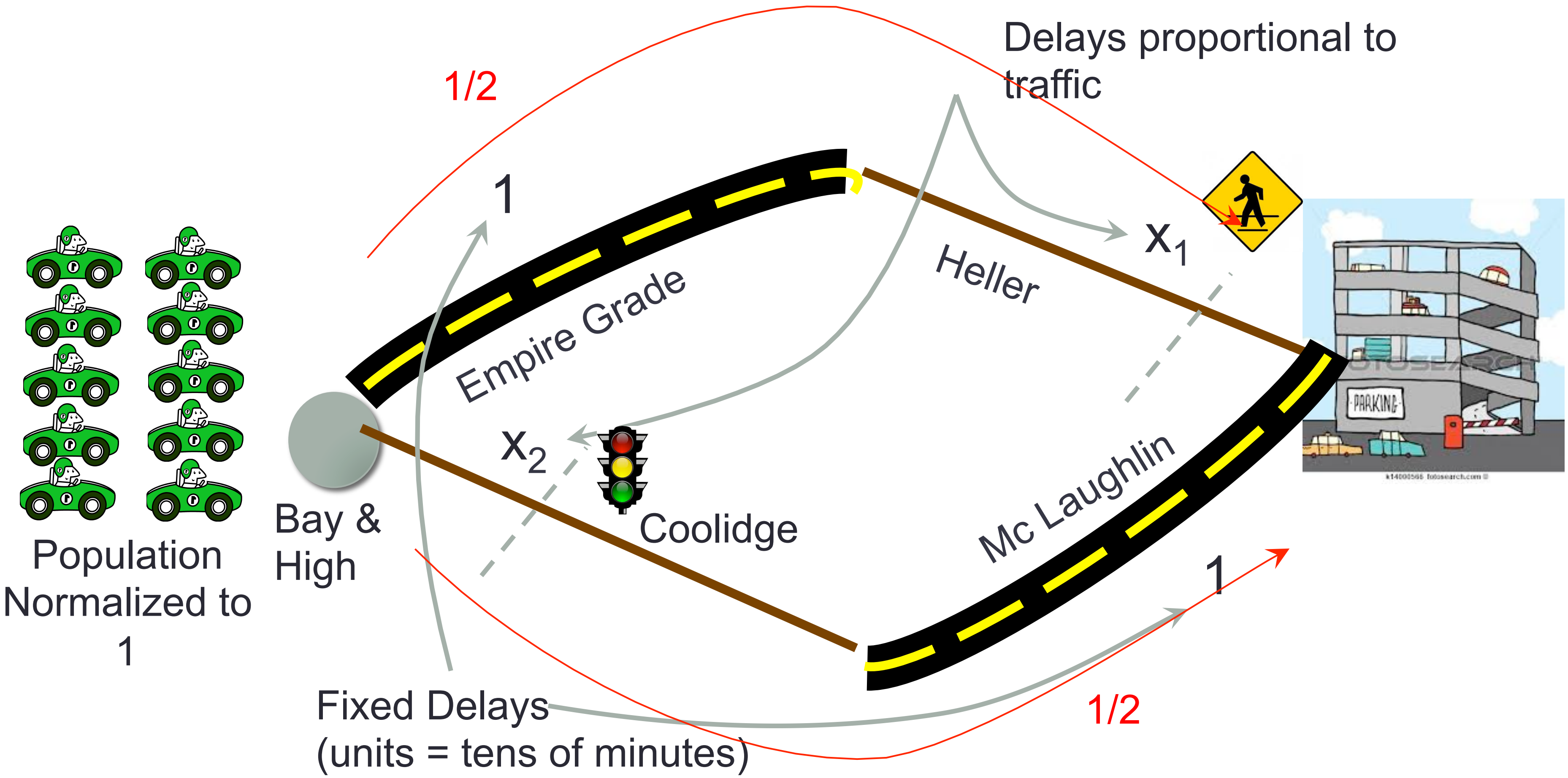
- E.g. My decision to drive during rush hour increases the delay of other drivers on my route

Congestion Externality: The more actors choose an action (route) the worse it gets

Figure 1: SUV driver imposing an externality on a pedestrian.

# Congestion Externalities

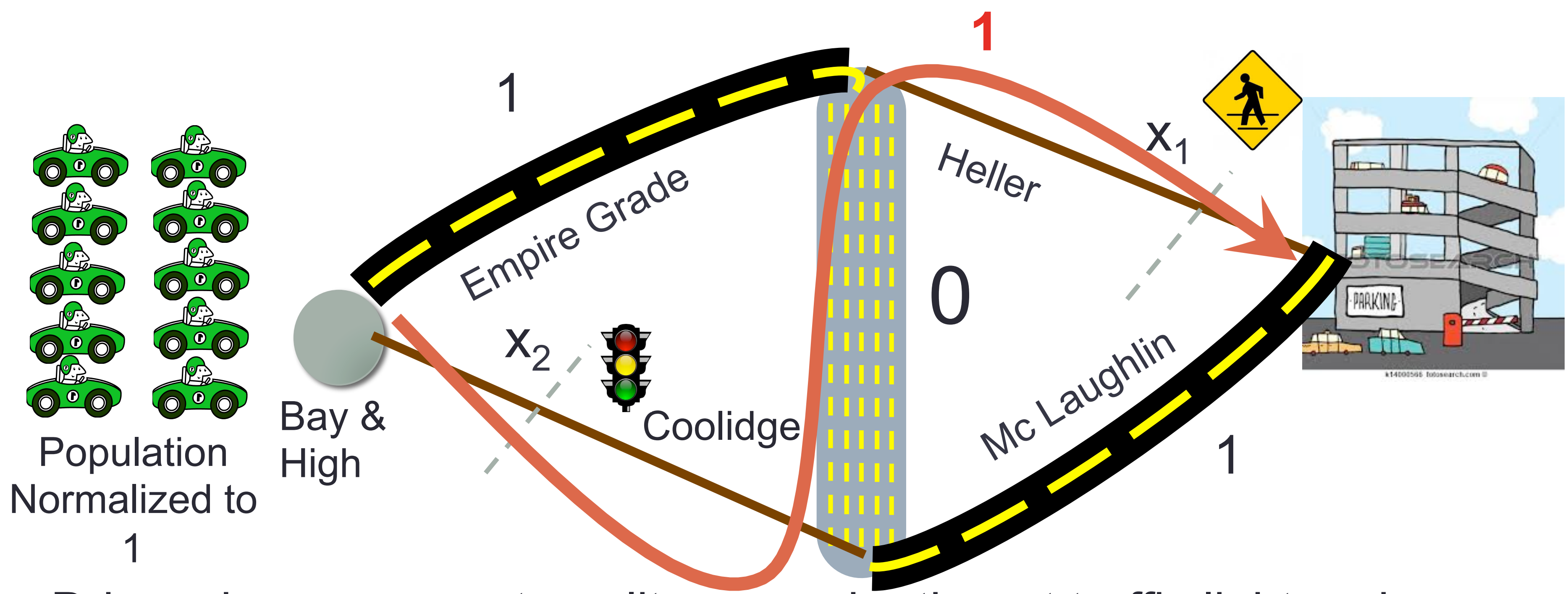
Example: Braess's Paradox




Equilibrium Delay: 1.5 (15 minutes)

# Congestion Externalities

Example: Braess's Paradox

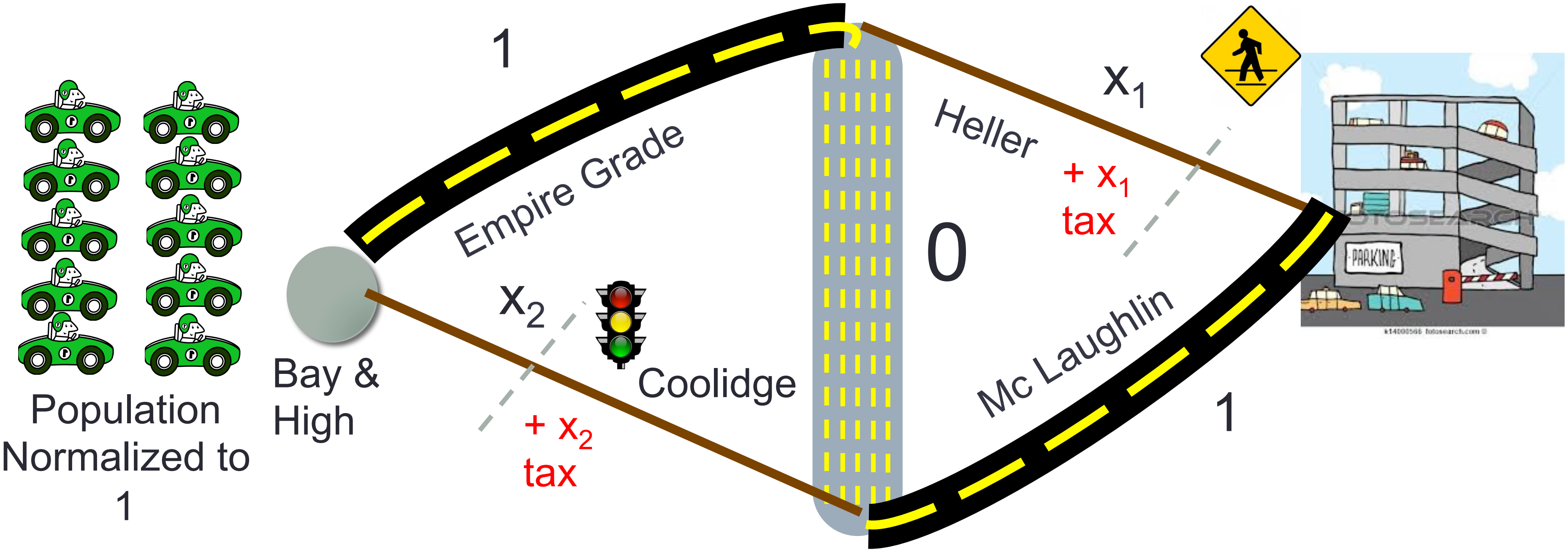



Drivers impose an externality on each other at traffic light and crosswalk queues

- Total crosswalk delay: $x_1^2$ (Delay times population suffering it)
- Marginal cost to whole population for increasing crosswalk traffic: $2x_1$
- …But each driver only sees cost of $x_1$. Make them pay!

# Congestion Externalities

Example: Braess's Paradox Equilibrium Delay: 2 (20 minutes)




**Pigovian Tax**

- Make people pay for their externality
- Aligns individual and social optimization problems to make optimum achieved
- Lots of challenges for practical implementation
  - E.g. Monetary value of time different for different people, measurement difficulties, disincentive for revealing willingness to pay, etc…

# A Two-Sided Market Analysis of Provider Investment Incentives With an Application to the Net-Neutrality Issue.

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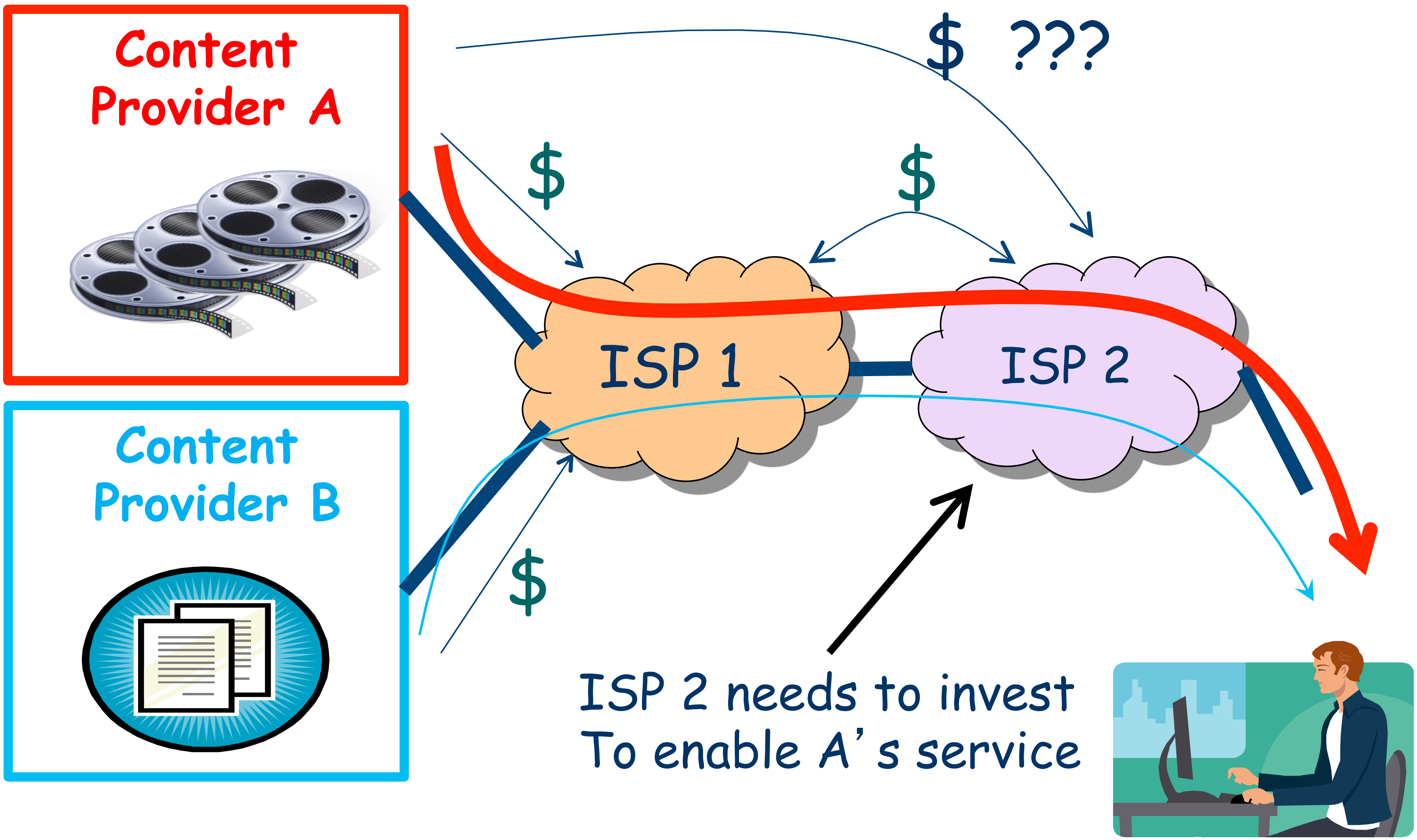
# Net-Neutrality

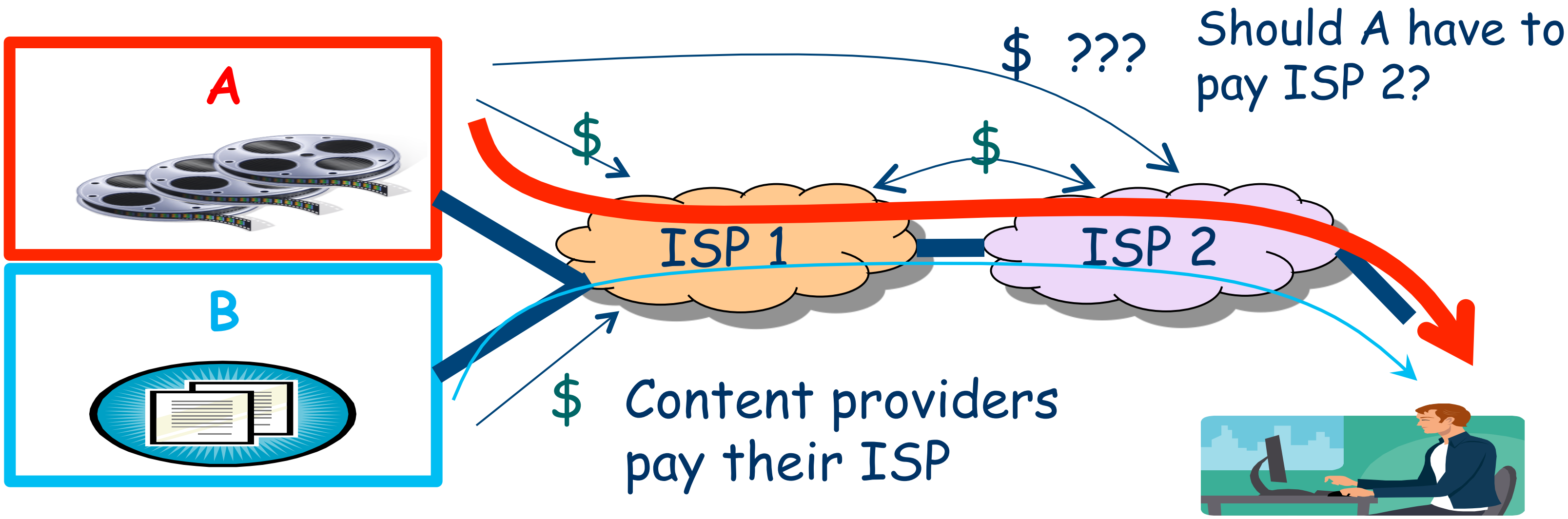
Dimensions of Debate

- Offering of grades of service
- Freedom of speech
- Whether Local ISPs should be allowed to charge content providers
- …

# Overview


Content Provider A
Content Provider B
$ ???
$
$
$
ISP 1
ISP 2
ISP 2 needs to invest
To enable A's service

# Overview




- Would allowing 2 to charge A
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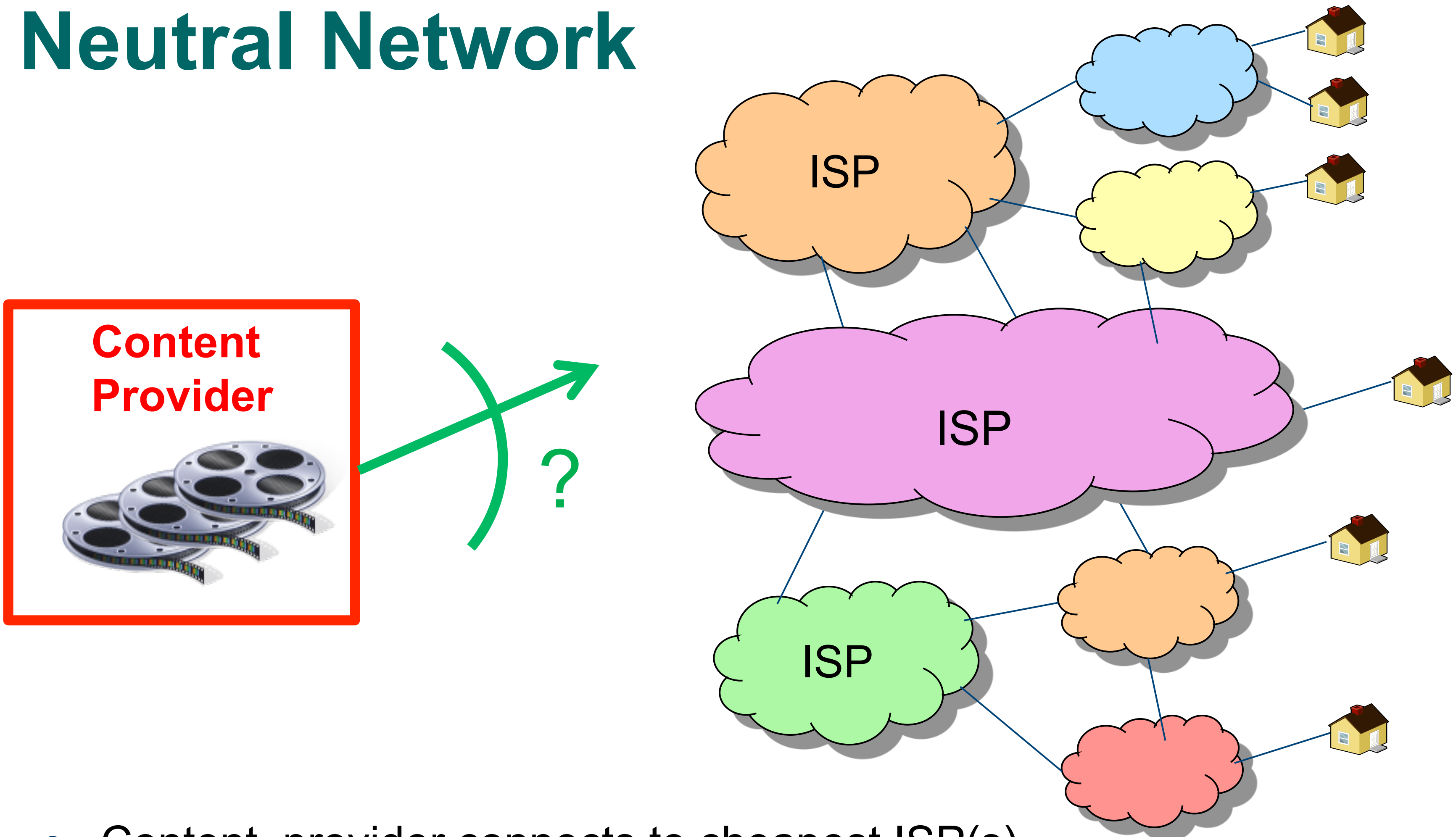
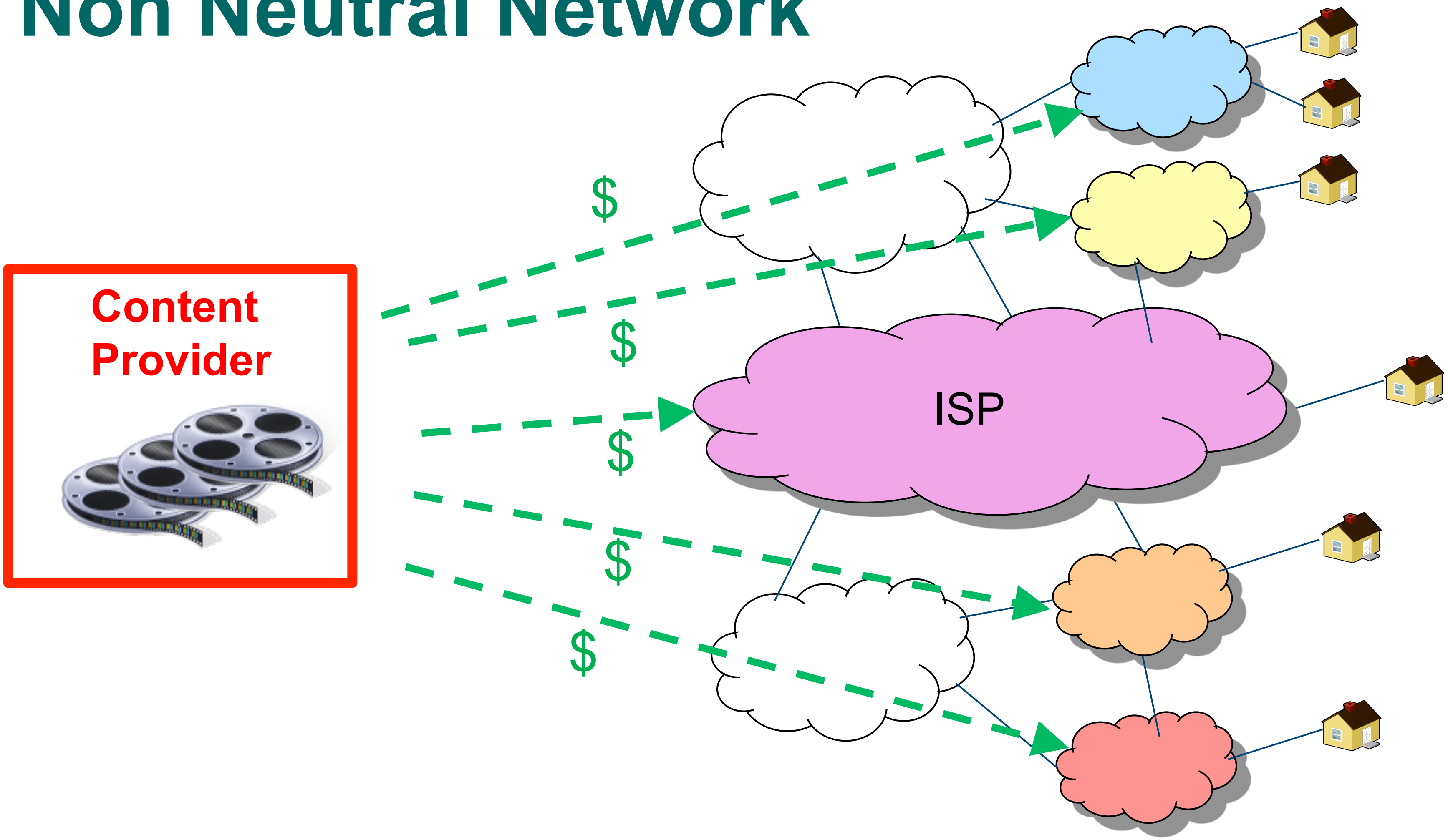
# Neutral Network



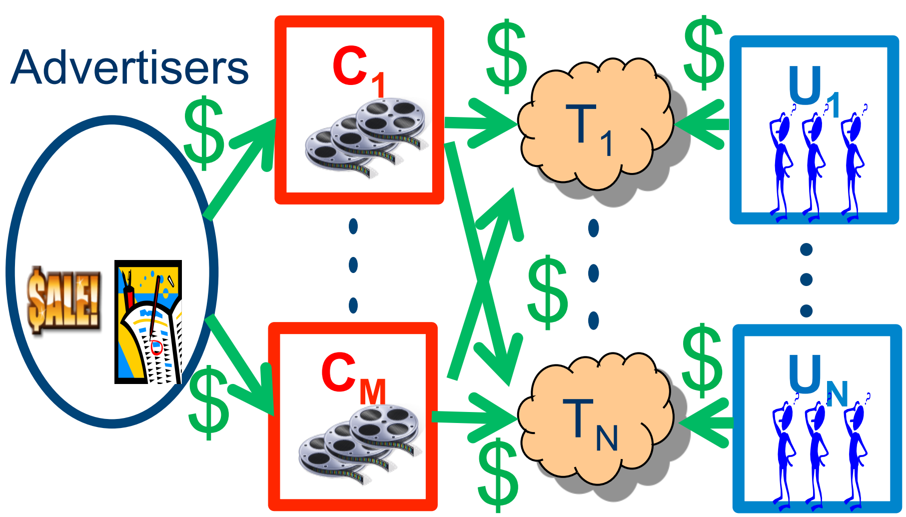

- Content  provider connects to cheapest ISP(s)
- Any such connection allows communication with all end-users
- Competition drives connection prices to marginal cost
- We normalize so that
  - **Content providers pay 0 for connection**

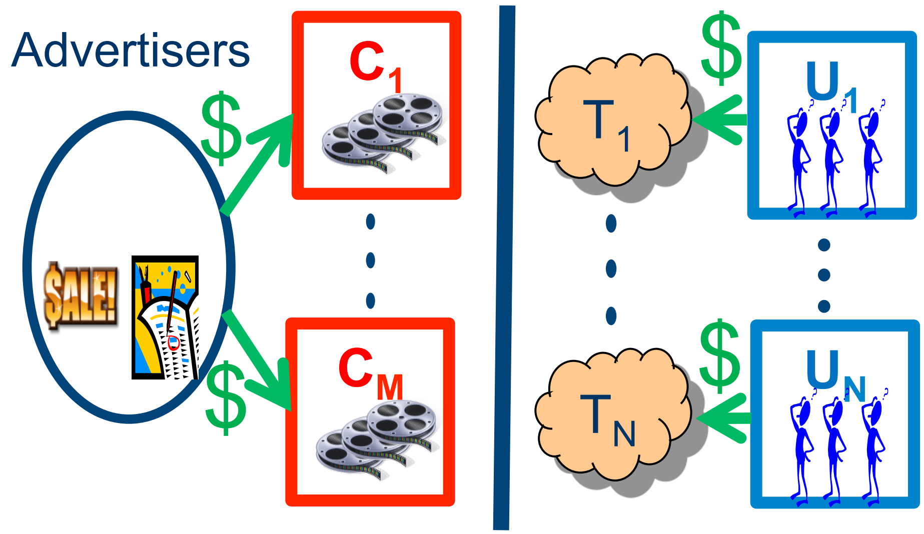
# Non Neutral Network




- All ISPs can charge the content provider
- Content provider forced to pay all ISPs that serve end users.

# Two-Sided (Non-Neutral) | One-Sided (Neutral)




## Which is better?

- Study Investment Incentives
- Model Overview
  - usage ("clicks") function of provider investments
  - Provider revenue function of usage and regime (one- vs. two-sided)
  - Content and transit providers play a game

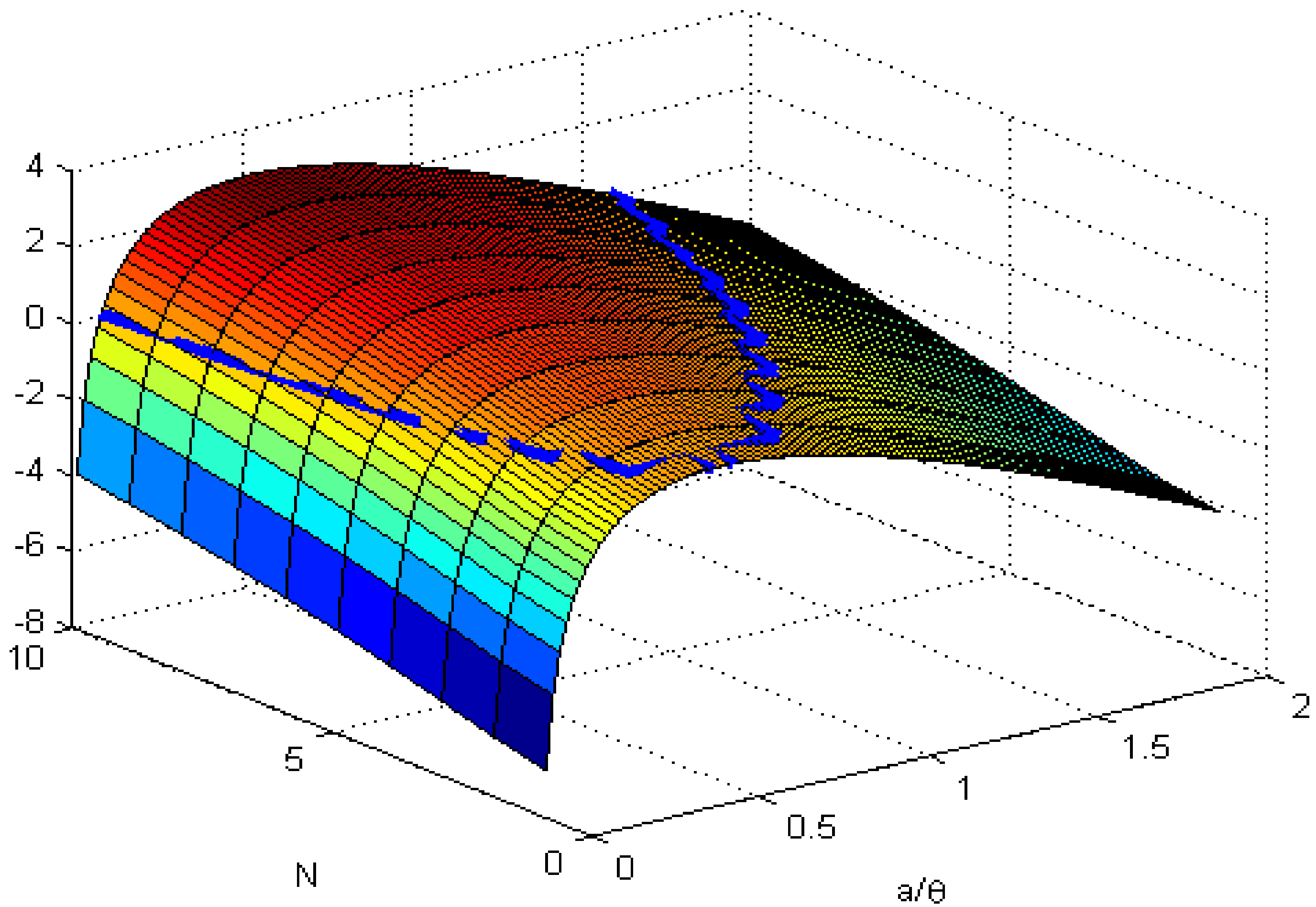
# Two-Sided Markets

- Large Literature
  - See Rochet and Tirole (2006) for overview
- Idea
  - Platform mediating two types of participants
  - E.g. Videogame Console needs to attract end-users and game makers
- Novelty of our model
  - Model Investment incentives to  compare two regimes.
- Previous application to Net-Neutrality issue
  - Hogedorn (2006)
    - "conduits," "service providers", content
    - Study "open access" of conduits by to "service providers"

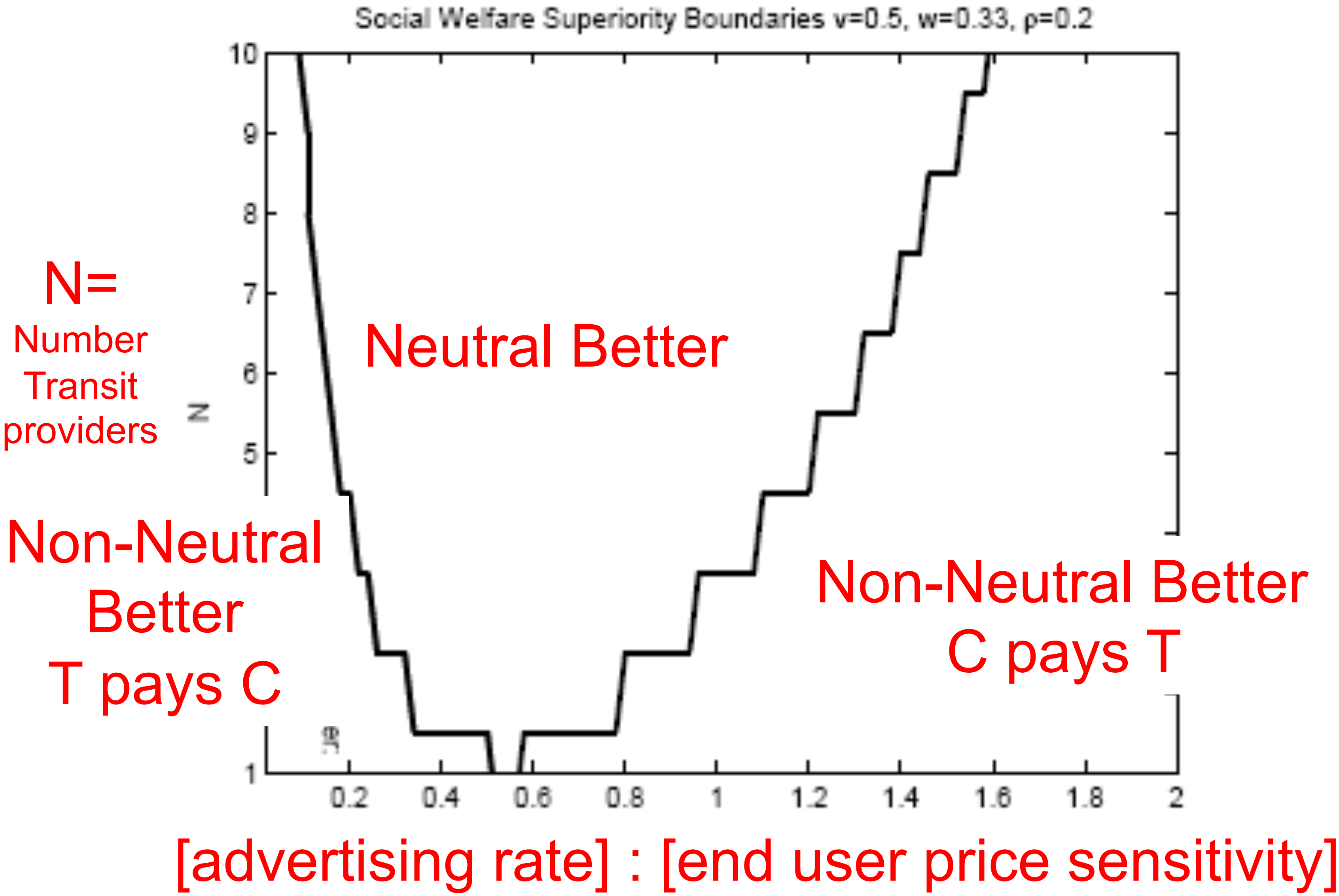
# Comparison

$$\log\left(\frac{\text{Social Welfare Neutral}}{\text{Social Welfare Non Neutral}}\right)$$

$$v = 0.5, w = 0.33, \rho = 0.2$$



# Comparison




J. Musacchio, G. Schwartz, J. Walrand, “Network Neutrality and Provider Investment Incentives,” in submission (2007).

# Castles

Toll: $q_1$

Toll: $q_2$

Toll: $q_3$

Toll: $q_4$

Tolls collected are a product of toll rate and traffic rate,

A castle sees any benefit of  his toll increase, but the downside (the traffic decrease) is borne by all castles.

Consequently, each castle tends to tax higher than would be optimum socially.

# Conclusions

- Two competing effects
  - Need to adjust revenue sharing between content and transit providers.
  - “Castles on the Rhine” effect of transit providers charging higher than optimal tolls.
- Whether neutral or non-neutral is better depends on
  - number of providers
  - advertising rates vs. user price sensitivity
- For parameters that make non-neutral superior, both content and transit providers are better off!

# References


- Rochet, J.-C. and J. Tirole (2006) "Two-Sided Markets: A Progress Report," RAND Journal of Economics, 37(3): 645-667.
- Hermalin, B. and M. Katz (2007), "The Economics of Product-Line Restrictions With an Application to the Network Neutrality Debate," Competition Policy Center
- Hogendorn, C. (2007) "Broadband Internet: net neutrality versus open access," International Economics and Economic Policy, 4: 185-208.