User-Provided Connectivity Services A Basic Model and Pricing Strategies

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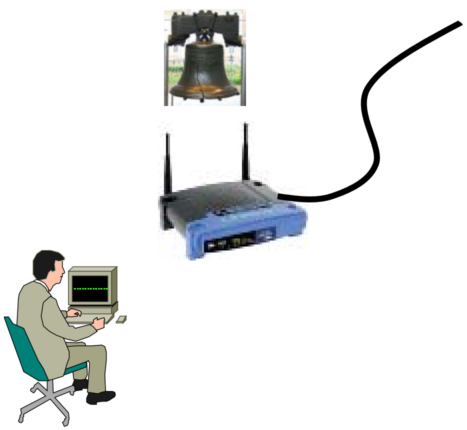
Outline

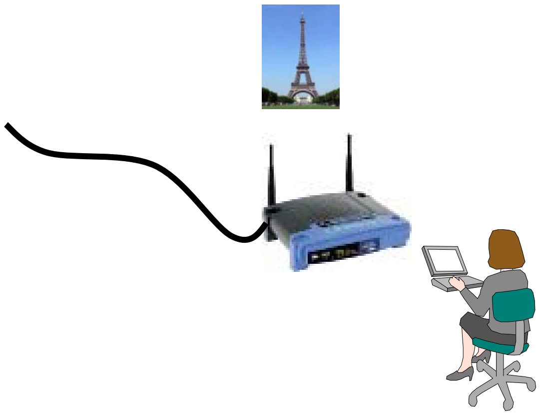
- Background and motivations
- Model formulation methodology
- Results on service adoption and their interpretation
- Pricing strategies
  - Single-price, two-price (introductory + final price)
  - Guidelines

What Is "User-Provided Connectivity"?

- In a UPC system, some users allow other users to access their own connectivity
  - Community-based networks, FON, Keywifi
- Different compensation schemes
  - Cost sharing, payments, or reciprocation
- An organic growth model
  - The more users participate, the more ubiquitous and valuable the connectivity

Internet





- Bob connects to the Internet in Philadelphia
- Jane connects to the Internet in Paris

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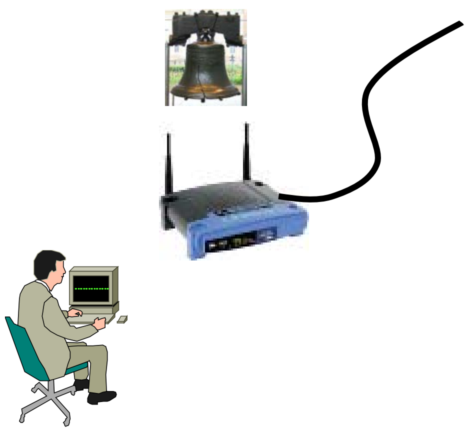

- Jane travels to Philadelphia
- Jane connects to the Internet through Bob’s access point

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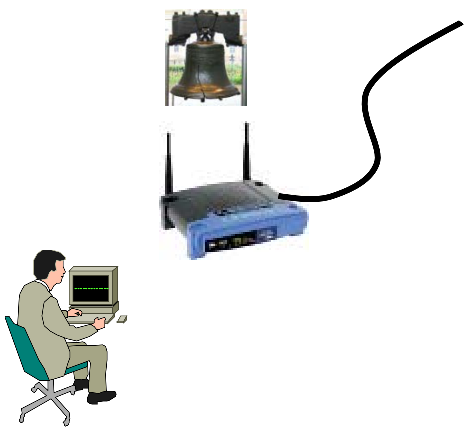


- Bob travels to Paris
- Bob connects to the Internet through Jane’s access point

Why “User-Provided Connectivity”?

- We want connectivity everywhere, all the time
  - Wireless technology has brought us very close to truly ubiquitous physical connectivity
- But, traditional “infrastructure” solutions, *e.g.*, cellular, have a high up-front cost as well as capacity limitations
- UPC offers an alternative, organic growth option
  - Limited up-front cost, and increasing capacity as more users join
  - But UPC systems face “bootstrapping” issues (positive and negative externalities)

Q: When and how can a UPC solution succeed?

Modeling UPC Adoption (Or Not)

- A model should allow us to characterize adoption outcomes as a function of exogenous parameters
- Among a large user population, individual users adopt if the *utility* they derive from the UPC service is non-negative
- A user's utility should capture
  - Value of basic (home) connectivity
  - Value of connectivity while "roaming"
  - Impact of roaming traffic on home connectivity
  - Incentives for accommodating roaming traffic
  - Service price

  (Involve externalities: roaming value, roaming impact, incentives)

and allow *heterogeneity* in how users value the service

A General Users' Utility

- Users are heterogeneous in their propensity to seek connectivity "away from home," *i.e.*, their roaming profile
  - Captured by a roaming random variable θ
    - Known distribution
    - $\theta \in [0,1]$, $\theta = 0$ (never roams), $\theta = 1$ (always roaming)
- Utility function of user with roaming value θ

$$U(\theta) = F(\theta,x)+G(\theta,m) - p_\theta$$

  - $F(.,.)$ is utility of connectivity (at home and while roaming)
    - x is current level of adoption (coverage assumed function of adoption)
  - $G(.,.)$ accounts for negative impact of roaming traffic, and positive impact of possible compensation
    - m is current volume of roaming traffic (depends on number **and** identity –their θ values– of adopters)
  - p_θ is price charged to user with roaming value θ
- A user adopts if $U(\theta) \geq 0$

A Simple Instantiation

- Linear (positive and negative) externalities

$$U(\theta) = (1 - \theta)\gamma + \rho\theta x + (b - c)m - p$$

- θ : Uniformly distributed in [0,1]
- γ : Value of home connectivity (affected by a user's roaming frequency)
- ρ : Value of connectivity while roaming $\rho > \gamma$ (affected by both coverage x, and a user's roaming frequency θ)
- b : Compensation for providing access to roaming traffic (proportional to volume of roaming traffic m)
- c : Impact of volume of roaming traffic, m, on user connectivity
- m : Roaming traffic uniformly distributed across users' home connections
- p : Service price (identical for all users)

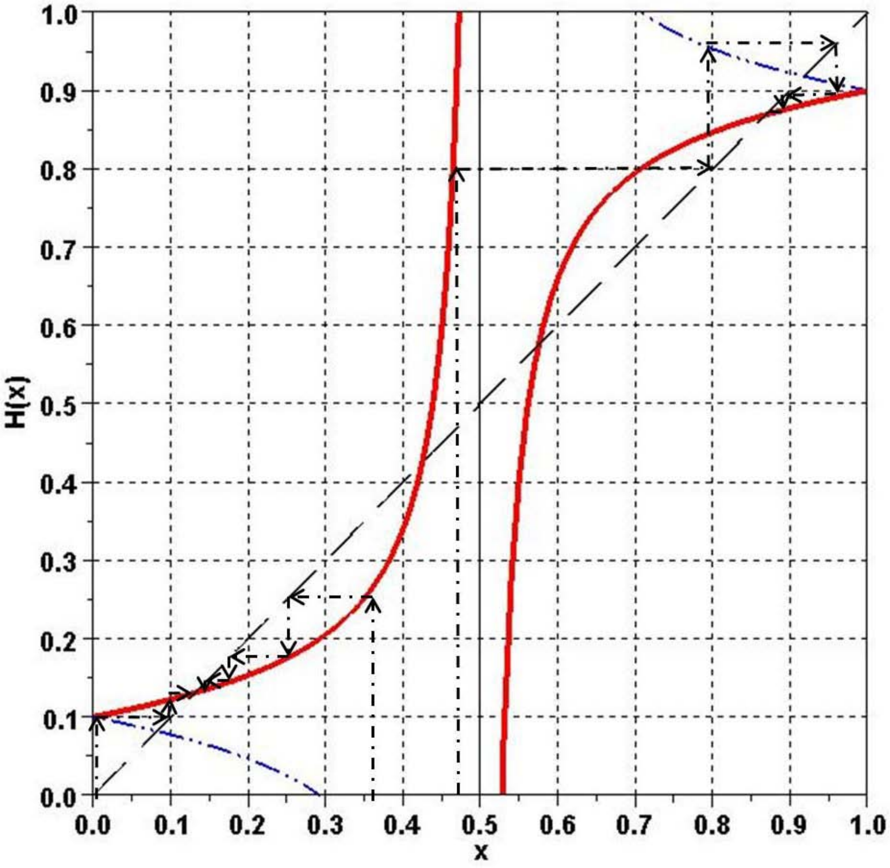
- Equivalent formulation: $U(\theta) = (\gamma - p) + (b - c)m + \theta(\rho x - \gamma)$

  For illustration purposes we use $\rho \sim 2\gamma$, so that

$$U(\theta) = k + lm + \theta(2x - 1), \text{ where } k = (\gamma - p)/\gamma \text{ and } l = (b - c)/\gamma$$

Adoption Model & Evolution

- A simple discrete time model
  - Adoption *level* at epoch n+1, x_{n+1}, is determined by adoption *state* at epoch n, X_n (a two-dimensional quantity – number x_n ***and type*** y of adopters)
  - Users evaluate their utility based on X_n and adopt if it is non-negative, *i.e.*, $X_{n+1}=H(X_n)$
- Adoption evolves based on the shape and position of the function(s) $H(X)$ relative to X
  - Different functions before and after a transition to a state of high/low adoption
- Equilibria correspond to $H(X) = X$ (or $H(0) \leq \underline{0}$, or $H(1) \geq \underline{1}$)

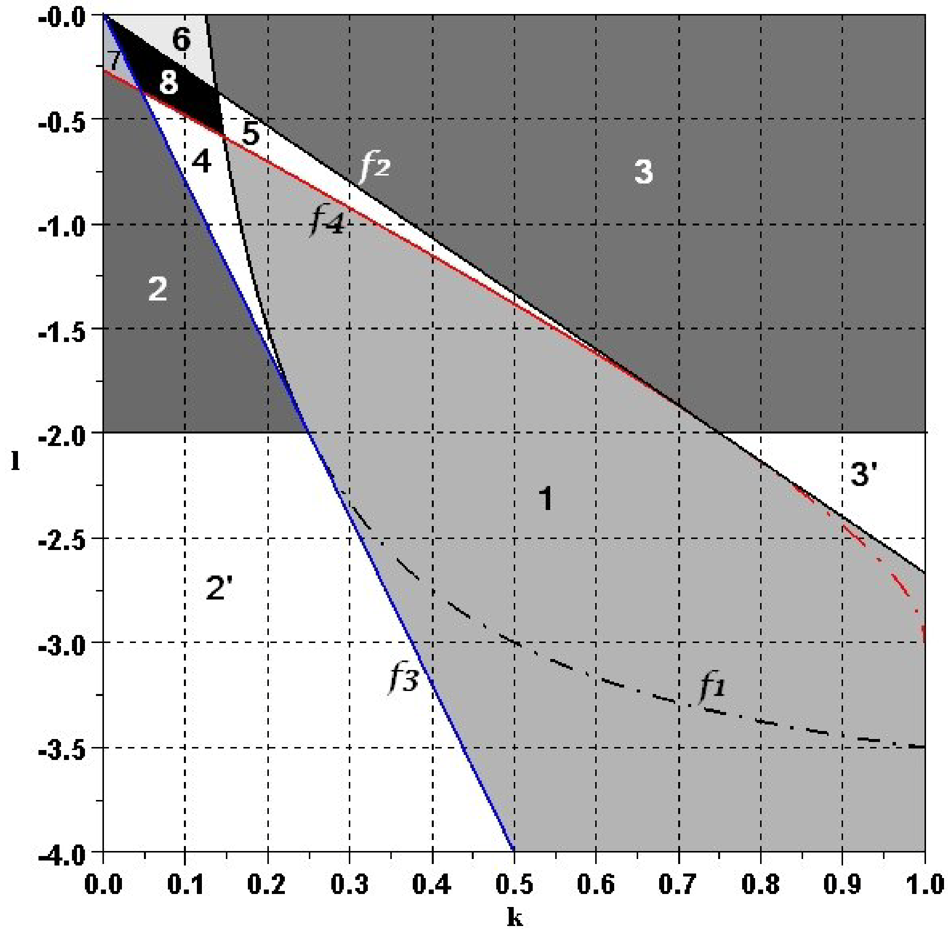


Adoption Outcomes

- Associated with different regions of the (k,l) plane
  - $U(\theta) = k + lm + \theta(2x - 1)$
- Various possible combinations of equilibria or absence thereof

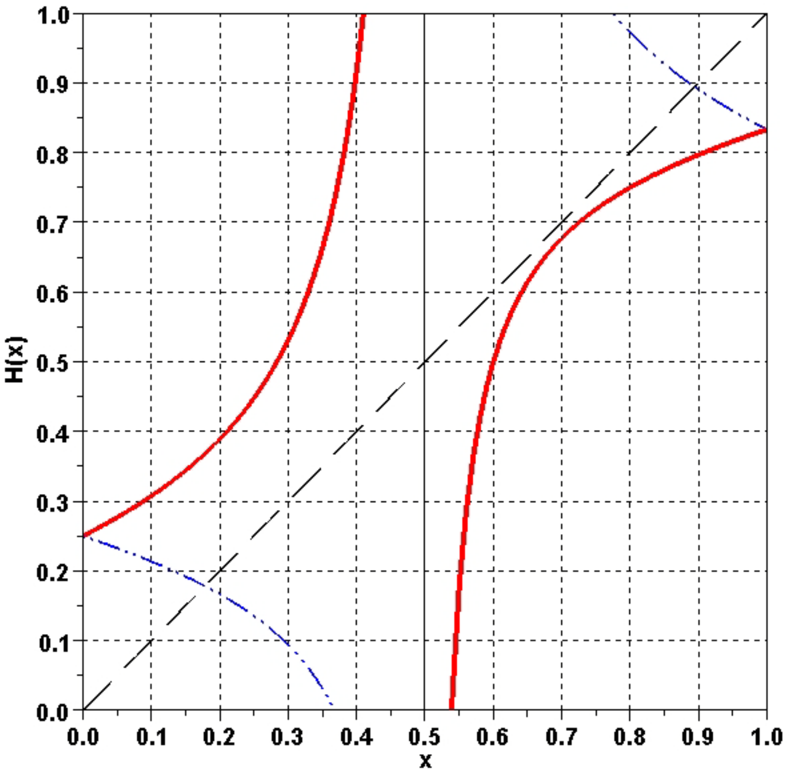
Cases	$[0, 1/2)$	$[1/2, 1]$
1	—	—
2	●	—
2'	↻	—
3	—	●
3'	—	↻
4	●, ○	—
5	—	●, ○
6	●, ○	●
7	●	●, ○
8	●, ○	●, ○

Recall that $k = (\gamma - p)/\gamma$ and $l = (b - c)/\gamma$

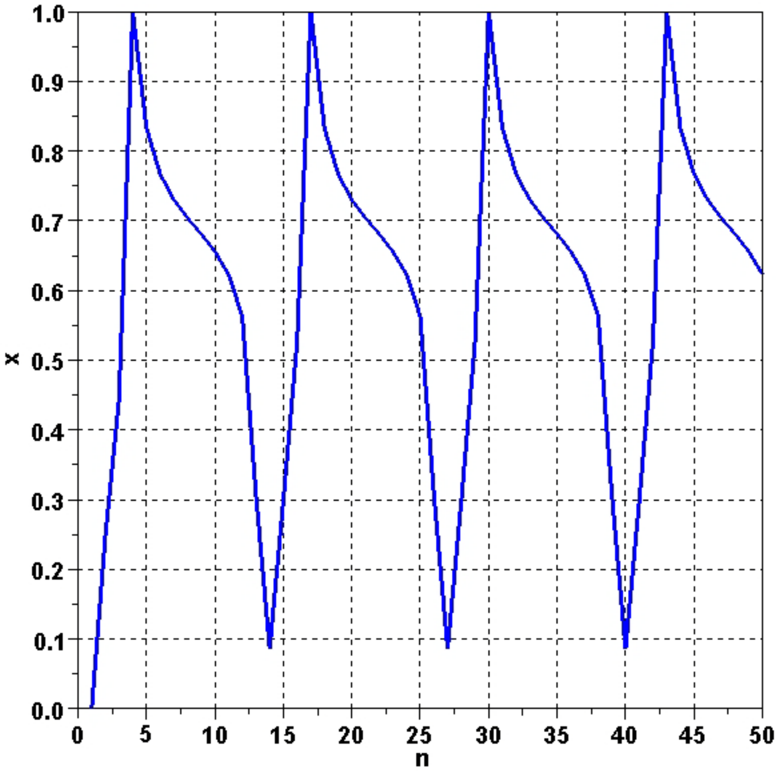


Representative Outcomes (1)
Absence of Equilibria

H(*X*) functions

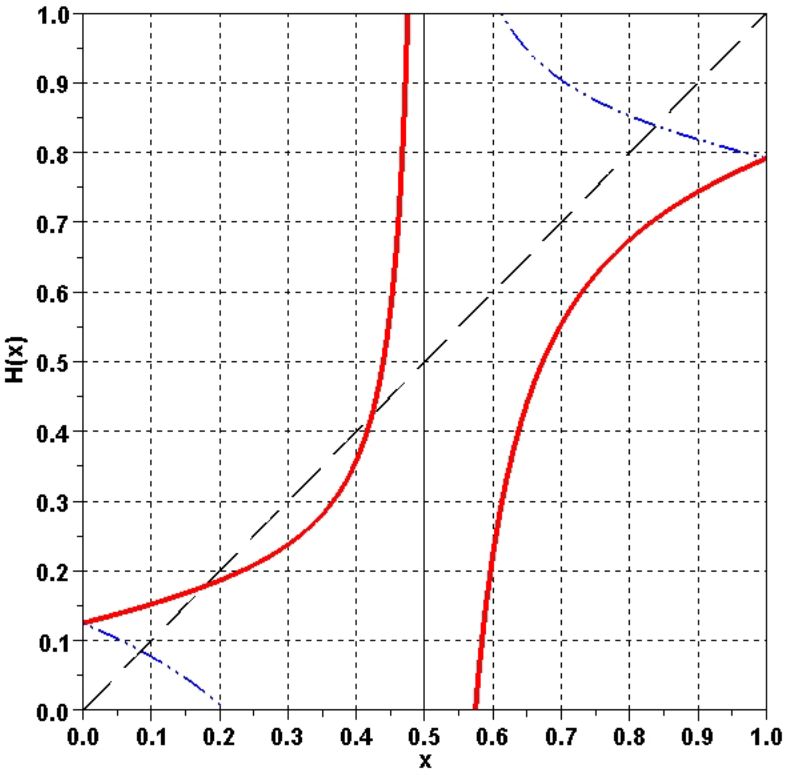


Adoption Evolution

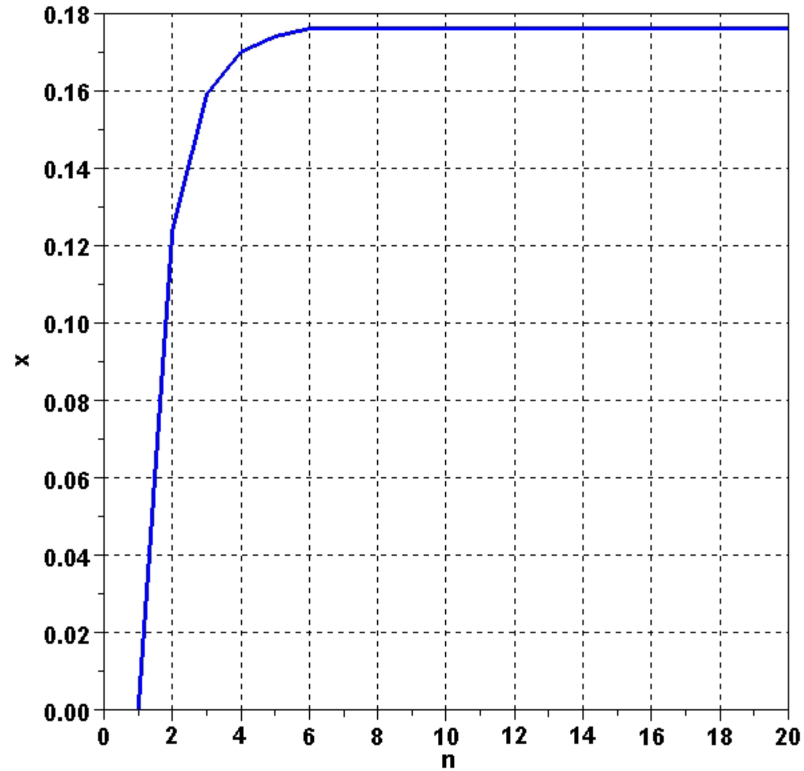


Representative Outcomes (2)
Single Stable Equilibrium (Low Adoption)

H(*X*) functions

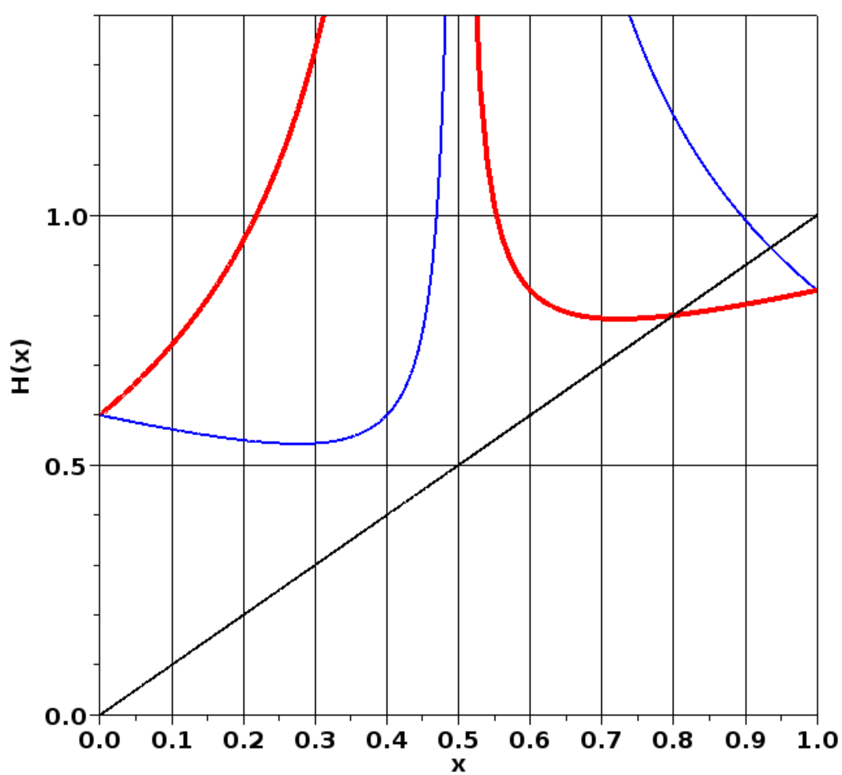


Adoption Evolution

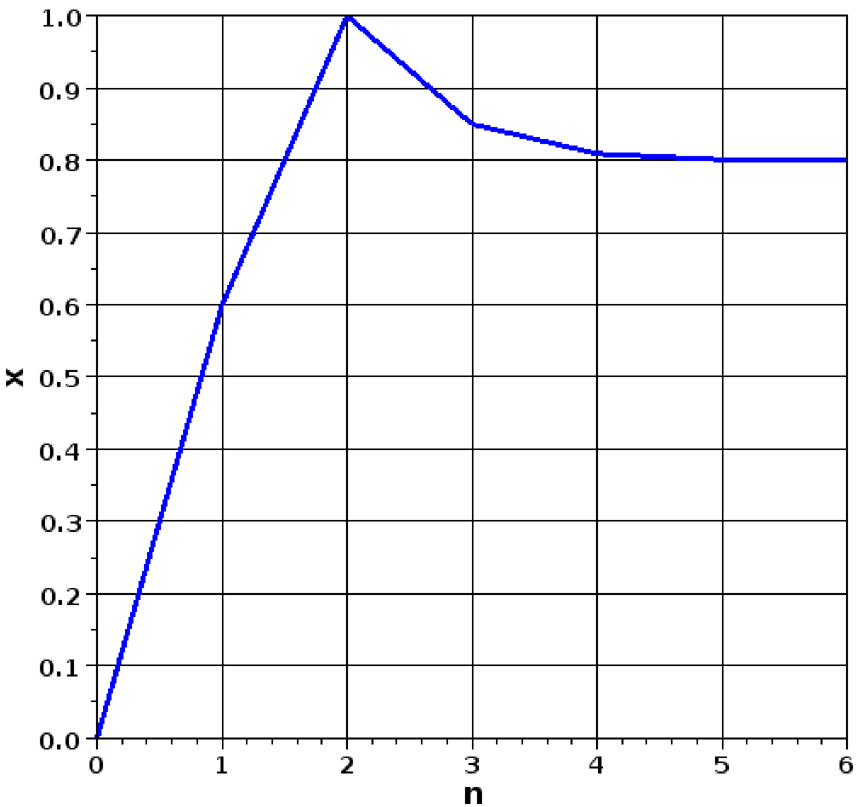


Representative Outcomes (3)
Single Stable Equilibrium (High Adoption)

H(*X*) functions



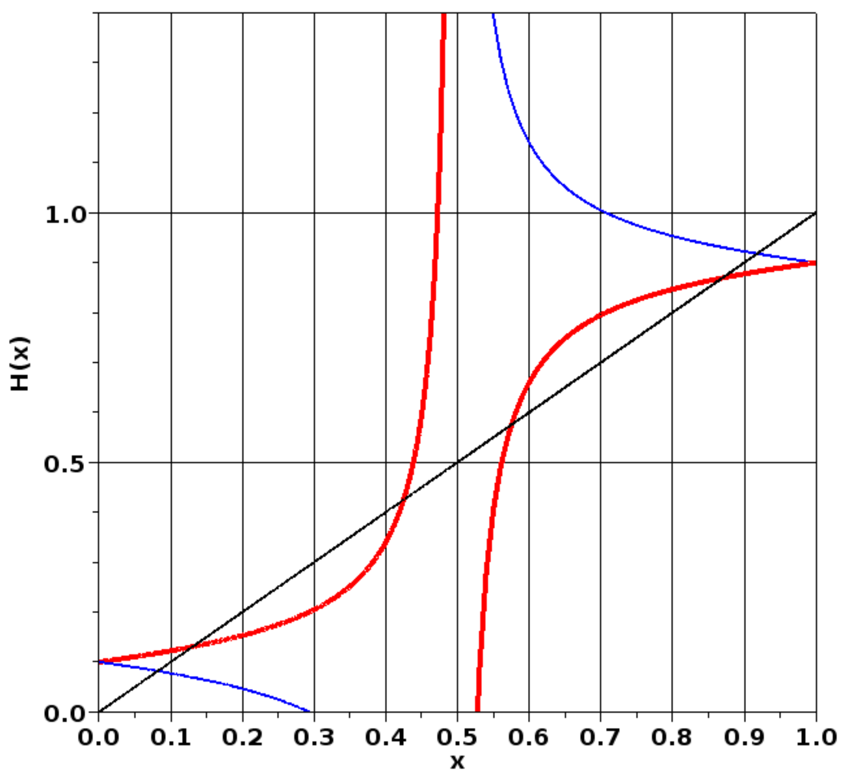
Adoption Evolution



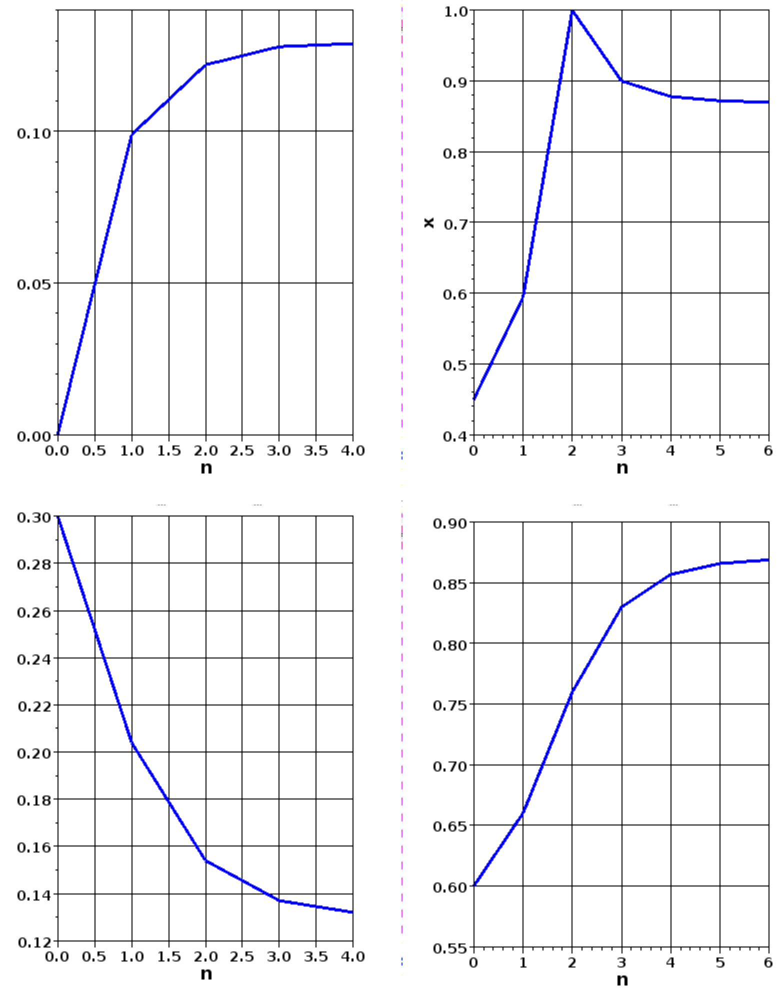
Representative Outcomes (4)

Two Stable Equilibria (High & Low Adoption)

H(*X*) functions



Adoption Evolution(s)

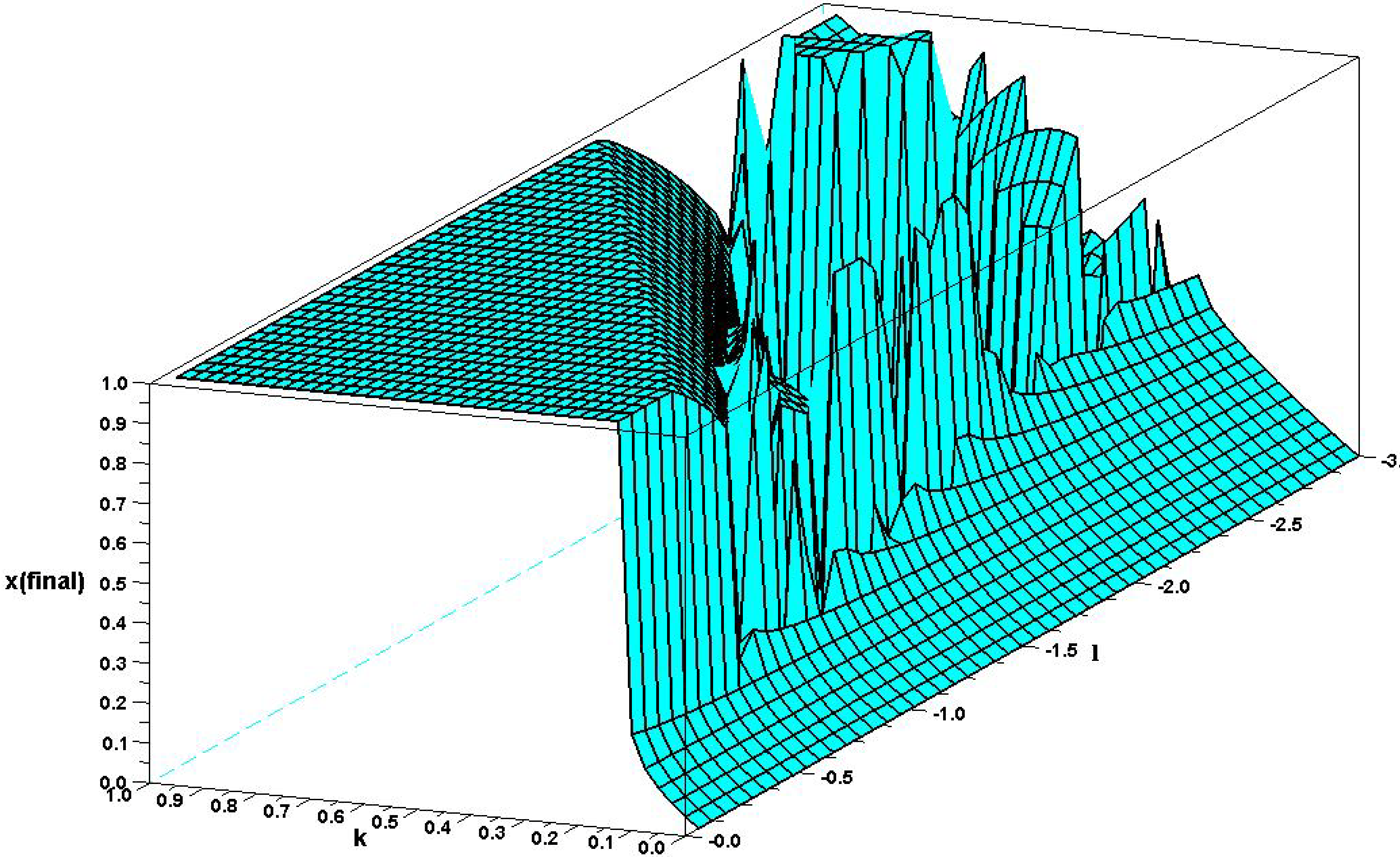


Summarizing Outcomes

- Three main "types" of behaviors

1. No or unlikely convergence to a stable adoption equilibrium
   - Primarily in regions where roaming traffic has a strong negative impact that creates boom-and-bust cycles
2. Convergence to a global, stable equilibrium
   - Convergence can be to either low or high adoption depending on how valuable connectivity is
3. Convergence to one of two possible stable equilibria depending on initial adoption (seeding)
   - Impact of roaming traffic is low, but so is value of connectivity
     - Without enough of an initial critical mass, adoption never takes off
     - Large enough seeding helps overcome initial inertia

An Evolution Snapshot



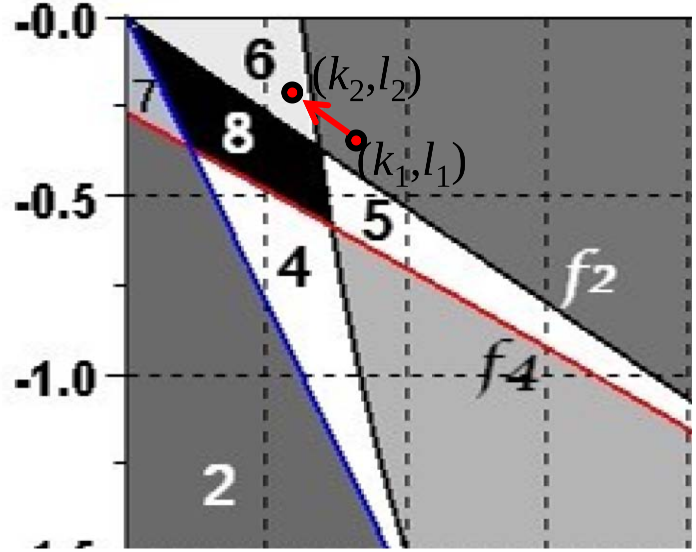
On the Impact of Incentives

- Recall a user's utility function
  - $U(\theta) = k + lm + \theta(2x - 1)$

    where $k = \gamma - p$ and $l = b - c$, with b corresponding to incentives to offset the impact of roaming traffic
- At equilibrium bm is equivalent to a decrease in price, *i.e.*, $p' = p - bm$, but impact on adoption dynamics can be significant, *i.e.*, because of the possible introduction of a ***second*** low adoption equilibrium

$(k_1, l_1) = (\gamma - p_1, -c)$, *i.e.*, $b=0$

$(k_2, l_2) = (\gamma - (p_1 + \boldsymbol{bm}), \boldsymbol{b} - c)$



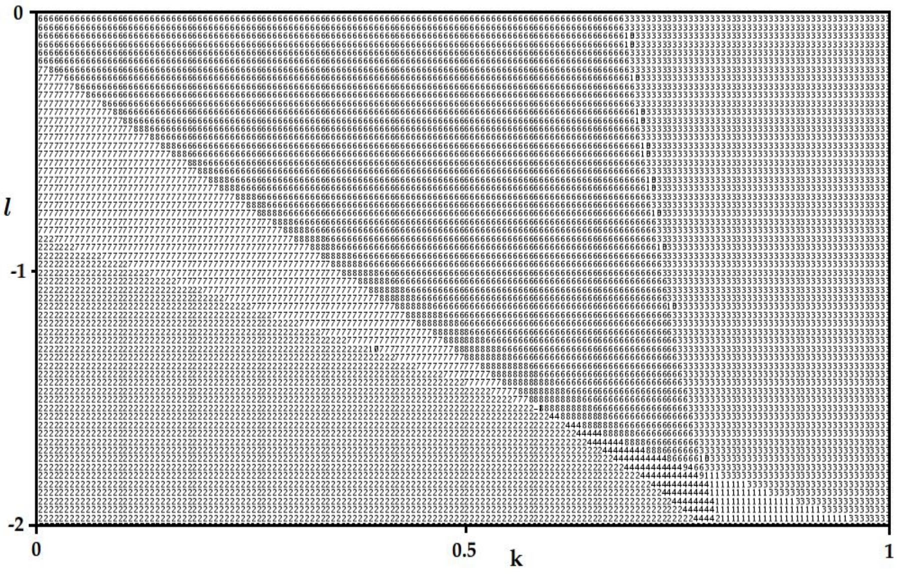
- In general, UPC adoption can be difficult to predict in the presence of multiple equilibria

Results Robustness

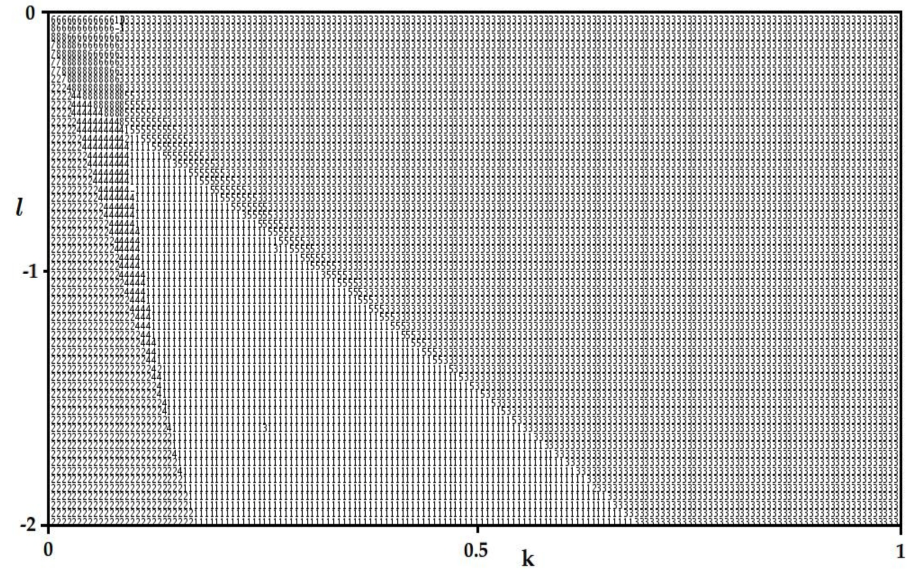
- Both users' utility and adoption processes are overly simplified, even if they capture key aspects
- Are the results affected when relaxing the model's assumptions?
  – Non-linear externality functions
  – Non-uniform roaming characteristics
  – A more realistic (diffusion-like) adoption process
- Assessing behavior of relaxed models must be done numerically
- Adoption trajectories can differ and region boundaries shift, but general outcomes remain unchanged

Shifting Regions Boundaries

Unimodal roaming (θ=1) and non-linear externalities

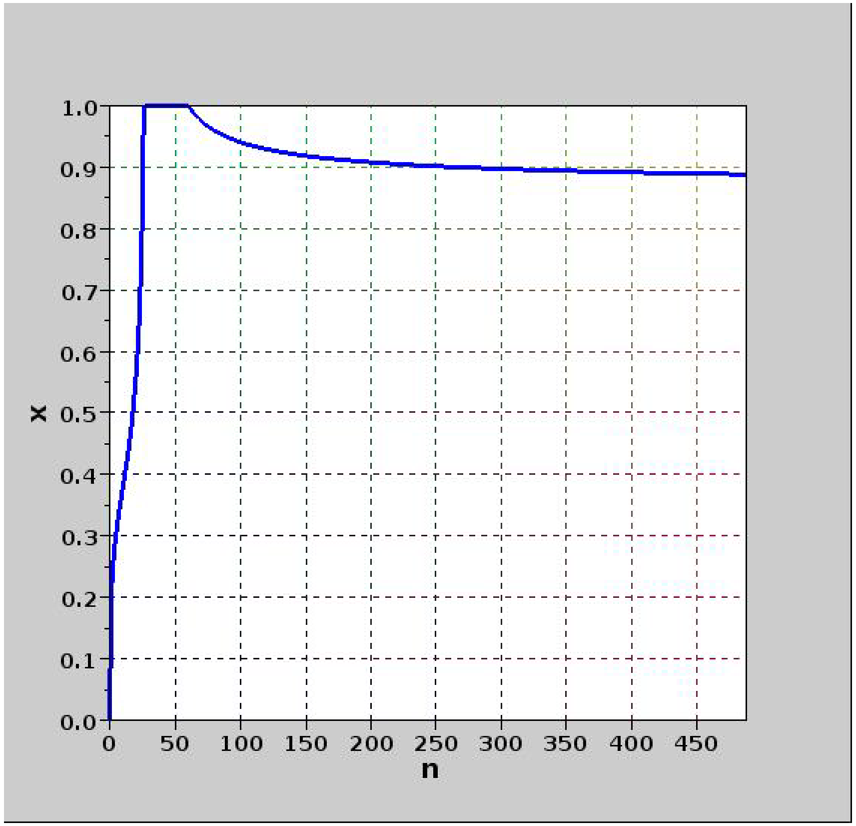


Unimodal roaming (θ=0) and linear externalities

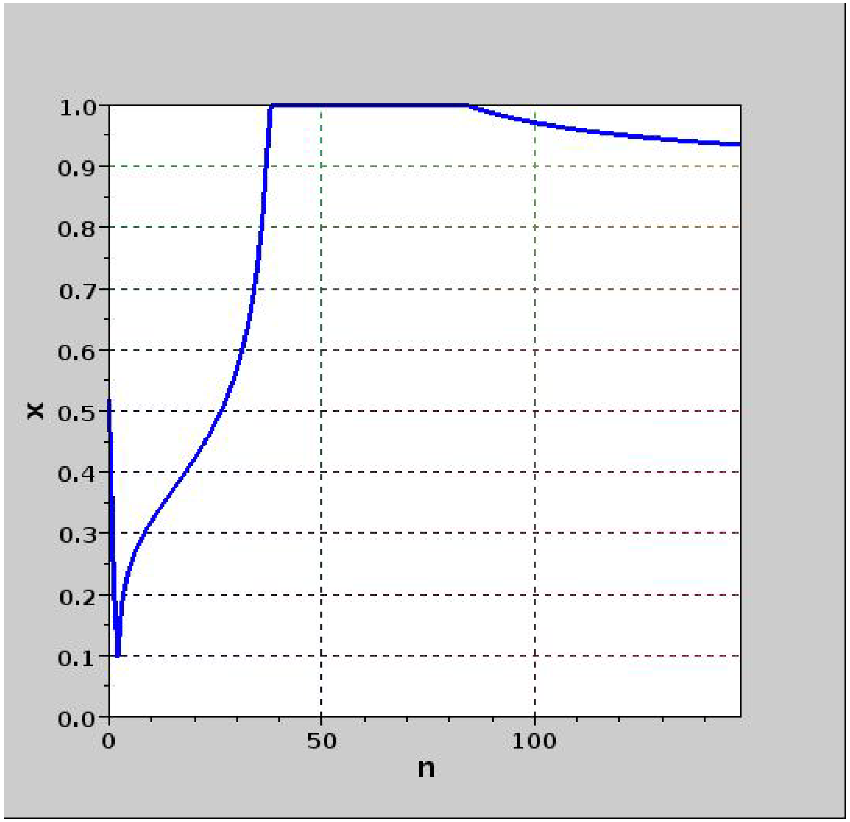


A Diffusion-like Adoption Model
Two levels of initial penetration (seeding)

No seeding



>50% initial seeding



From Adoption Dynamics To Pricing Policies

- The results allow us to "predict" adoption levels for given ***exogenous*** parameters γ, ρ, b, c, and p
  - But only γ, ρ, and c are truly exogenous
  - Both b (incentives) and p (price) are under the control of the system designer and should, therefore, be endogenized, *e.g.*, to optimize profit
- Given that incentives eventually map to a price offset, we'll assume that b=0 and focus on exploring how to set p
- We consider both single-price and two-price (introductory & final) policies
  - A two-price policy can help address the inefficiency of a single-price policy
    - Initial price is set low enough to build-up adoption, while final (higher) price allows the provider to extract the added value generated by high coverage
- Single-price policy characterized by p
- Two-price policy involves p_i (introductory price), x_{th} (adoption level at which price switch occurs), p_f (final price)

Pricing Policies

- Profit under single-price policy

  $\Pi^{(1)}(p) = (p - e)x$, where p is the service price, e is its cost, and x is the final adoption level

  - The goal is to find p^* such that $\Pi^{(1)}(p^*)$ is maximized

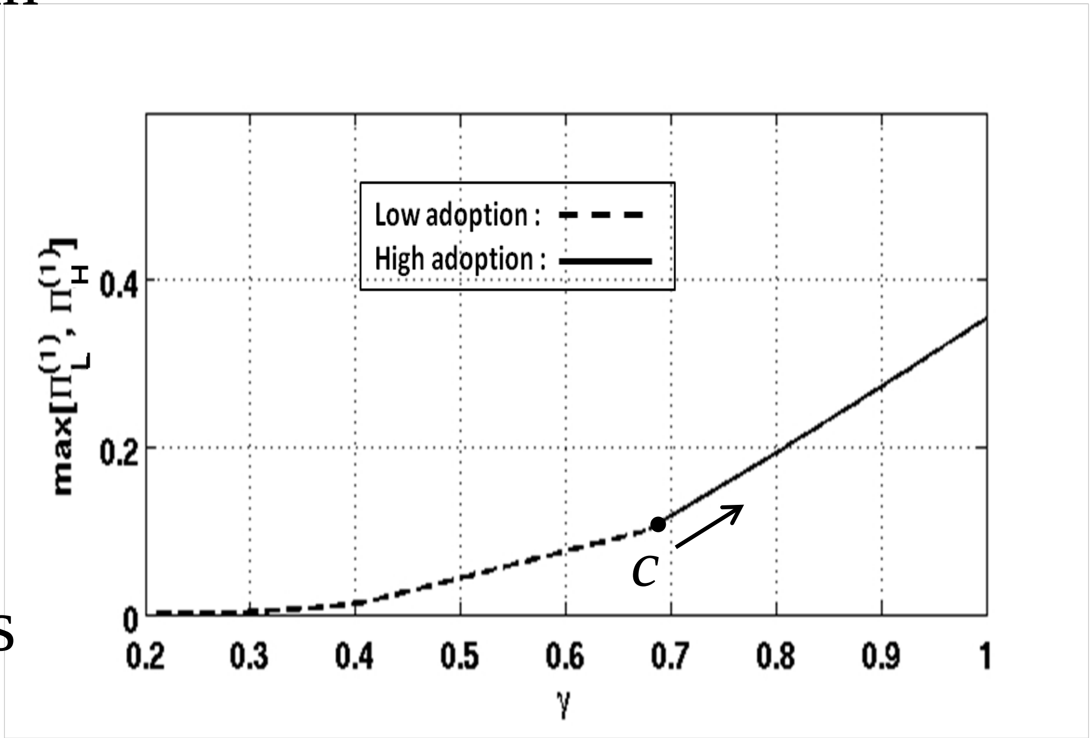
- Profit under two-price policy

  $\Pi^{(2)}(p_i, p_f, x_{th}) = (p_i - e)x_i + (p_f - e)x_f$, where x_i and x_f denote the fraction of adopters who pay the original and final prices, respectively

  - The goal is to find p_i^*, p_f^*, x_{th}^*, such that $\Pi^{(2)}(p_i^*, p_f^*, x_{th}^*)$ is maximized
  - Note that implicitly the two-price policy targets a reasonably high final level of adoption

Single-Price Optimization

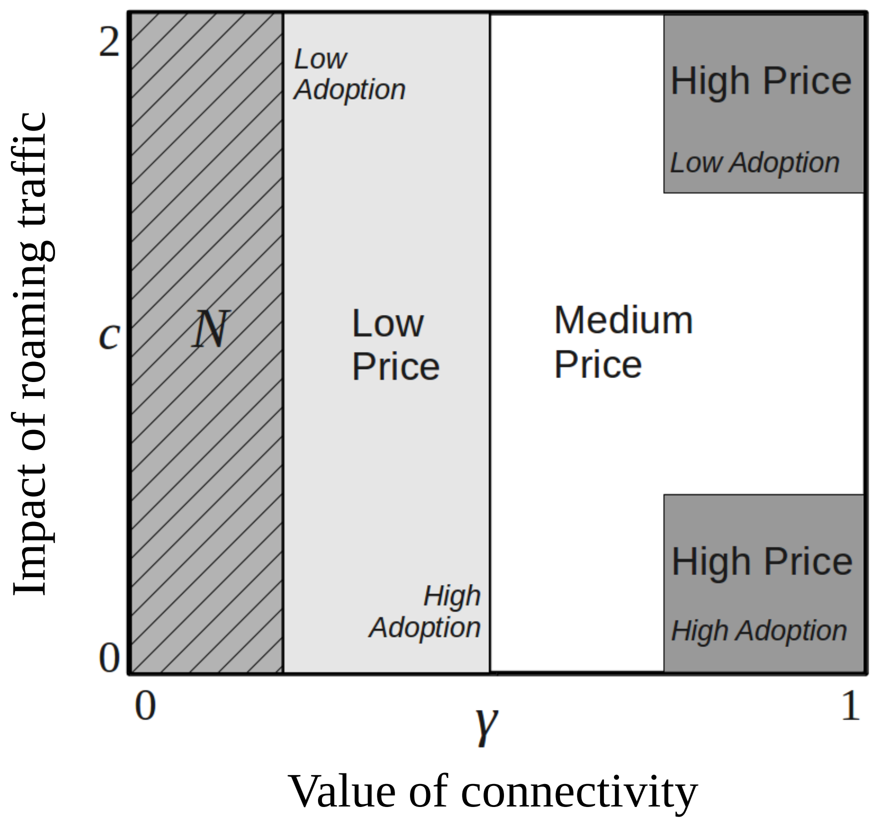
- Profit-optimal price can be obtained from adoption equilibrium expression under both low and high adoption outcomes
- Adoption level for optimal profit varies as a function of γ and c



Guidelines for Single-Price Policy

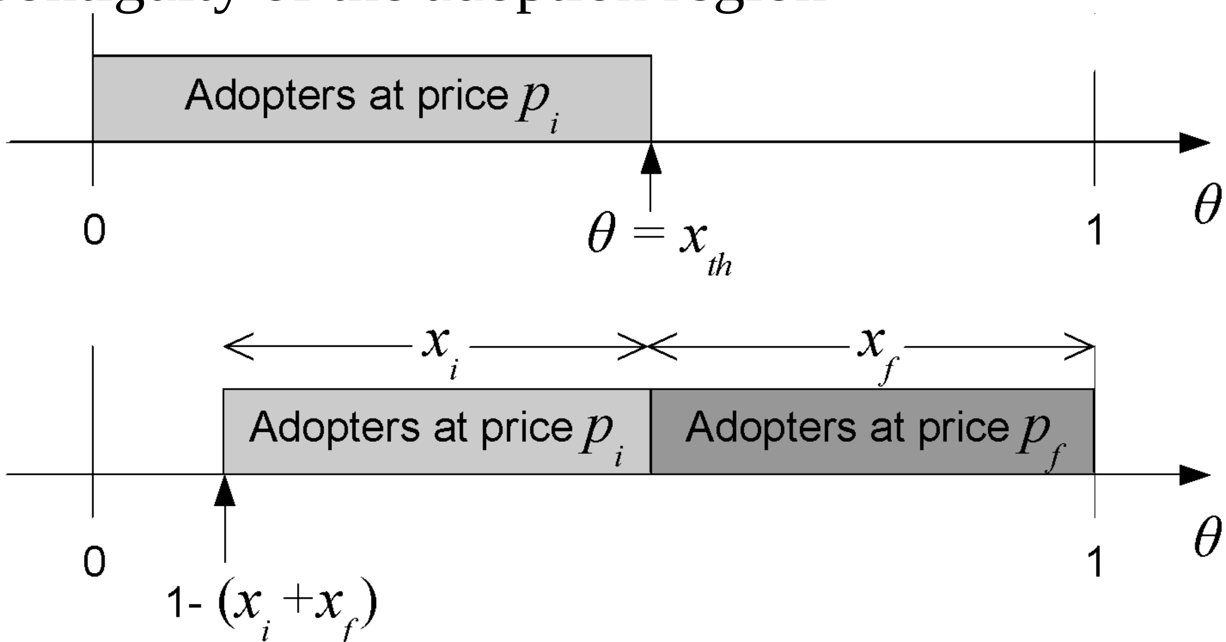
- When connectivity utility is low, price must be set low
  - Low service adoption when negative impact of roaming traffic is high
  - High adoption otherwise
- When connectivity utility is high, a high price is optimal in two distinct scenarios
  - Roaming traffic has limited impact, and high adoption is feasible even when price is high
  - Roaming traffic has a major impact, and realizing high adoption would call for too low a price

$$p \in [e, \gamma + 1 - c/2]$$

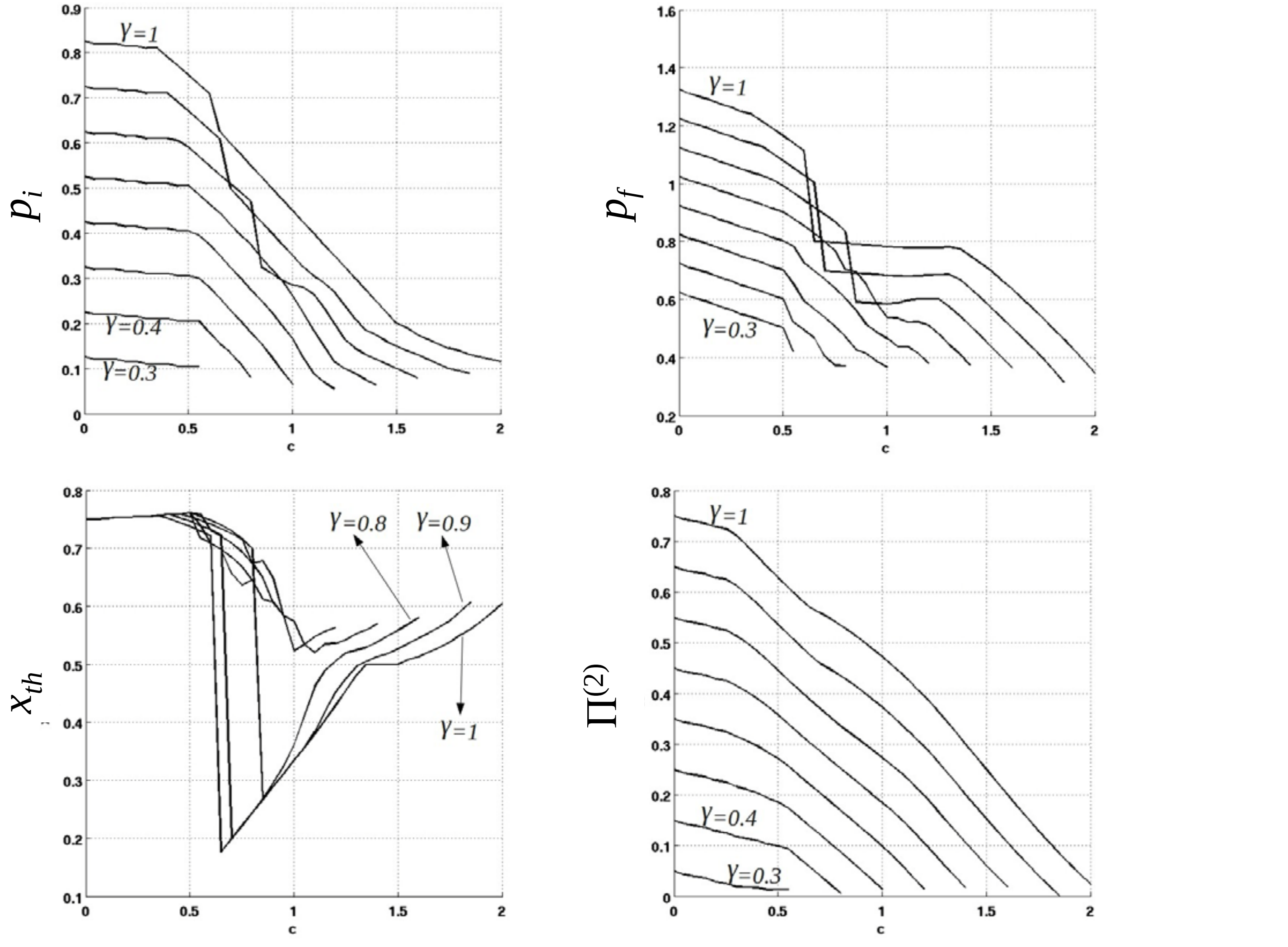


Adoption Under Two-Price Policy

- Under a two-price policy, complex adoption patterns can emerge
- For analytical tractability, policies are “constrained” to
  - Convergence to a high level of adoption
  - Contiguity of the adoption region

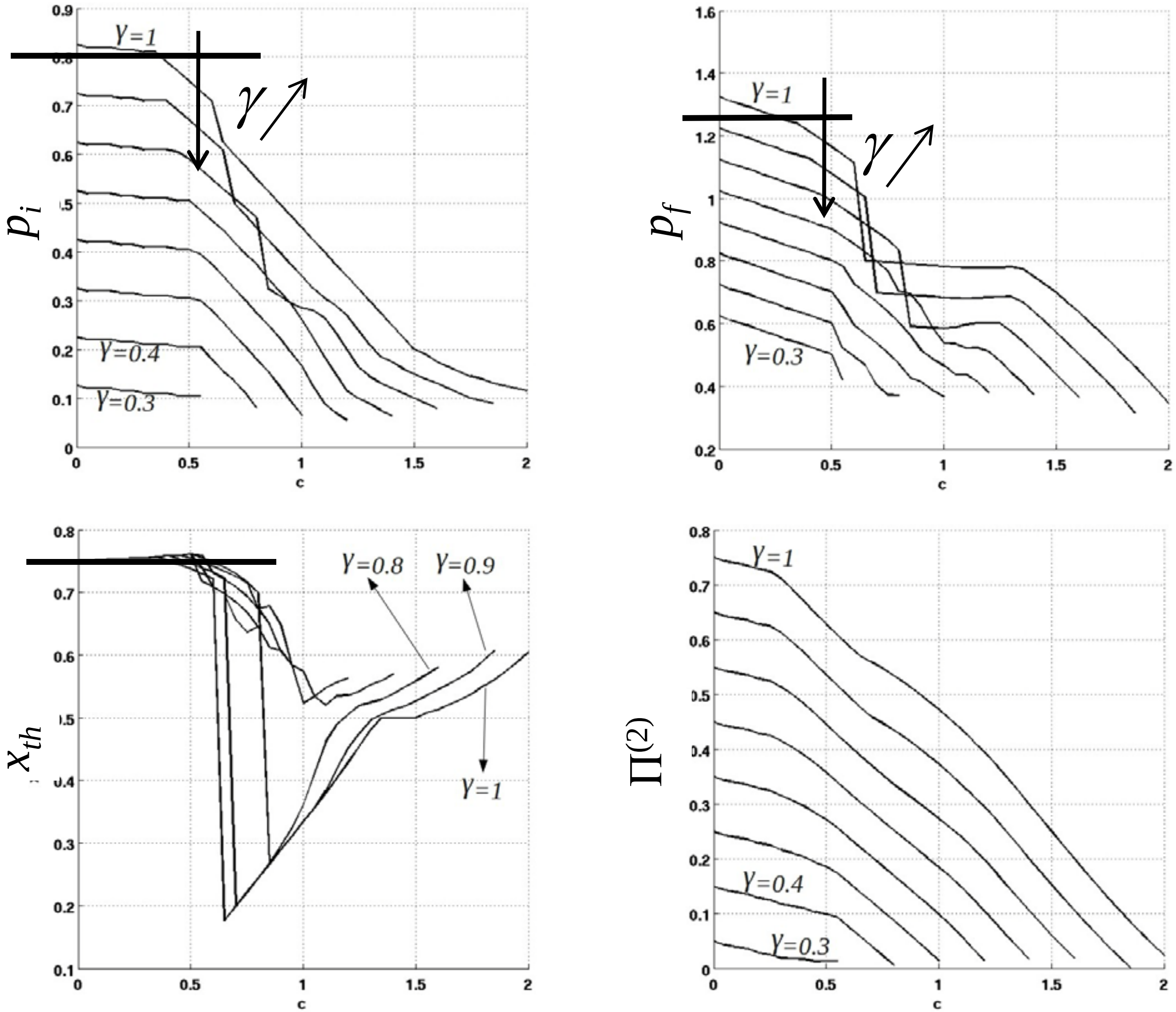


“Optimal” Policy Behavior



Three Broad “Regions” – (1)

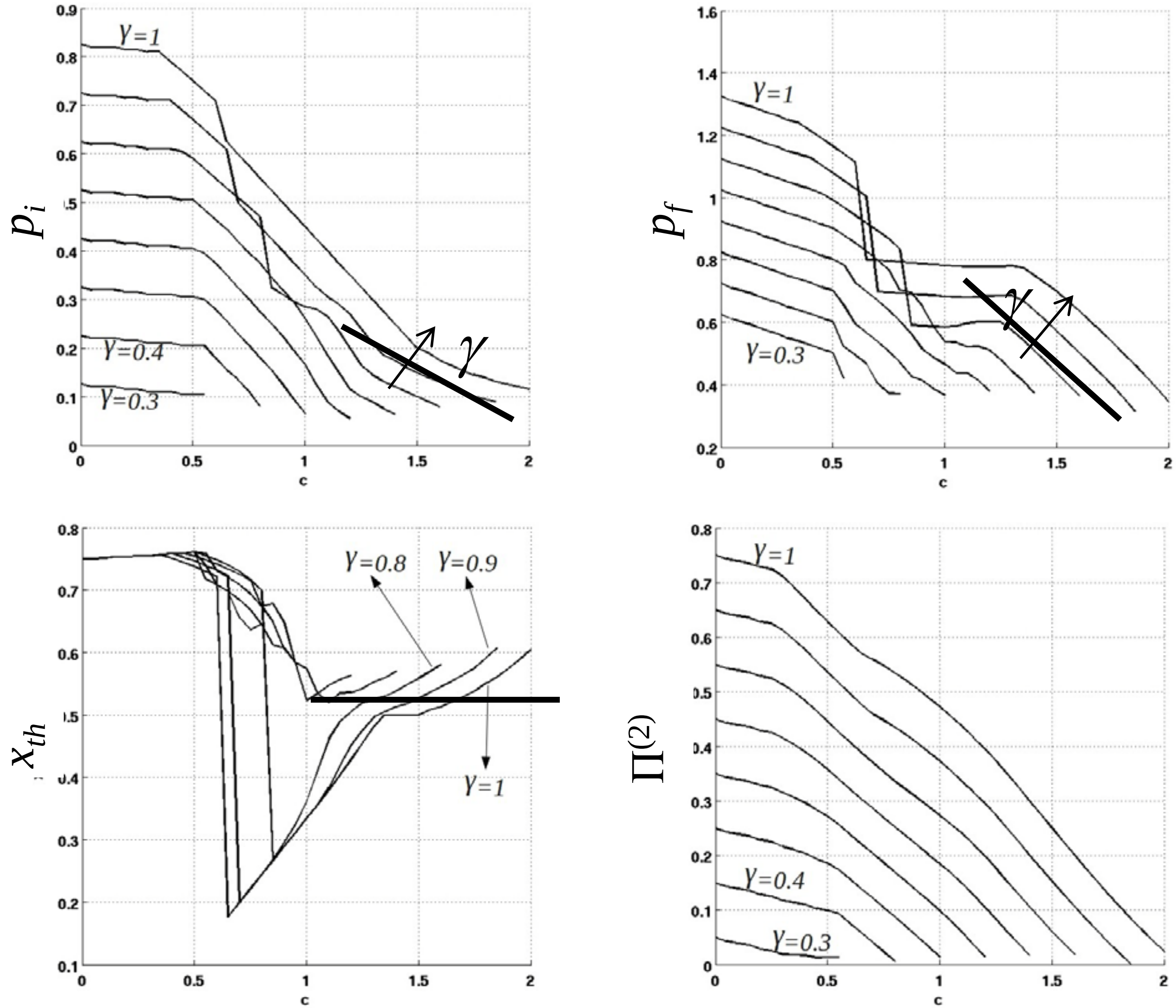
- At “low” c values, x_{th} remains approximately constant and independent of γ, while p_i and p_f are also roughly constant, and increasing linearly with γ



Three Broad “Regions” – (2)

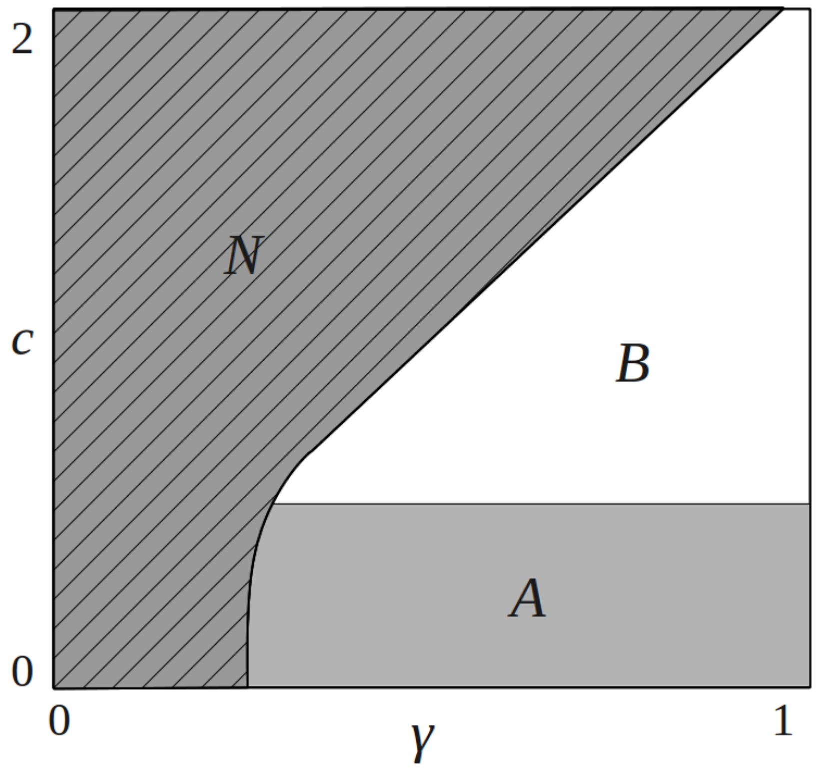
- At “high” c values, x_{th} is again approximately constant and independent of γ, and p_i and p_f vary roughly linearly with both c and γ

- At “intermediate” c values, behaviors are more chaotic and harder to characterize



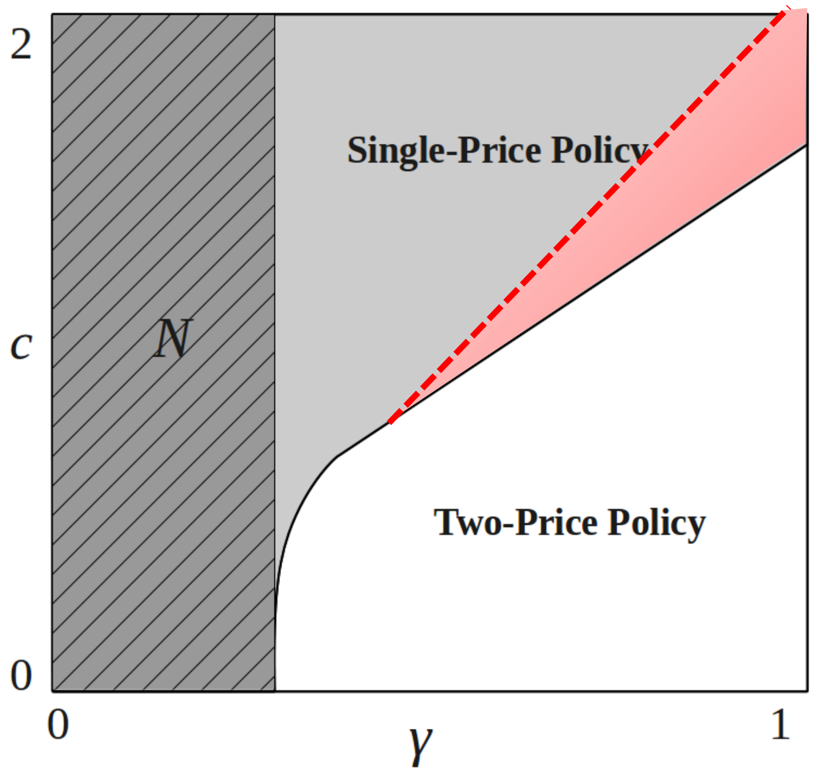
Guidelines for Two-Price Policy

- The guidelines essentially ignore the intermediate "*c*" behavior and identifies three distinct regions
- In region N (very low γ or γ that is too low relative to c), the two-price policy calls for subsidies ($p_i \approx 0$) that make it non-competitive
- As we enter region B (γ increases or c decreases), both prices increase essentially linearly, while x_{th} stays fixed as some moderate value
- In region A (low c), x_{th} switches to a higher value, prices are unaffected by further decreases in c, and increase linearly with γ



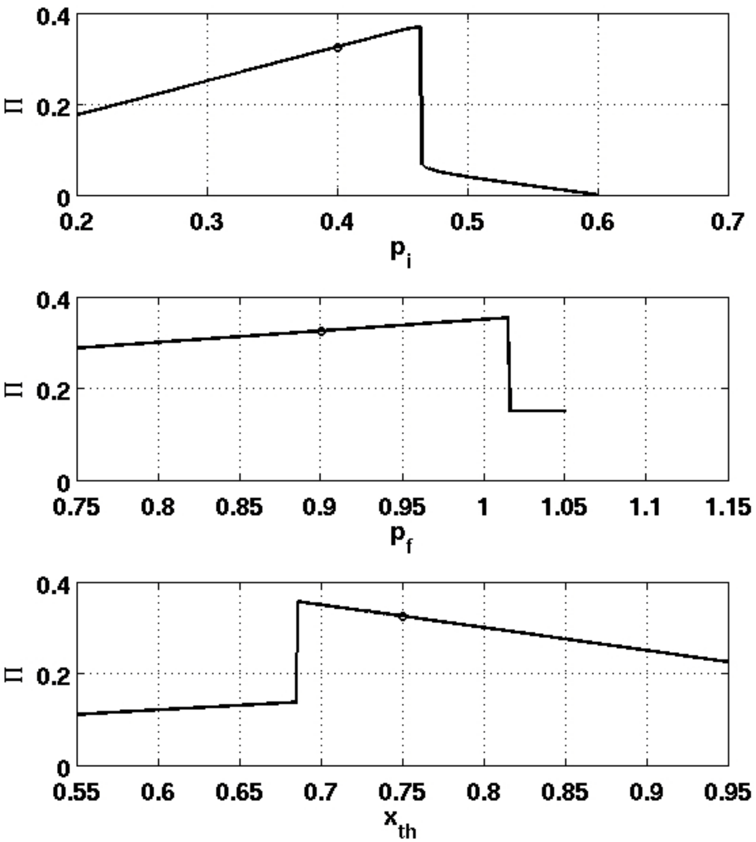
Global Pricing Guidelines

- A single-price policy is preferable, whenever high adoption levels are not desirable (γ too low relative to c)
- A two-price policy delivers a higher profit otherwise



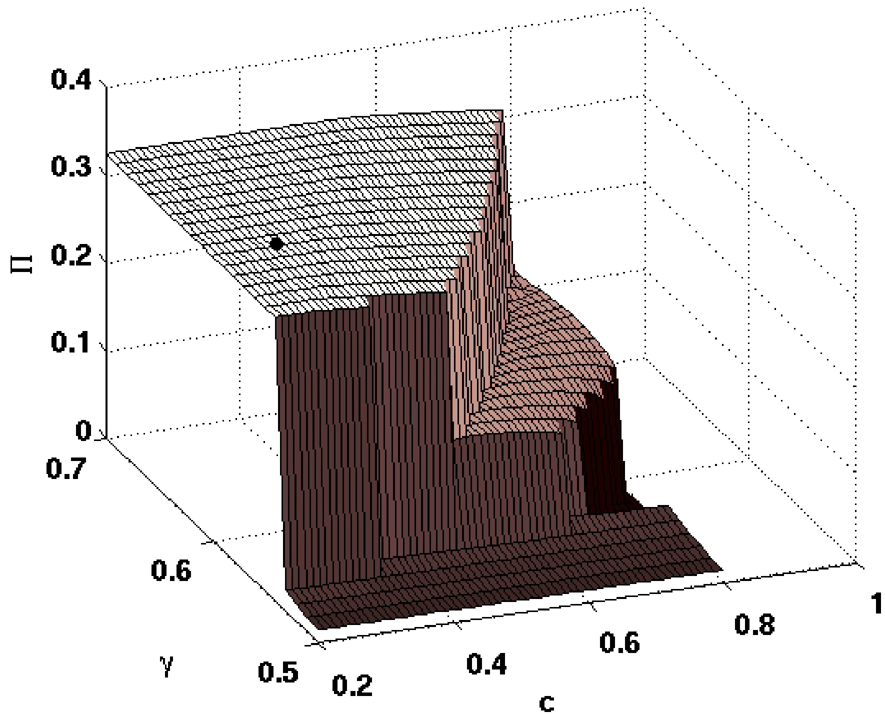
Guidelines Robustness
A Word of Caution

- Adoption levels experience sharp transitions after small changes in parameters around the "optimal" point
- Both policies are subject to such behaviors
- This is *intrinsic* to the service adoption process
  - Similar behaviors are observed (numerically) when relaxing the model's assumptions, *i.e.*, non-linear externalities, different coverage and roaming distributions, etc.
- Pricing guidelines must factor this in, *i.e.*, include margins to ensure robustness



Guidelines Robustness To Estimation Errors

- The good news is that once, prices have “backed-off” from the optimal values that are uncomfortably close to sharp transitions, profits remain relatively stable including to errors in system parameters



Summary

- A UPC service involves both positive and negative externalities that depend on ***both*** the number and type of users that adopt it
- A simple model was developed that offers
  - Insight into adoption dynamic and pricing strategies
  - A platform to investigate pricing strategies
- Single-price and two-price policies were investigated
  - A two-price policy can significantly enhance profit, when targeting high service adoption is meaningful (the value of connectivity dominates the negative impact of roaming traffic)
  - The model helped reveal the potential fragility of "optimal" pricing strategies, which led to the formulation of robust guidelines that can assist in the successful deployment of a UPC service