Washington University in St. Louis

Engineering

Assessing the Potential Opportunities of User-Provided Connectivity

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- All errors and/or lack of clarity are, however, my own doing

- More details can be found at

[1] M. H. Afrasiabi and R. Guérin, *"Exploring User-Provided Connectivity."* To appear in ACM Transactions on Networking, November 2014 (full-length version available at http://openscholarship.wustl.edu/cse_research/157/)

[2] M. H. Afrasiabi and R. Guérin, *"Pricing Strategies for User-Provided Connectivity Services."* Proc. IEEE INFOCOM 2012 mini-conference, Orlando, FL, March 2012.

[3] M. H. Afrasiabi and R. Guérin, *"Exploring User-Provided Connectivity - A Simple Model."* Proc. ICQT'11 Workshop, Paris, France, October 2011.

Premises

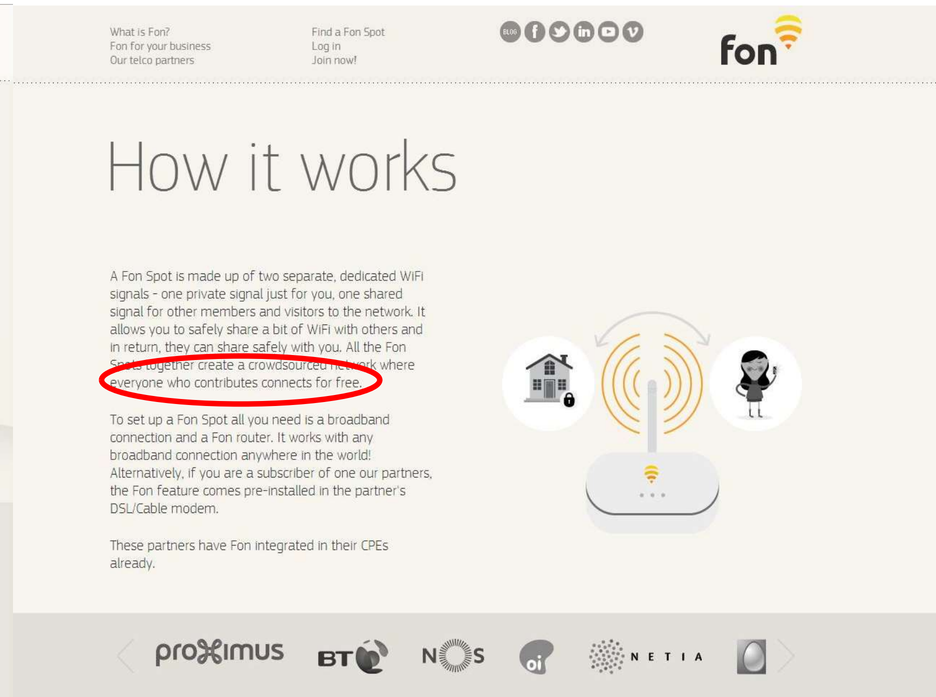
- The rise of the sharing economy
  - Car sharing, *e.g.,* Uber, Lyft, RelayRides, Zipcar, car2go, etc.
  - Home sharing, *e.g.,* Airbnb, HomeAway, VRBO, Wimdu, 9flats, etc.

  ⇒ Connectivity sharing: FON, AnyFi, airfy, (KeyWifi), Comcast XFINITY WiFi sharing, etc.

- The user as the infrastructure
  - Organic growth
  - Lower costs

But when and how does it work or be made to work?

The FON Model (Over 14 Millions Users)



- FON users trade ability to access other users' WiFi hotspots for reciprocation (*i.e.*, allowing other FON users to access their own WiFi hotspot)
- Alternative options are also possible, *e.g.*, provide access in exchange for compensation but without reciprocation rights

Framing the Investigation

Key features behind a "user as the network" system

- The network value depends on adoption
  - More users means broader coverage
  - But, with more users, having to share (whether at home or on the road) becomes more likely
- It also depends on how often users need access to and can access shared resources
  - FON's main benefit is while "roaming"
  - FON is only useful if you can find a FON spot
- Finally, it depends on cost, pricing, and possible "compensation" (for sharing)

Methodology

- Develop and analyze a “stylized” analytical model
  - Simplifying assumptions for analytical tractability
  - Explore solutions’ structure
  - Extract insight and guidelines
- Validation through numerical evaluation and simulations
  - Relaxation of simplifying assumptions
  - Do major outcomes still (qualitatively) hold?

High-Level Model Definition

- Consider a *service* offered to a (very) large population of *heterogeneous* users
- Users evaluate the service and adopt (purchase), only if they derive positive value from it
  - Value is measured through a *utility* function incorporating different parameters that characterize the service and its users
  - As mentioned, a key aspect of a FON-like service is that its value *changes* with its adoption (because of positive and negative externalities)

Specifying The Model

- Users' heterogeneity is in their *roaming* propensity θ, $\theta \in [0,1]$
  - The main feature of a FON-like service is connectivity while away from home
- Utility of user with roaming value θ given a set of adopters Θ:

$$U(\Theta,\theta) = F(\theta,\kappa(\Theta)) + G(m(\Theta)) - p(\Theta,\theta)$$

  - $F(.,.)$: value of connectivity (at home and while roaming)
    - $\kappa(\Theta)$: service coverage given Θ
  - $G(.)$: (negative) impact of roaming traffic, and positive impact of possible compensation
    - $m(\Theta)$: volume of roaming traffic generated by Θ adopters
  - $p(\Theta, \theta)$: service price for user θ, given Θ

User θ adopts iff $U(\Theta,\theta) > 0$

Making Things Tractable

(To Facilitate Analytical Insight)

- Linear value functions and uniform distributions
  - Value is proportional to frequency of connectivity
  - θ is uniformly distributed in [0,1]
  - Users are uniformly distributed over service area
    - Service coverage κ equals adoption level x
  - Roaming patterns are uniform over service area
    - Roaming traffic m is evenly distributed across adopters
  - Each user contributes one unit of traffic
- Utility is then of the form

$$U(\Theta,\theta) = (1-\theta)\gamma + \theta r x(\Theta) - cm(\Theta) - p(\Theta,\theta)$$

at home
roaming
finding
connectivity

  - γ is value of home connectivity, r is value of roaming connectivity, and c is impact of roaming traffic (minus any compensation) – We assume $c < r$

Questions of Interest

- When can the service succeed and generate substantial value?
  - Maximum total welfare?
  - When are maximum welfare and maximum adoption congruent?
- What pricing strategies?
  - Pricing controls
    - Users adoption
    - Provider's ability to extract welfare from users
    - Whether welfare or profit is maximized, or both
  - Complexity of implementation (how much information)

A Two-Prong Investigation

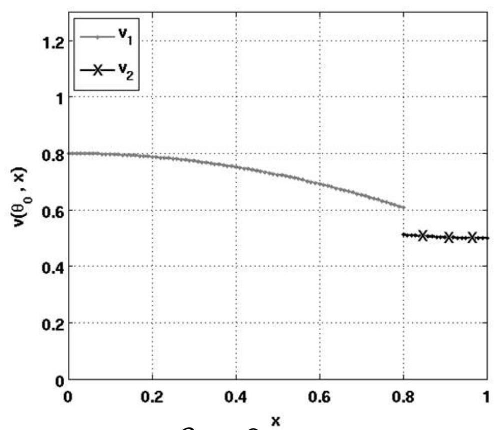
1. Characterizing system welfare
   – How useful is the service and for whom?
2. Exploring pricing strategies and their impact
   – A benchmark: Discriminatory pricing
   – Four practical pricing strategies with different levels of implementation complexity

Where Is The Value in UPC?

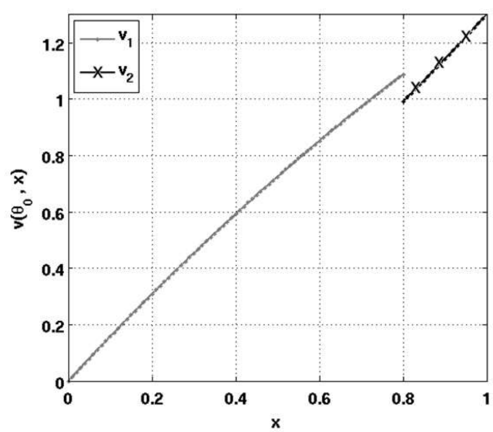
Value of user θ: $(1-\theta)\gamma + \theta r x - cm(\Theta) - e$, e = cost

- Different users see different changes in the value they contribute as adoption varies
  - Low θ users see *decreases* in utility as x increases
  - High θ users see *increases* in utility as x increases

Individual value

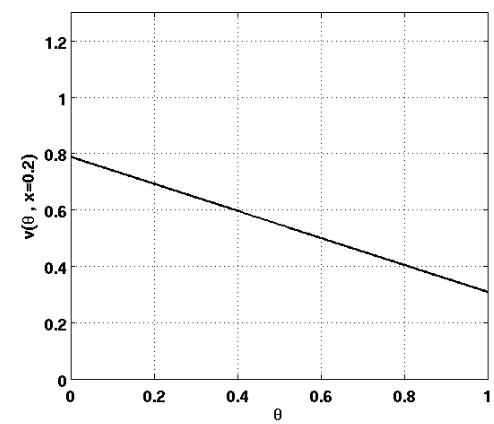


$\theta = 0$ user

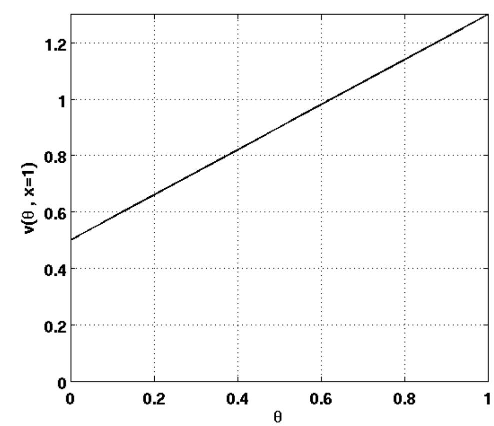


$\theta = 1$ user

Overall value



$x = 0.2$

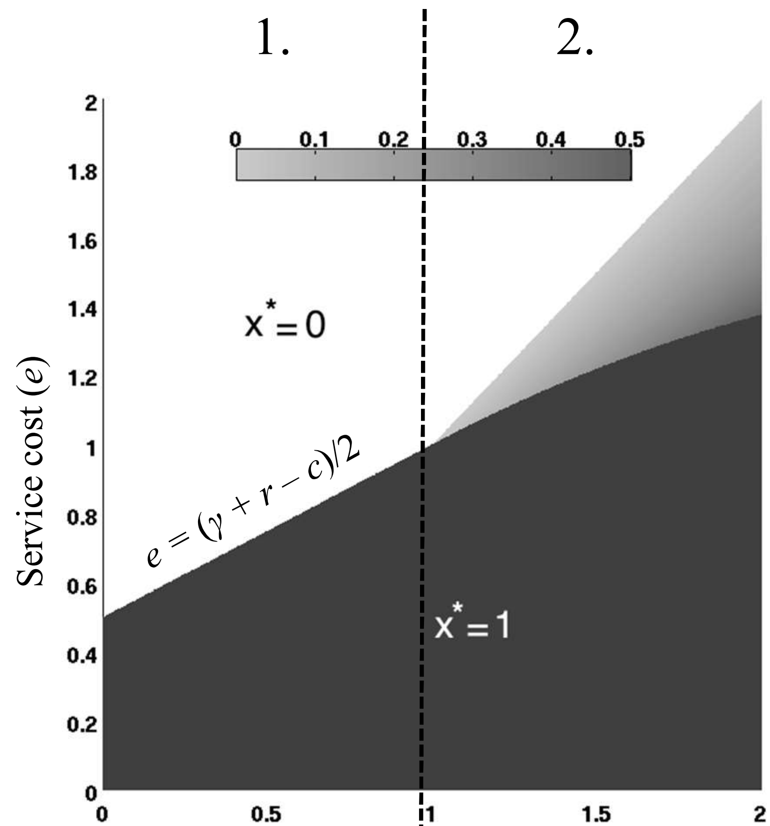


$x = 1$

Maximizing Welfare

Value of user θ: $(1-\theta)\gamma + \theta r x - cm(\Theta) - e$, e = cost

- Two main welfare regimes
  1. $\gamma \le (r-c)$, welfare is maximized at full or zero adoption depending on service cost, e
  2. $\gamma > (r-c)$, intermediate regime can emerge
- **Intuition**: When home connectivity value is
  - low relative to the net value of roaming connectivity, service cost is the main factor
  - high relative to the net value of roaming connectivity, limiting adoption can be preferable when service cost is high



Value of home connectivity (γ)
($r - c = 1$)

From Welfare to Profit

- Provider seeks control on converting welfare into profit
- Pricing is the tool that realizes this goal
  - Users' heterogeneity implies pricing heterogeneity
  - Pricing also affects adoption (service value varies)
- Discriminatory pricing as an impractical benchmark
  - Each user's price set to "value + cost – ε", $\varepsilon > 0$
    - $p(\Theta,\theta) = [(1-\theta)\gamma + \theta rx - cm(\Theta) - e] + e - \varepsilon$
  - Realizes full adoption (all users have positive utility $\varepsilon > 0$)
  - Can arbitrarily adjust transfer of welfare between users and provider
  - **Note**: Setting $p(\Theta,\theta) = e$, also results in a provider's profit of 0, but does so very differently (more on this later)

Pricing Strategies

- We investigate four (practical) pricing policies that offer different trade-offs between efficiency and complexity
  1. Usage based pricing, p_h per unit of traffic from home and p_r per unit of traffic while roaming
  2. Hybrid pricing, fixed price p_h for home connectivity, and p_r per unit of traffic while roaming
  3. Fixed price p for home and roaming connectivity (FON model)
  4. Pricing options: Users choose the best of two alternatives
     a. Fixed price p_h for home connectivity and free roaming
     b. Fixed price p_h for home connectivity, p_r per unit of traffic while roaming, and compensation of b per unit of roaming traffic using their home access

Usage-Based Pricing

- Mimics discriminatory pricing (based on roaming profile, θ)
  - $p(u_h,u_r) = p_h \,.\, u_h + p_r \,.\, u_r - a$, ($a$ is allowance, and u_h and u_r are home and roaming usages, respectively)

    $$p_\theta = p_h(1-\theta) + p_r\theta x(\Theta) - a$$

  - $U(\Theta,\theta) = \gamma(1-\theta) + r\theta x(\Theta) - cm(\Theta) - p_h(1-\theta) - p_r\theta x(\Theta) + a$

    Set $p_h = \gamma$ and $p_r = r$, $\Rightarrow U(\Theta,\theta) = a - cm(\Theta)$, $\forall\, \theta$, *i.e.,* for all users
  - Full adoption, *i.e.,* $x([0,1]) = 1$, (hence, maximum welfare) is readily realized by setting $a > cm([0,1])$ (= $c/2$ for uniform roaming traffic)

    $\Rightarrow$ All users have the *same* positive utility
- Allowance, a, is a "control knob" for *arbitrarily* shifting welfare from users to provider (from 0 to max value)

Usage-Based Pricing Summary

- A highly effective though complex policy
  - Can simultaneously maximize welfare and profit
  - Can be "tuned" to arbitrarily shift welfare from users to provider

- **Note:** Maximizing welfare may require *subsidies*
  - $p_\theta = \gamma(1 - \theta) + r\theta - a = \gamma - a + \theta(r - \gamma)$
    - $p_\theta < 0 \Leftrightarrow \theta < (a - \gamma)/(r - \gamma)$
  - Sedentary users must be enticed to stay when value of home connectivity, γ, is low compared to allowance, a

Hybrid Pricing

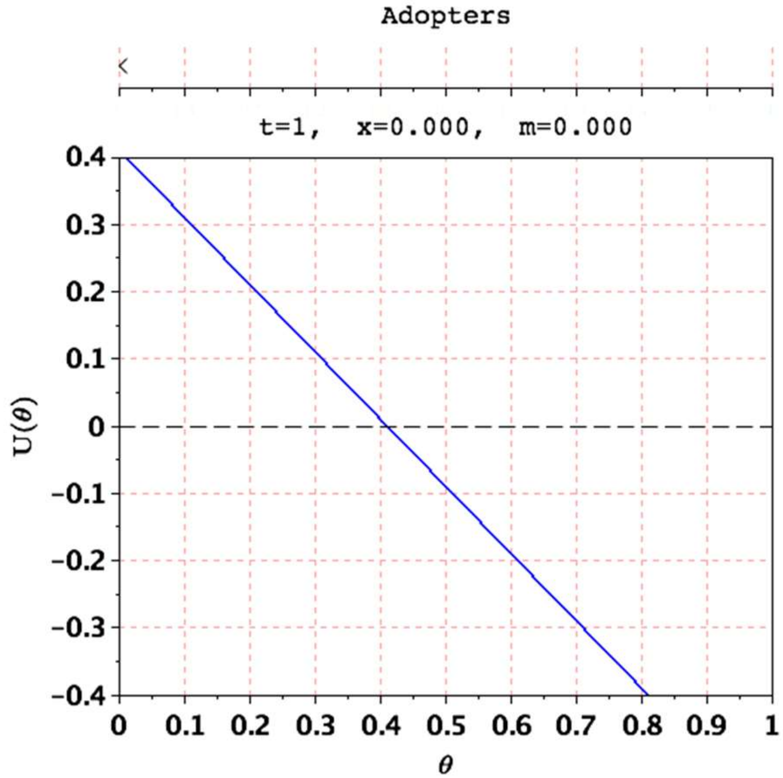
- Fixed-price, p_h, at home, and usage-based roaming pricing, p_r
  - $p(u_r) = p_h + p_r \, . \, u_r, = p_h + p_r\theta x(\Theta)$
  - $U(\Theta,\theta) = \gamma(1 - \theta) + r\theta x(\Theta) - cm(\Theta) - p_h - p_r\theta x(\Theta)$

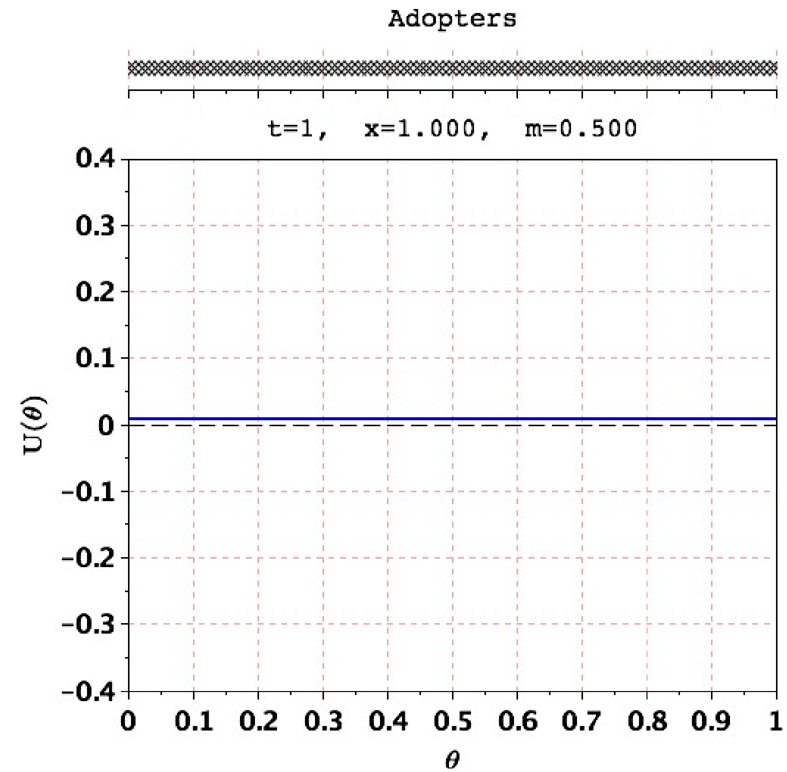
    $= (\gamma - cm(\Theta) - p_h) + \theta(rx(\Theta) - \gamma - p_r x(\Theta))$

    $= (\gamma - c/2 - p_h) + \theta(r - \gamma - p_r)$, at full adoption, $x = 1$
- Full adoption is *unique* equilibrium iff
  - $\theta = 0$ user has positive utility, *i.e.,* $p_h < \gamma - c/2$
  - $\theta = 1$ user has positive utility, *i.e.,* $r - c/2 > p_r + p_h$
  - **And** either $\gamma < c$, or when $\gamma \geq c$, a more complex condition that upper-bounds p_h based on a decreasing function of p_r

$\Rightarrow$ **The latter can prevent recouping all welfare as profit**

Max Profit vs. Max Welfare





- Welfare = profit $\Rightarrow p_h = \gamma - c/2 - \varepsilon$ and $p_r = r - \gamma - \varepsilon$, $\varepsilon > 0$, $\varepsilon \approx 0$
- $r = 1.6$, $c = 0.8$, $\gamma = 1$ (>0.8), $p_h = 0.59$, $p_r = 0.6$
- As adoption increases, positive and negative externalities compete to change users' utility. When $\gamma \geq c$, the relative utility margin of early adopters (low θ) is lower, and a "cross-over" becomes possible

Fixed Price Policy (FON-Like)

- Structurally, a fixed price cannot maximize profit and/or welfare
  - Unable to capture different users' utility
  - Unable to afford subsidies when needed
- But it has the benefit of simplicity
- Two main questions
  - Price effect on ability to maximize welfare
  - Tension between profit and welfare maximization

Fixed Price Policy Properties

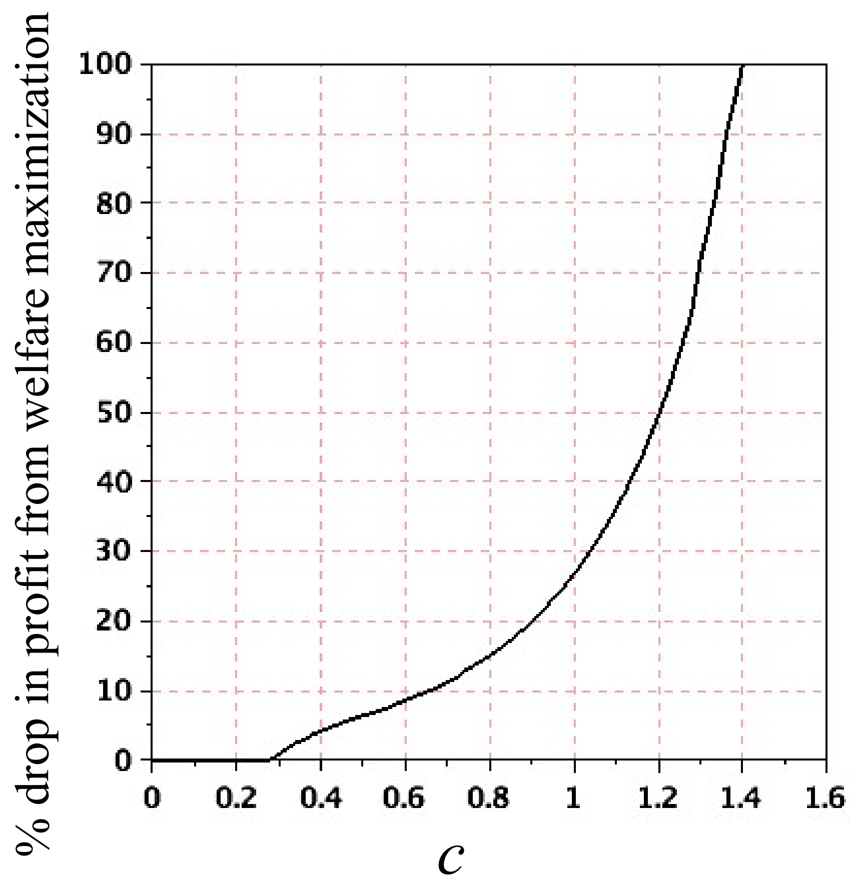
$$U(\Theta,\theta) = \gamma(1 - \theta) + r\theta x(\Theta) - cm(\Theta) - p$$

$$U([0,1],\theta) = \gamma - c/2 - p + \theta(r - \gamma)$$

- Maximizing welfare calls for a low enough price
  - $p < \min\{\gamma - c/2, \gamma - \gamma^2/(4r - 2c)\}$
  - Positive utility for $\theta = 0$ user at full adoption, and additional condition to avoid "cross-over" as adoption increases
- However, simultaneously maximizing welfare and profit conflicts unless negative impact of roaming traffic, c, is small

The "Cost" of Welfare Maximization

- Targeting maximum service adoption can result in a substantial drop in profit
- Controlling the negative impact of roaming traffic is key to mitigating this



Giving Users Pricing Options

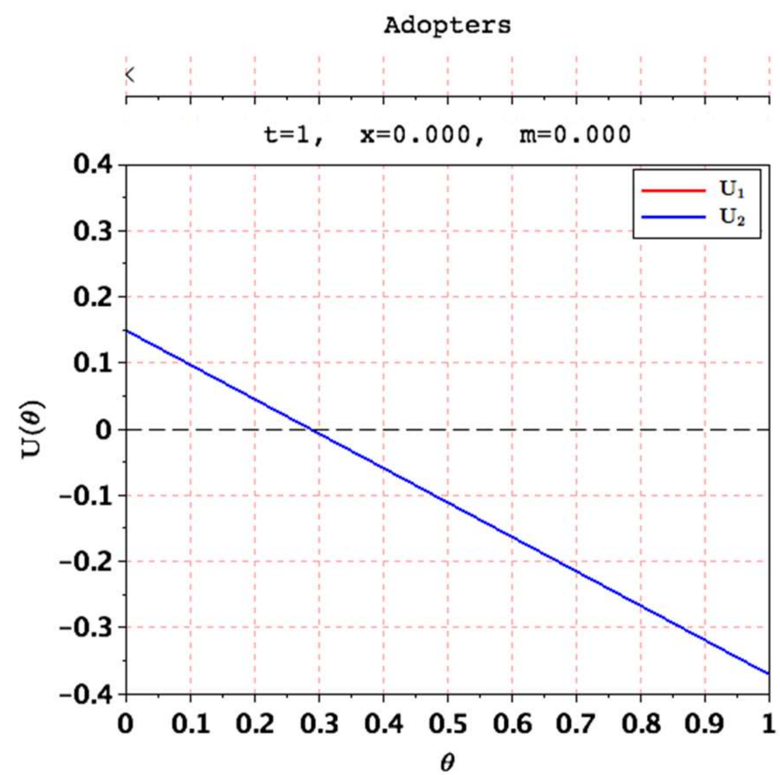
- Motivation: Instead of subsidies, users that roam infrequently are offered compensation, but they have to pay when roaming
  1. Pay p plus pay p_r when roaming, but get compensated b per unit of roaming traffic your home WiFi carries; or
  2. Pay p and roam for free

  Seeks to combine the best of fixed-price and hybrid policies
- However, giving users the option to choose between policies adds significant complexity to the analysis
  - Adoption regions can become disconnected

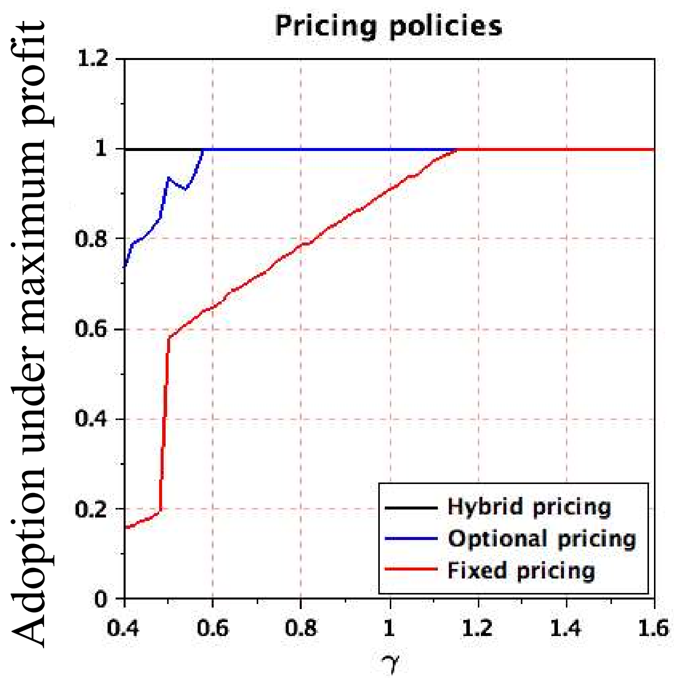
Adoption Progression Under a Two-Price Policy

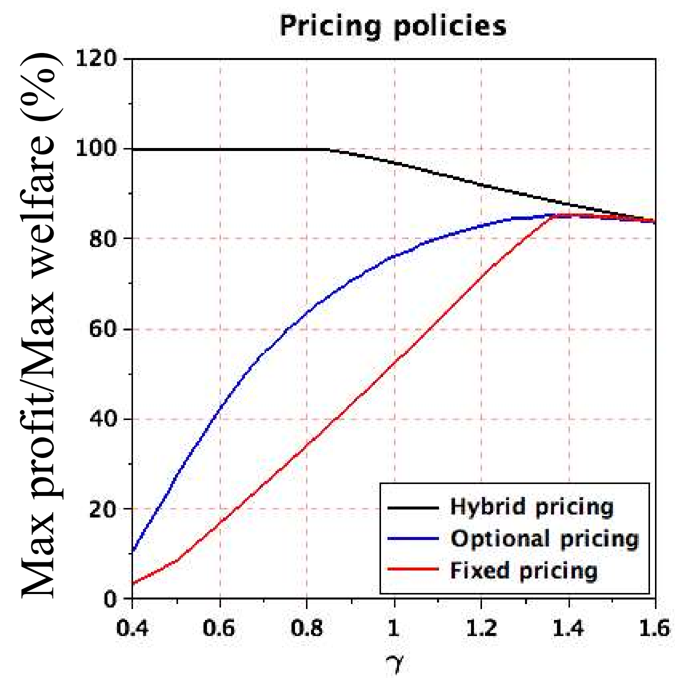
$r = 1.6, c = 0.8, \gamma = 0.2$

$p = 0.371, p_r = 0.08, \ b = 0.5$



Hybrid vs. Fixed vs. Optional Pricing





- **Of note**: Optimizing profit under the hybrid policy still maximizes welfare (though the profit needs not be equal to the maximum possible profit)
- Optional pricing policy offers and intermediate solution between hybrid and fixed-price policies
  - It achieves maximum adoption in most scenarios,
  - It improves profit over the fixed-prince policy, though it still lags behind the hybrid policy

Summary

- Unless the value of home connectivity is high relative to the *net* value of roaming connectivity, **the value of UPC grows with its user-base**
- A **usage-based pricing** scheme offers the **most flexibility** in maximizing value and in allocating it between users and provider, but it has a high implementation cost
- A **hybrid scheme** offers a possible **trade-off** between efficiency and cost
  - Main deficiency, somewhat surprisingly, arises when impact of roaming traffic is small
  - It can be addressed through the use of "introductory pricing"
- A **fixed-price scheme** (FON) has the benefit of simplicity, but **can quickly limit adoption in favor of higher profits**
  - Impact of roaming traffic needs to be tightly controlled
- **Two-price option** can improve on the fixed-price policy at the cost of some additional complexity

- The findings hold under various relaxations of the simplifying assumptions used to facilitate analytical tractability