The Public Option: A non-regulatory alternative to Network Neutrality

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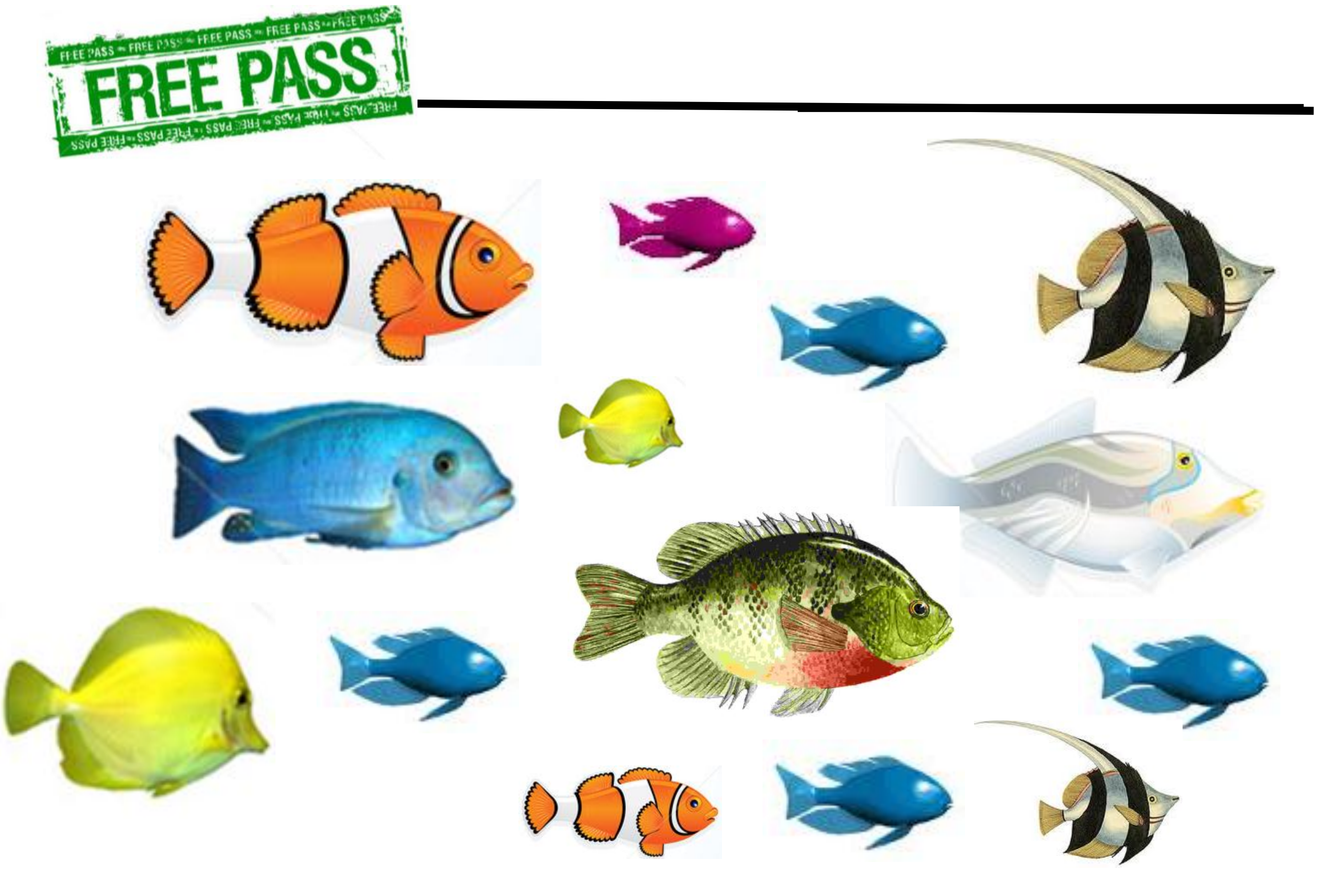
The Internet Landscape

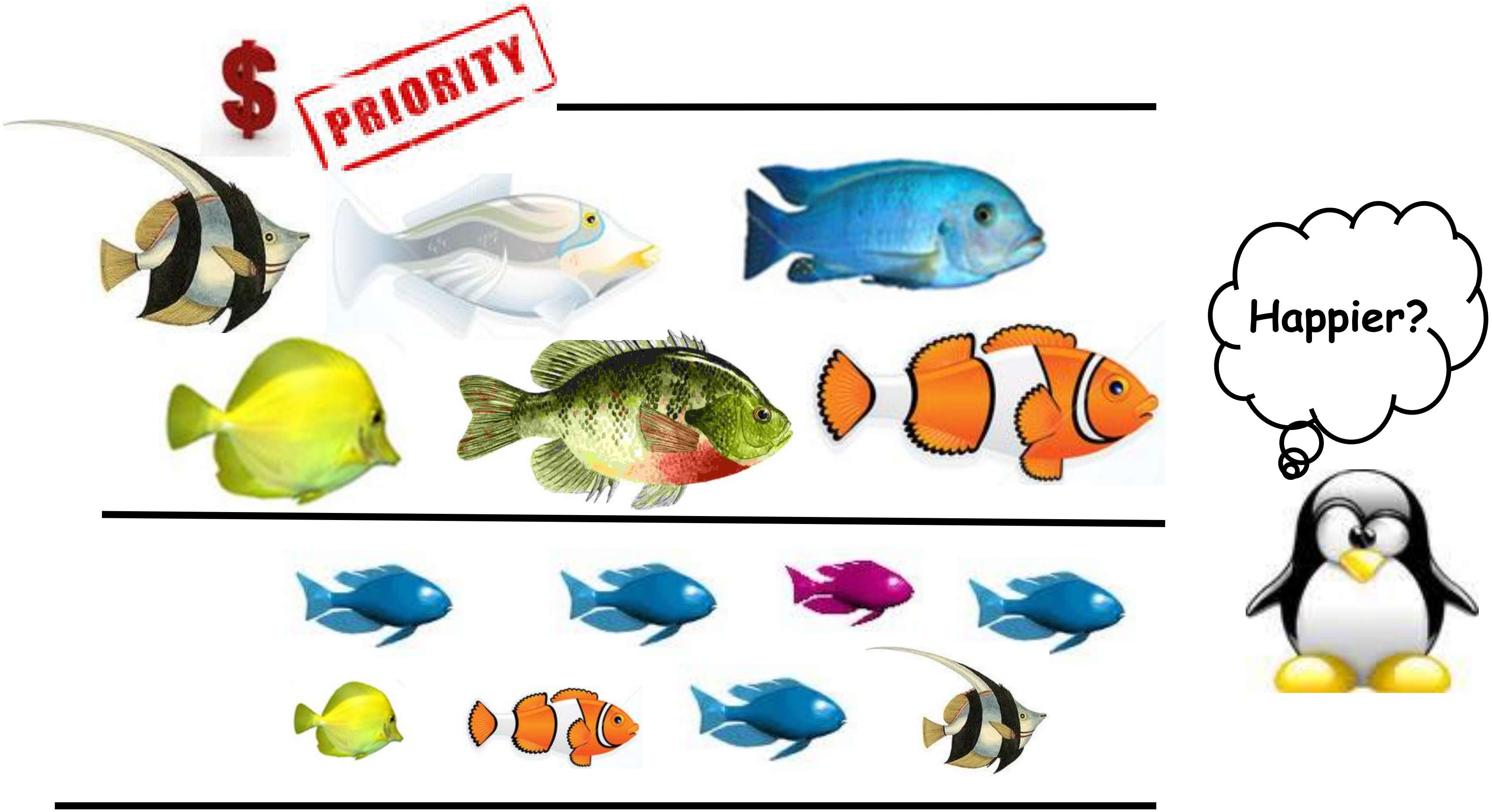
- Internet Service Providers (ISPs)
- Internet Content Providers (CPs)
- Regulatory Authorities
- Users/Consumers

Network Neutrality (NN)



Paid Prioritization (PP)

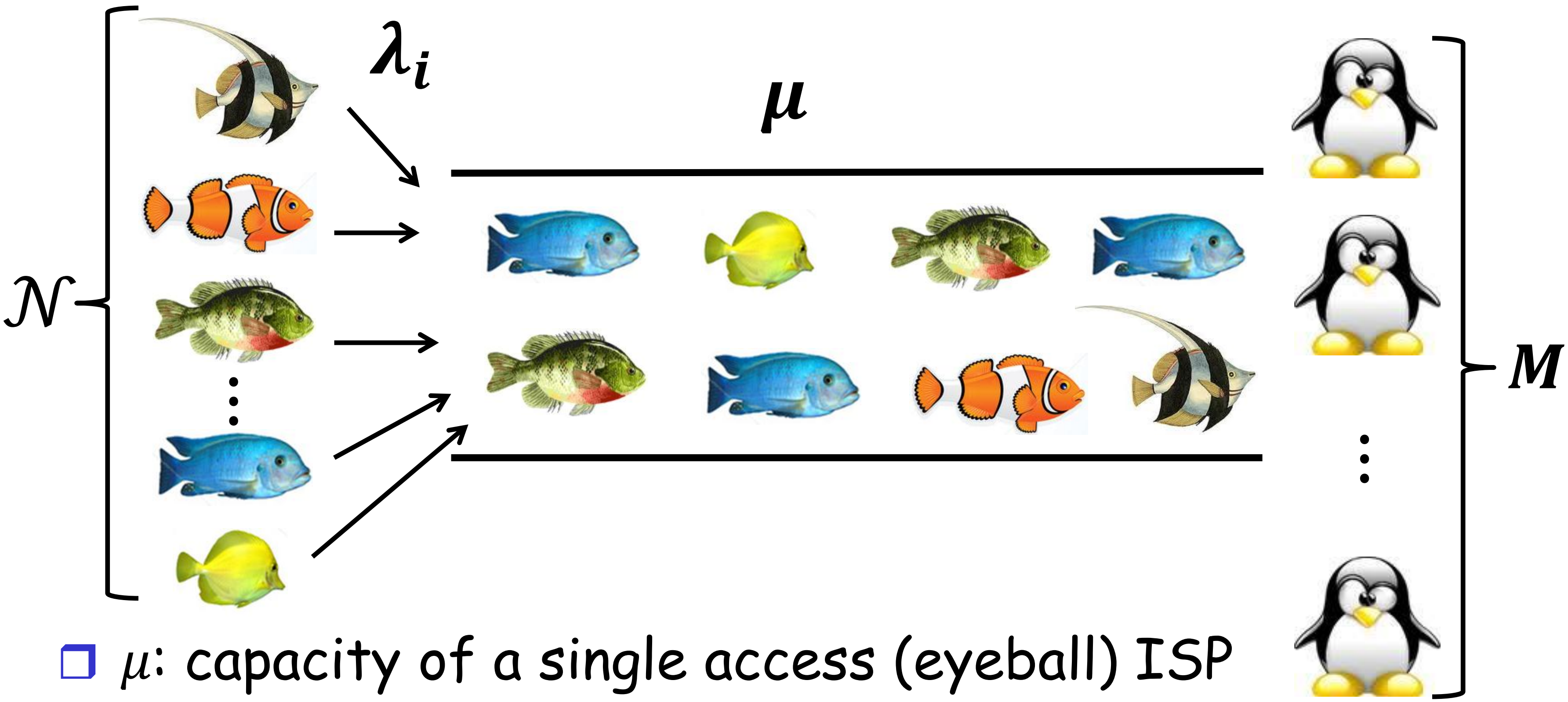
Hands Off the Internet



Highlights

- A more realistic equilibrium model of content traffic, based on
  - User demand for content
  - System protocol/mechanism
- Game theoretic analysis on user utility under different ISP market structures:
  - Monopoly, Duopoly & Oligopoly
- Regulatory implications for all scenarios and the notion of a *Public Option*

Three-party model $(M, \mu, \mathcal{N})$



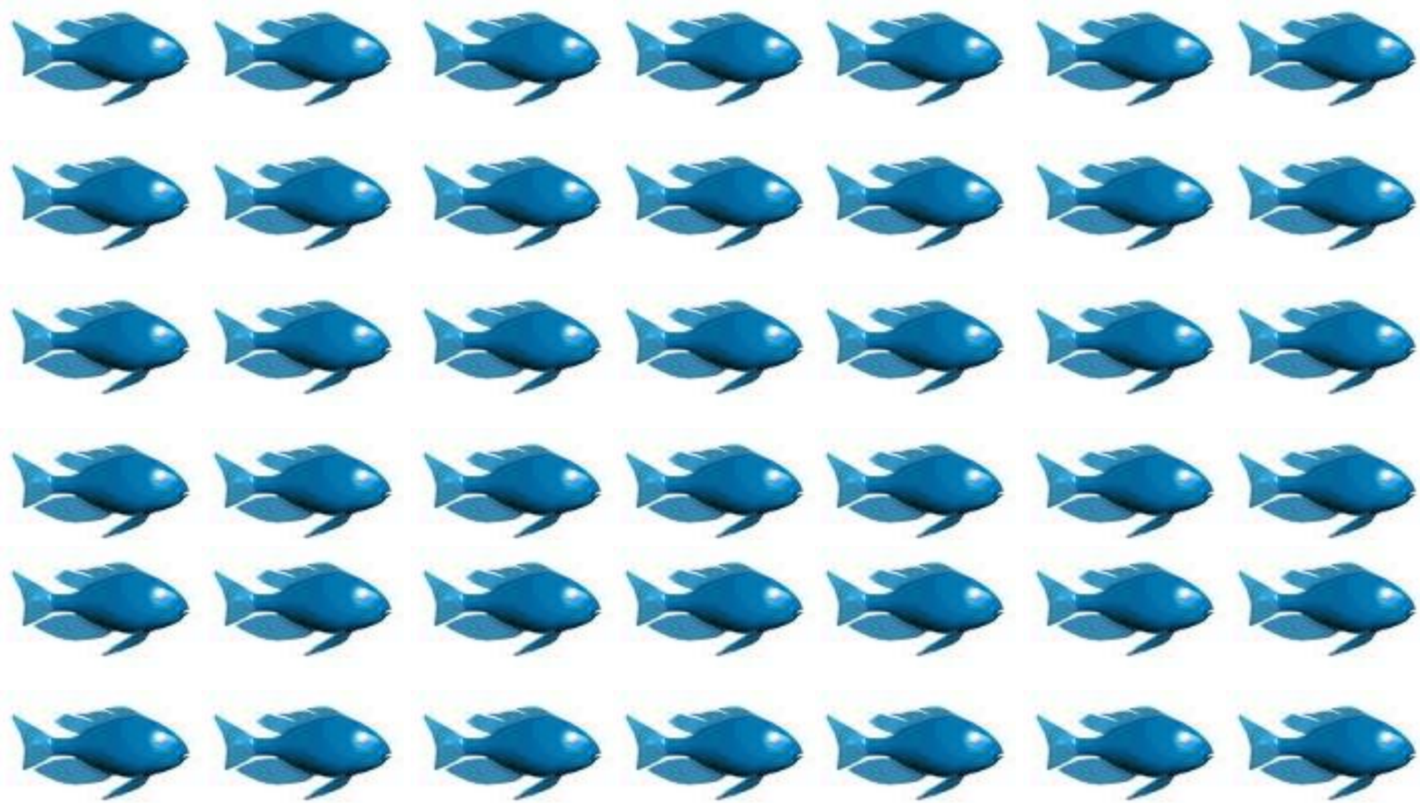
- μ: capacity of a single access (eyeball) ISP
- M: # of users of the ISP (# of active users)
- $\mathcal{N}$: set of all content providers (CPs)
- λ_i: throughput rate of CP $i \in \mathcal{N}$

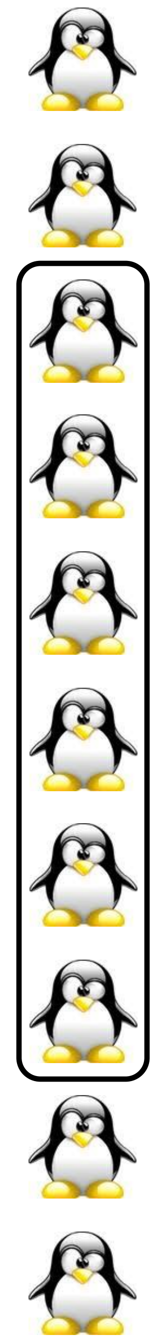
User-side: 3 Demand Factors

- Unconstrained throughput $\widehat{\theta}_i$
  - Upper-bound, achieved under unlimited capacity
  - E.g. 5Mbps for Netflix
- Popularity of the content α_i
  - Google has a larger user base than other CPs.
- Demand function of the content $d_i(\theta_i)$
  - Percentage of users still being active under the achievable throughput $\theta_i \leq \widehat{\theta}_i$

Unconstrained Throughput $\hat{\lambda}_i$

(Max) Throughput $\hat{\theta}_i (= 7Kbps)$ **User size** $M (= 10)$

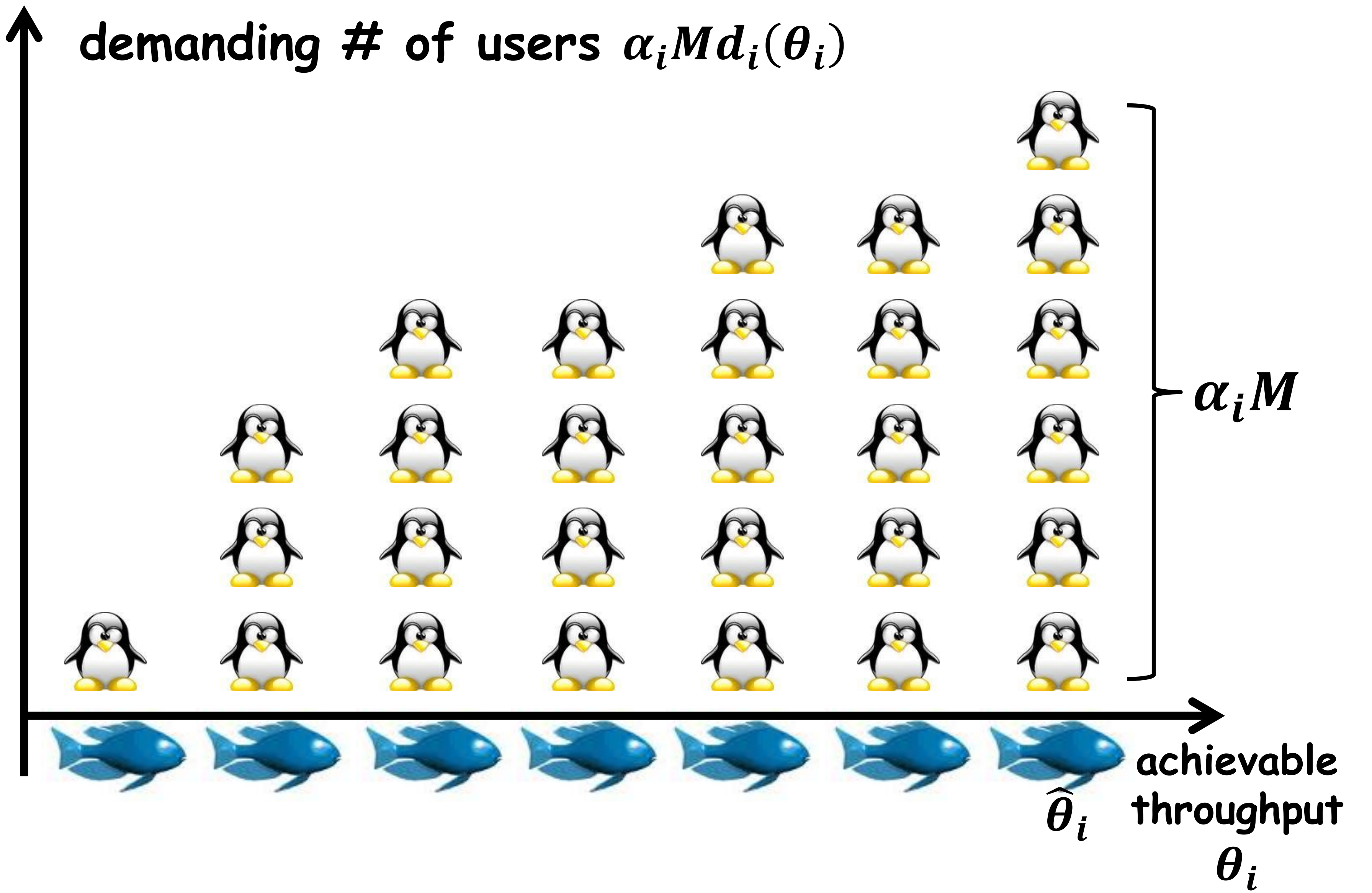




Content unconstrained throughput
$\hat{\lambda}_i = \alpha_i M \hat{\theta}_i (= 42Kbps)$

Content popularity
$\alpha_i (= 60\%)$

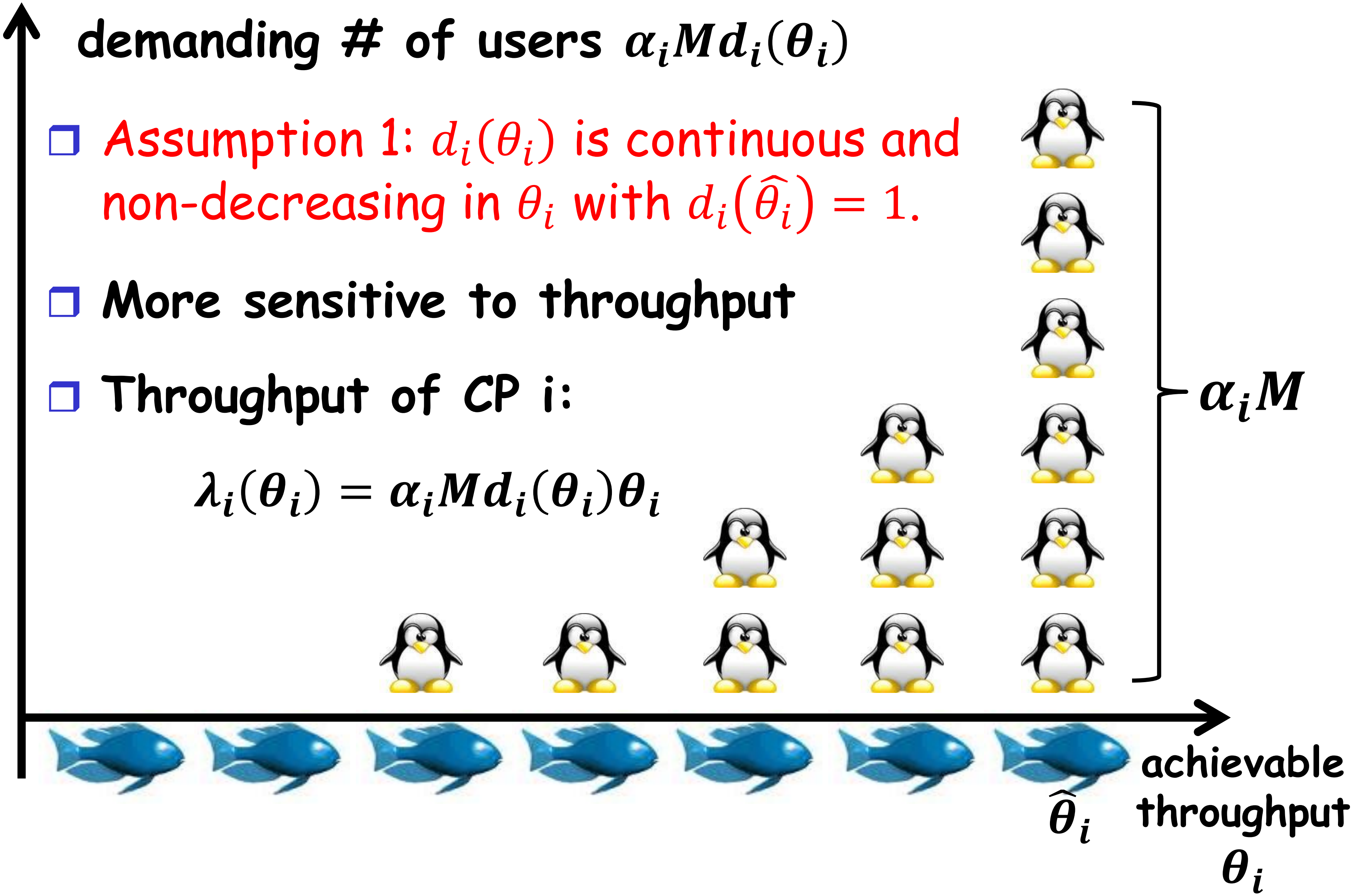
Demand Function $d_i(\theta_i)$



Demand Function $d_i(\theta_i)$

- Assumption 1: $d_i(\theta_i)$ is continuous and non-decreasing in θ_i with $d_i(\widehat{\theta}_i) = 1$.
- **More sensitive to throughput**
- **Throughput of CP i:**

$$\lambda_i(\theta_i) = \alpha_i M d_i(\theta_i)\theta_i$$



System Side: Rate Allocation

- Axiom 1 (Throughput upper-bound)

$$\theta_i \leq \hat{\theta}_i$$

- Axiom 2 (Work-conserving)

$$\lambda_{\mathcal{N}} = \sum_{i \in \mathcal{N}} \lambda_i = \min\left(\mu, \sum_{i \in \mathcal{N}} \hat{\lambda}_i\right)$$

- Axiom 3 (Monotonicity)

$$\theta_i(M, \mu_2, \mathcal{N}) \geq \theta_i(M, \mu_1, \mathcal{N}) \;\; \forall \, \mu_2 \geq \mu_1$$

Uniqueness of Rate Equilibrium

- Theorem (Uniqueness): *A* system $(M, \mu, \mathcal{N})$ has a unique equilibrium $\{\theta_i : i \in \mathcal{N}\}$ (and therefore $\{\lambda_i : i \in \mathcal{N}\}$) under *A*ssumption 1 and *A*xiom 1, 2 and 3.

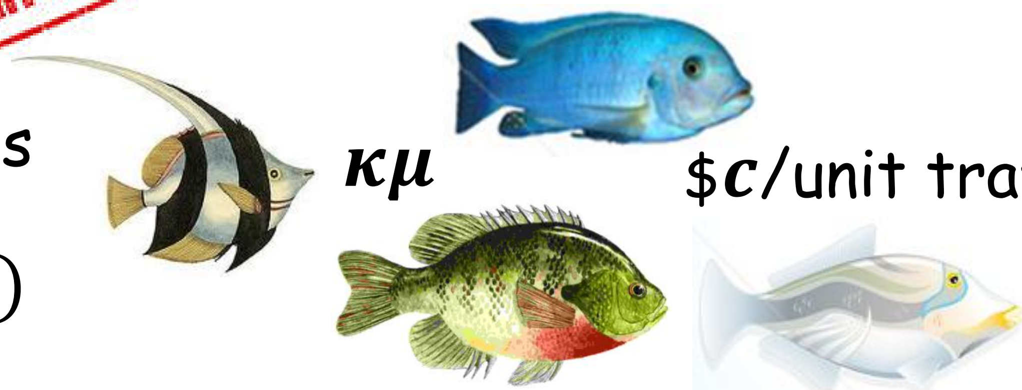
User demand: $\{\theta_i\} \rightarrow \{d_i\}$
Rate allocation: $\mu, \{d_i\} \rightarrow \{\theta_i\}$

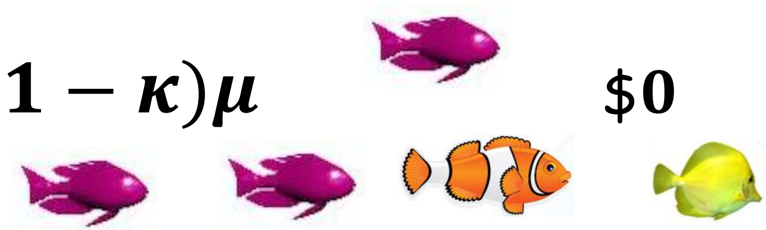
➔ Rate equalibrium: $(\{\theta_i^*\}, \{d_i^*\})$

ISP Paid Prioritization

ISP Payoff: $c\sum_{i\in\mathcal{P}}\lambda_i = c\lambda_{\mathcal{P}}$

	Capacity	Charge
Premium Class $(\boldsymbol{M}, \boldsymbol{\kappa\mu}, \boldsymbol{\mathcal{P}})$	$\boldsymbol{\kappa\mu}$	$\$\boldsymbol{c}$/unit traffic
Ordinary Class $(\boldsymbol{M}, (\mathbf{1}-\boldsymbol{\kappa})\boldsymbol{\mu}, \boldsymbol{\mathcal{O}})$	$(\mathbf{1}-\boldsymbol{\kappa})\boldsymbol{\mu}$	$\$\mathbf{0}$





Monopolistic Analysis

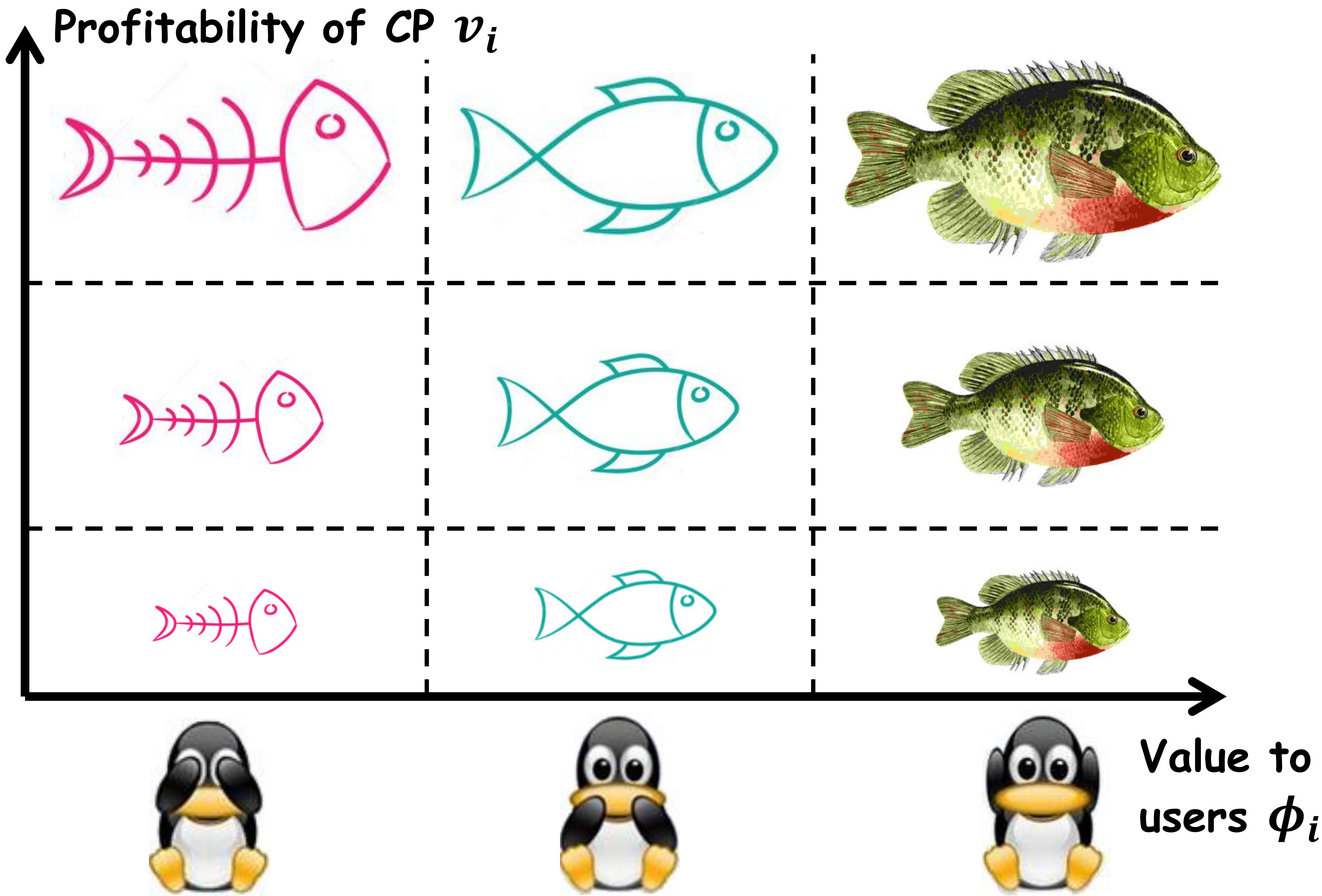
- Players: monopoly ISP I and the set of CPs $\mathcal{N}$
- A Two-stage Game Model $(M, \mu, \mathcal{N}, I)$
  - 1st stage, ISP chooses $s_I = (\kappa, c)$ announces s_I.
  - 2nd stage, CPs simultaneously choose service classes reach a joint decision $s_{\mathcal{N}} = (\mathcal{O}, \mathcal{P})$.
- Outcome (two subsystems):
  - $(M, \kappa\mu, \mathcal{P})$: set $\mathcal{P}$ (of CPs) share capacity $\kappa\mu$
  - $(M, (1-\kappa)\mu, \mathcal{O})$: set $\mathcal{O}$ share capacity $(1-\kappa)\mu$

Utilities (Surplus)

- ISP Surplus: $IS = c \sum_{i \in \mathcal{P}} \lambda_i = c\lambda_{\mathcal{P}}$;
- Consumer Surplus: $CS = \sum_{i \in \mathcal{N}} \phi_i \lambda_i$
  - ϕ_i : per unit traffic value to the users
- Content Provider:
  - v_i : per unit traffic profit of CP i

$$u_i(\lambda_i) = \begin{cases} v_i \lambda_i & \text{if } i \in \mathcal{O}, \\ (v_i - c)\lambda_i & \text{if } i \in \mathcal{P}. \end{cases}$$

Type of Content



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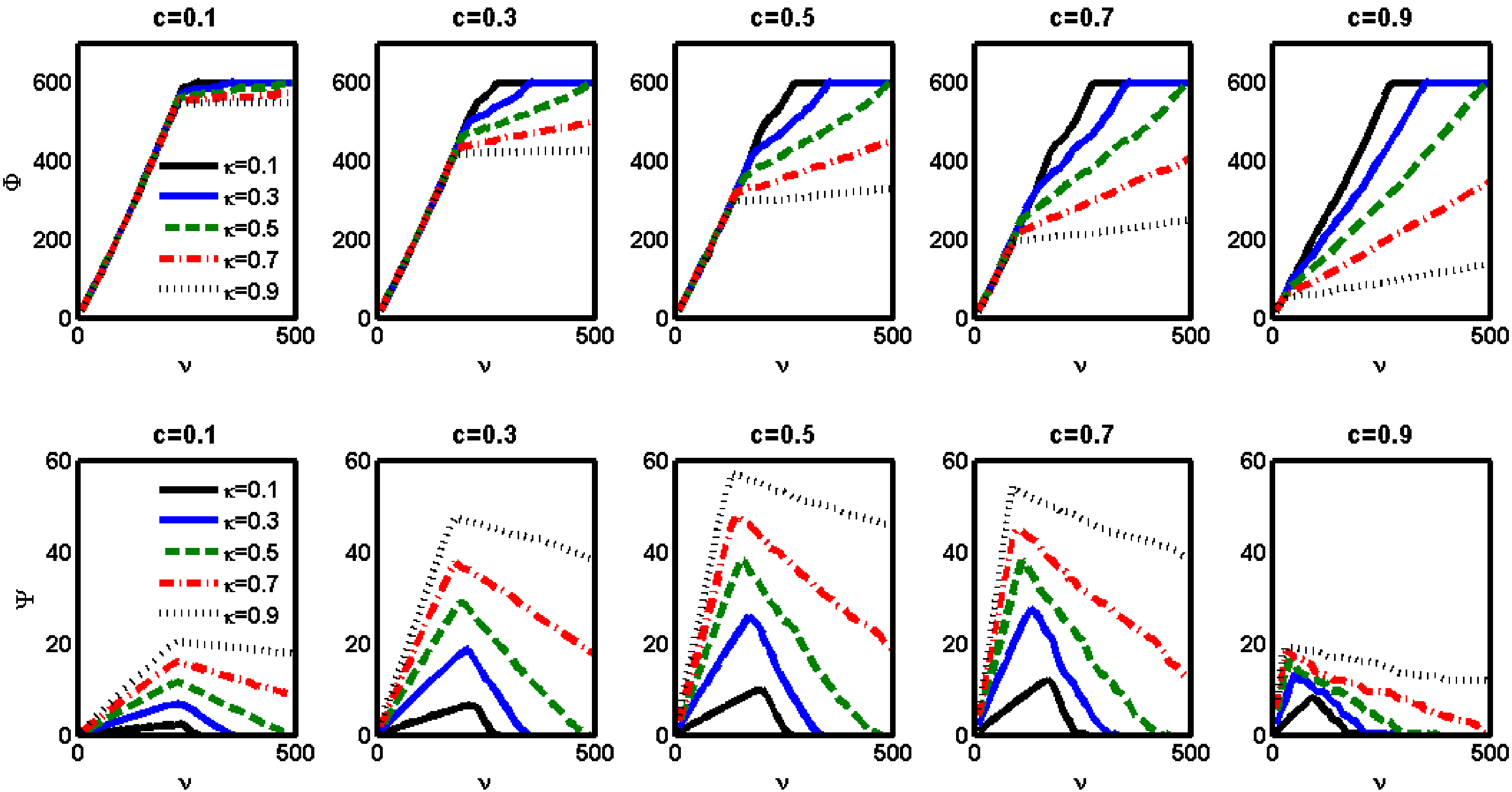
- Theorem: Given a fixed charge c, strategy $s_I = (\kappa, c)$ is dominated by $s_I' = (1, c)$.

- The monopoly ISP has incentive to allocate all capacity for the premium service class.

Utility Comparison: Φ vs Ψ



$\nu = \mu/M$ $\Phi = CS/M$ $\Psi = IS/M$

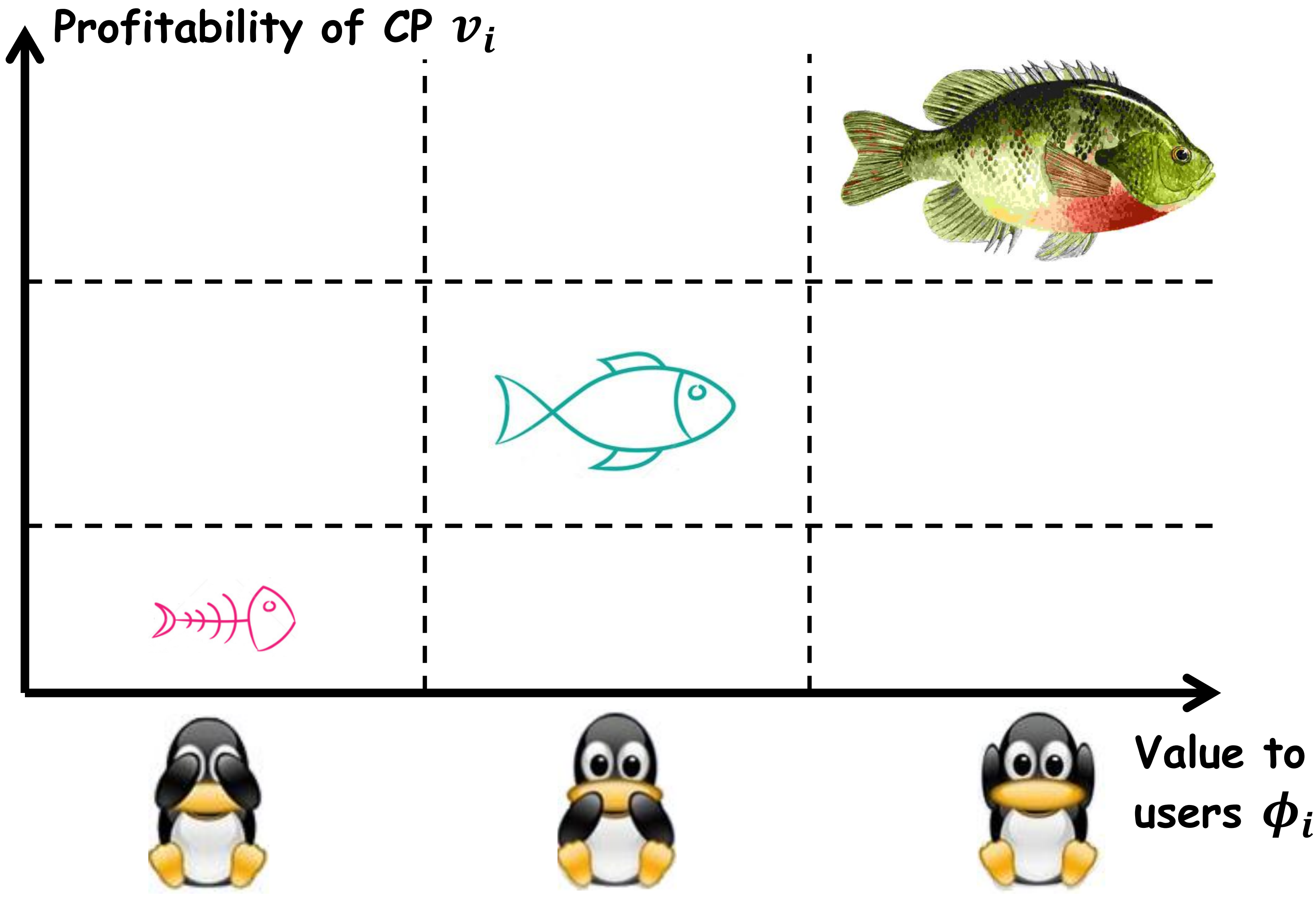
Regulatory Implications

- Ordinary service can be made "damaged goods", which hurts the user utility.

- Implication: ISP should not be allowed to use non-work-conserving policies (κ cannot be too large).

- Should we allow the ISP to charge an arbitrarily high price c?

High price c is good when



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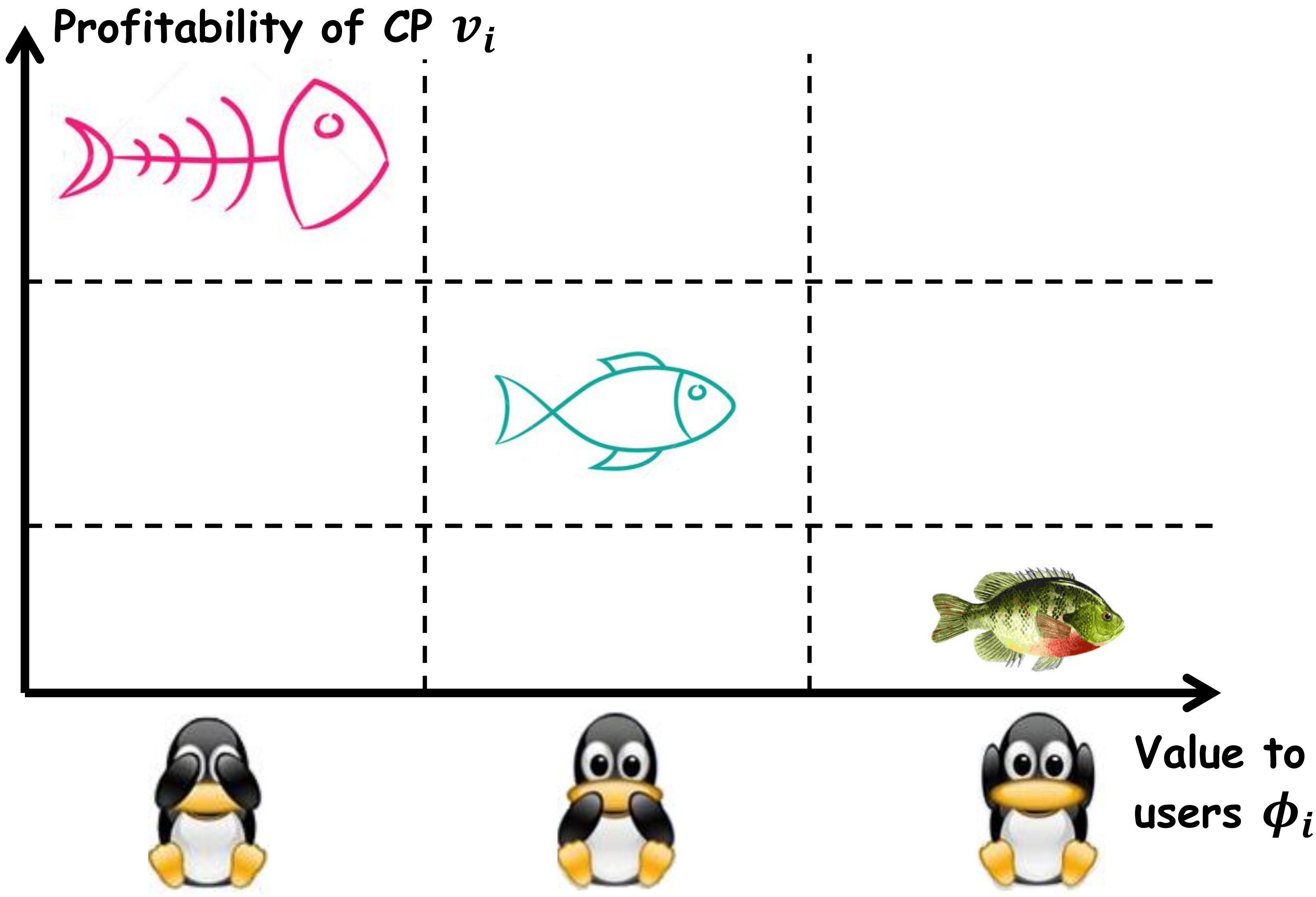
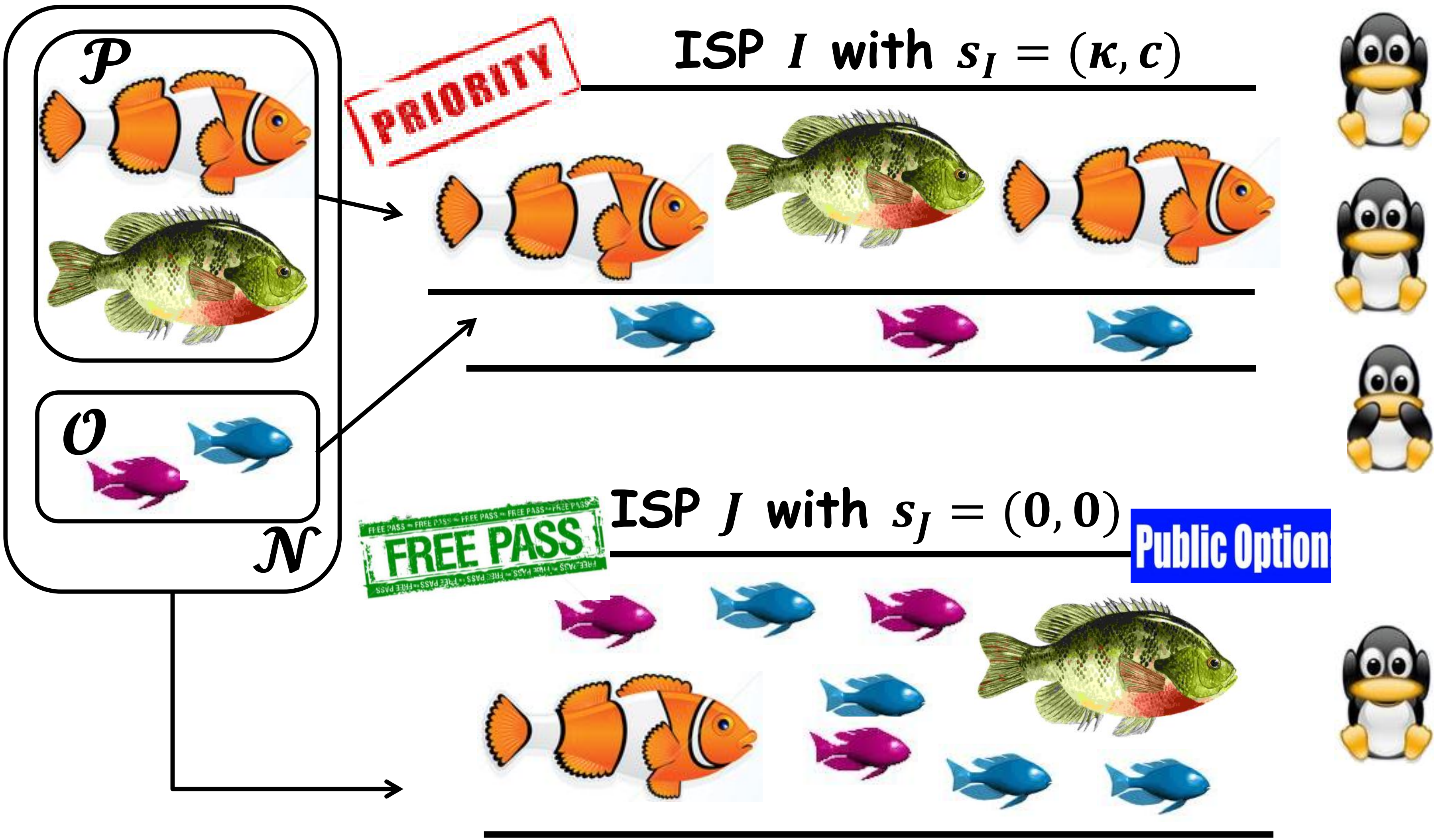


Oligopolistic Analysis

- A Two-stage Game Model $(M, \mu, \mathcal{N}, \mathcal{I})$
  - 1st stage: for each ISP $I \in \mathcal{I}$ chooses $s_I = (\kappa_I, c_I)$ simultanously.
  - 2nd stage: at each ISP $I \in \mathcal{I}$, CPs choose service classes with $s_{\mathcal{N}}^I = (\mathcal{O}_I, \mathcal{P}_I)$
- Difference with monopolistic scenarios:
  - Users move among ISPs until the per user utility Φ_I is the same, which determines the market share of the ISPs
  - ISPs try to maximize their market share.

Duopolistic Analysis



Duopolistic Analysis: Results

- Theorem: In the duopolistic game, where an ISP J is a Public Option, i.e. $s_J = (0,0)$, if s_I maximizes the non-neutral ISP I's market share, s_I also maximizes user utility.

- Regulatory implication for monopoly cases:

Public Option > Network Neutrality > Hands Off the Internet

Oligopolistic Analysis: Results

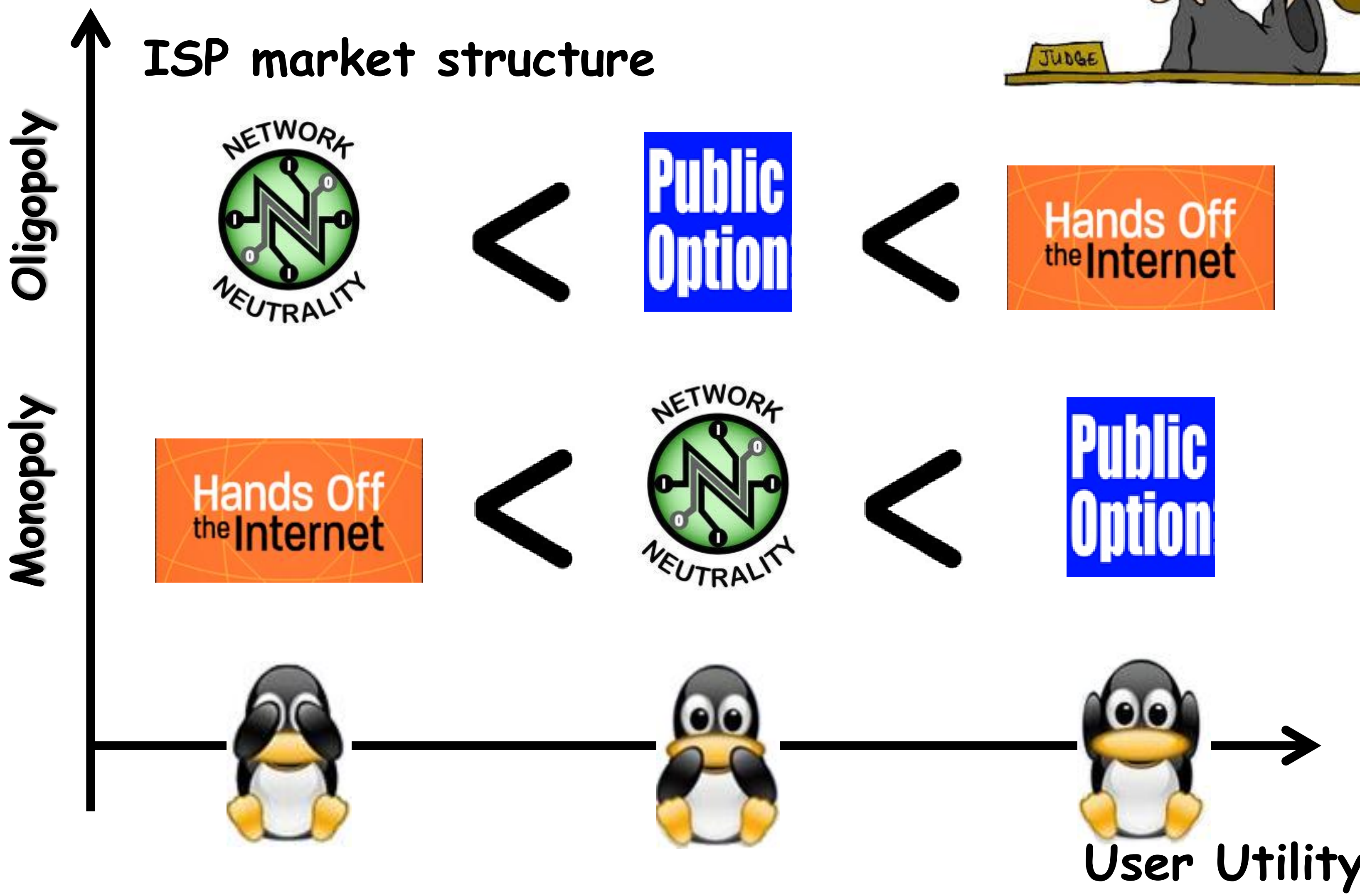
- Theorem: Under any strategy profile s_{-I}, if s_I is a best-response to s_{-I} that maximizes market share, then s_I is an ϵ-best-response for the per user utility Φ.

- The Nash equilibrium of market share is an ϵ-Nash equilibrium of user utility.

- Oligopolistic scenarios:

Hands Off the Internet > Public Option > Network Neutrality

Regulatory Preference




SENATOR, WHAT DO YOU THINK ABOUT THE PUBLIC OPTION?..
INSURANCE INDUSTRY
MIKE LUCKOVICH