

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)

What is Fon?
Fon for your business
Our telco partners

Find a Fon Spot
Log in
Join now!

fon

What is Fon?

Fon is your Global WiFi Network.
It's built by people just like you.

Fon members share a bit of their home WiFi, and in turn get free access at millions of other Fon hotspots worldwide.

Joining is easy. All you have to do is buy a Fon WiFi router and plug it into your broadband connection. No monthly fees!

Or, if you live in a country where Fon has a telco partner, just sign up with them to become a member.

[Join now!](#)

HOW IT WORKS



Join now

Fon is the world's largest WiFi network and growing. Be a part of something really big!

WHERE DO YOU LIVE?


What is Fon?
Fon for your business
Our telco partners

Find a Fon Spot
Log in
Join now!

fon

How it works

A Fon Spot is made up of two separate, dedicated WiFi signals - one private signal just for you, one shared signal for other members and visitors to the network. It allows you to safely share a bit of WiFi with others and in return, they can share safely with you. All the Fon Spots together create a crowdsourced network where everyone who contributes connects for free.



To set up a Fon Spot all you need is a broadband connection and a Fon router. It works with any broadband connection anywhere in the world! Alternatively, if you are a subscriber of one of our partners, the Fon feature comes pre-installed in the partner's DSL/Cable modem.

These partners have Fon integrated in their CPEs already.

proximus BT NOS oi NETIA

- 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

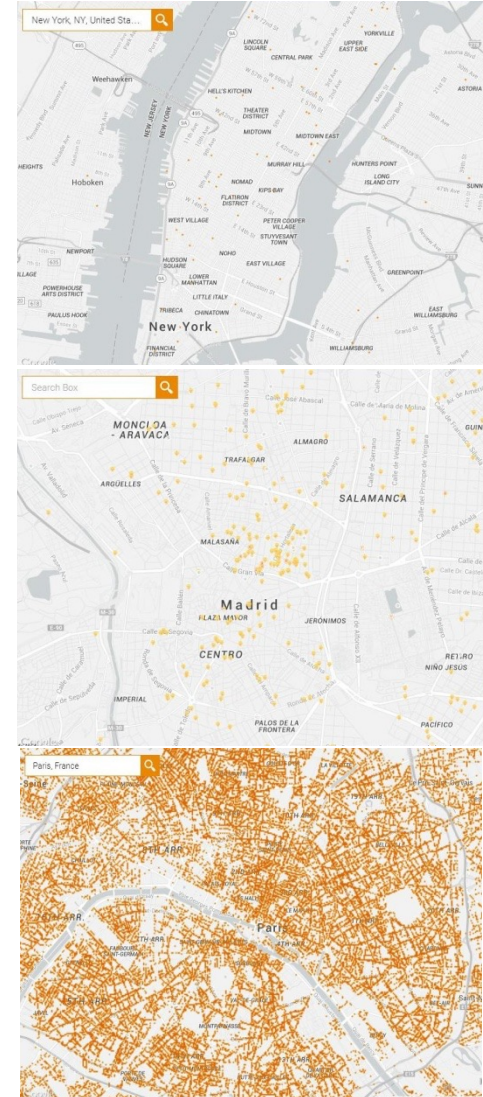
- The network value depends on adoption
 - More users means broader coverage
 - But, with more users, having to share (whether at home or on the road) becomes more likely
- It also depends on how often users need access to and can access shared resources
 - FON’s main benefit is while “roaming”
 - FON 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

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

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

at home
roaming
finding
connectivity

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

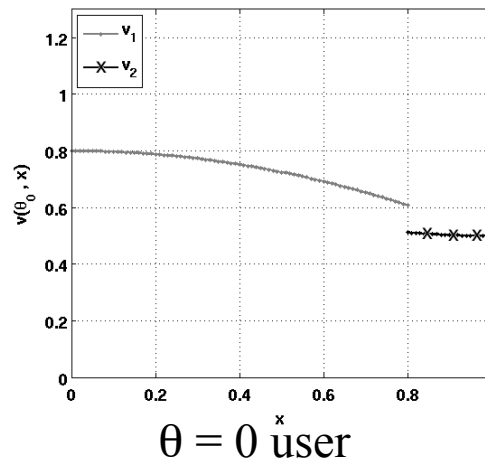
1. Characterizing system welfare
 - How useful is the service and for whom?
2. Exploring pricing strategies and their impact
 - A benchmark: Discriminatory pricing
 - Four practical pricing strategies with different levels of implementation complexity

Where Is The Value in UPC?

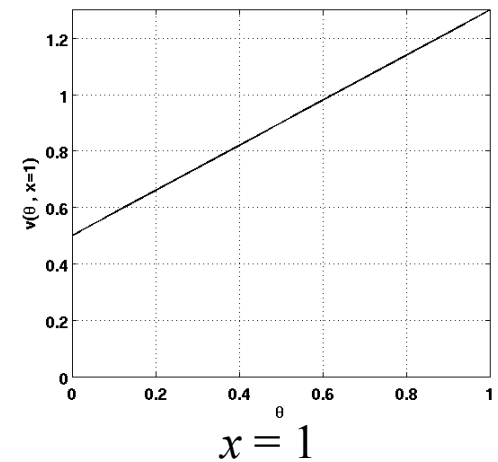
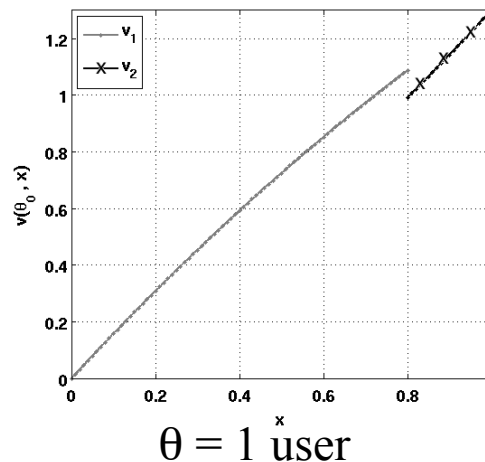
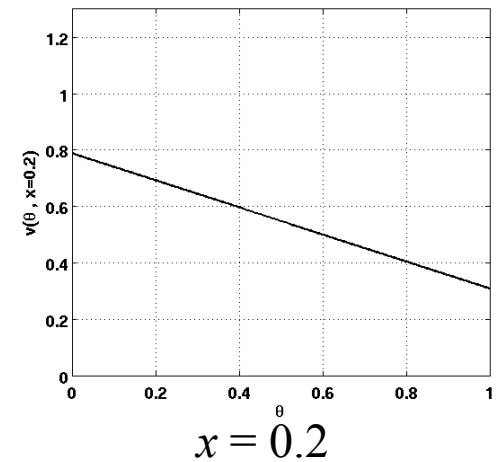
Value of user θ : $(1 - \theta)\gamma + \theta rx - cm(\Theta) - e$, $e = \text{cost}$

- 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



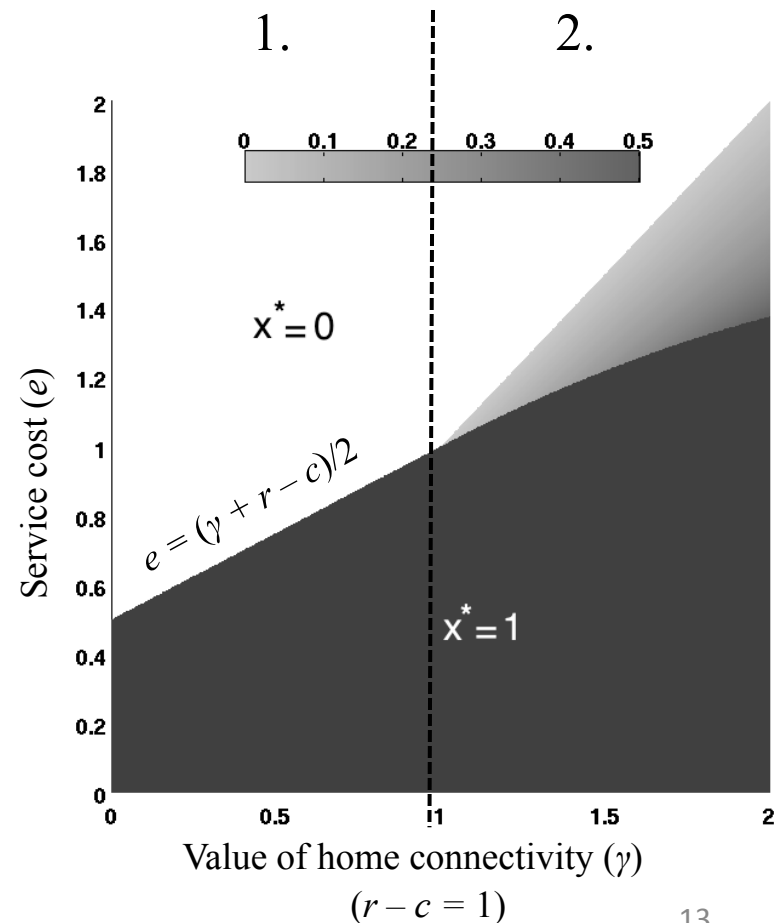
Overall value



Maximizing Welfare

Value of user θ : $(1 - \theta)\gamma + \theta rx - cm(\Theta) - e$, $e = \text{cost}$

- Two main welfare regimes
 1. $\gamma \leq (r - c)$, 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



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)
 - $p(u_h, u_r) = p_h \cdot u_h + p_r \cdot u_r - a$, (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

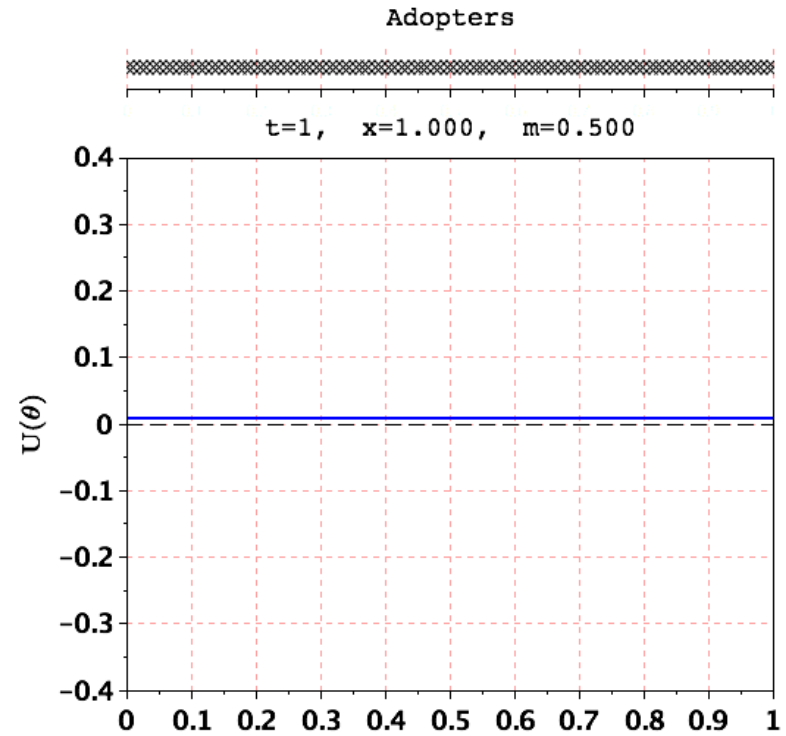
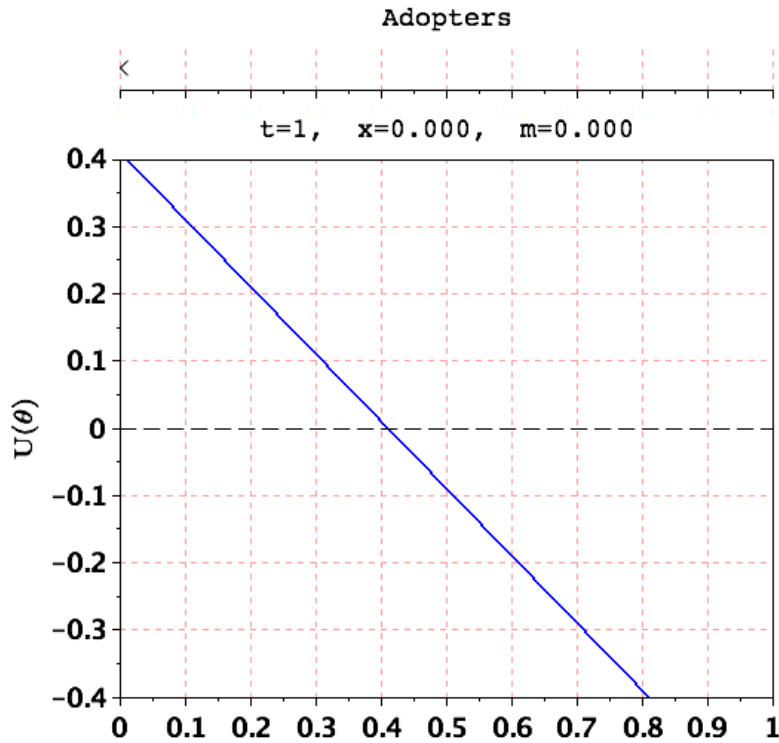
Hybrid Pricing

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

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

$$= (\gamma - c/2 - p_h) + \theta(r - \gamma - p_r), \text{ at full adoption, } x = 1$$
 - 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

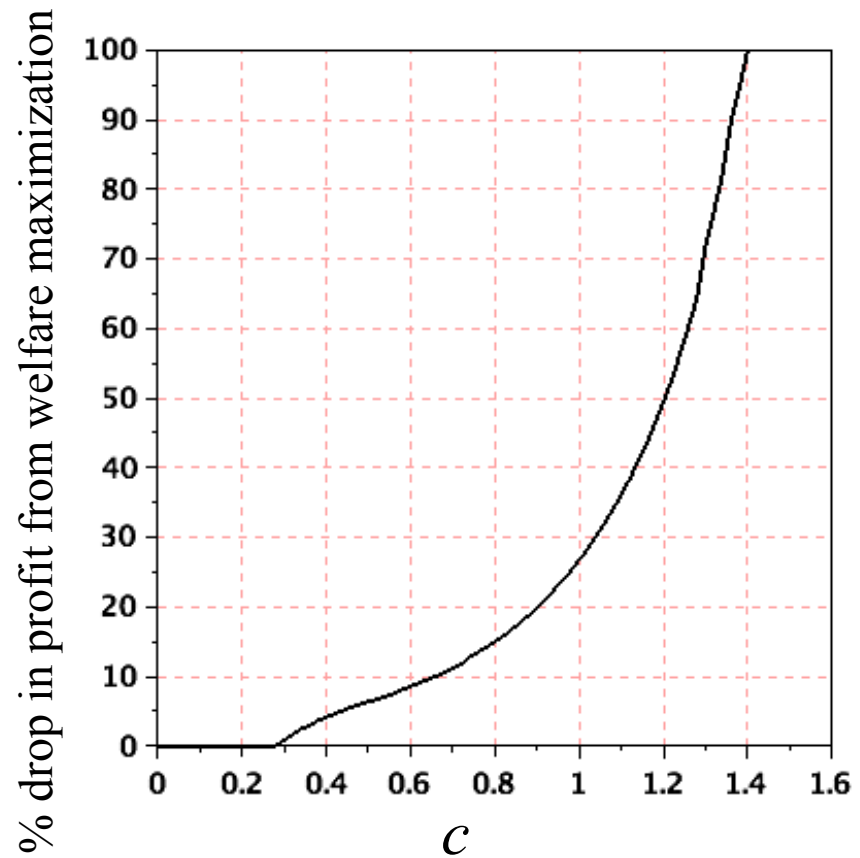
$$U(\Theta, \theta) = \gamma(1 - \theta) + r\theta x(\Theta) - cm(\Theta) - p$$

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

- 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



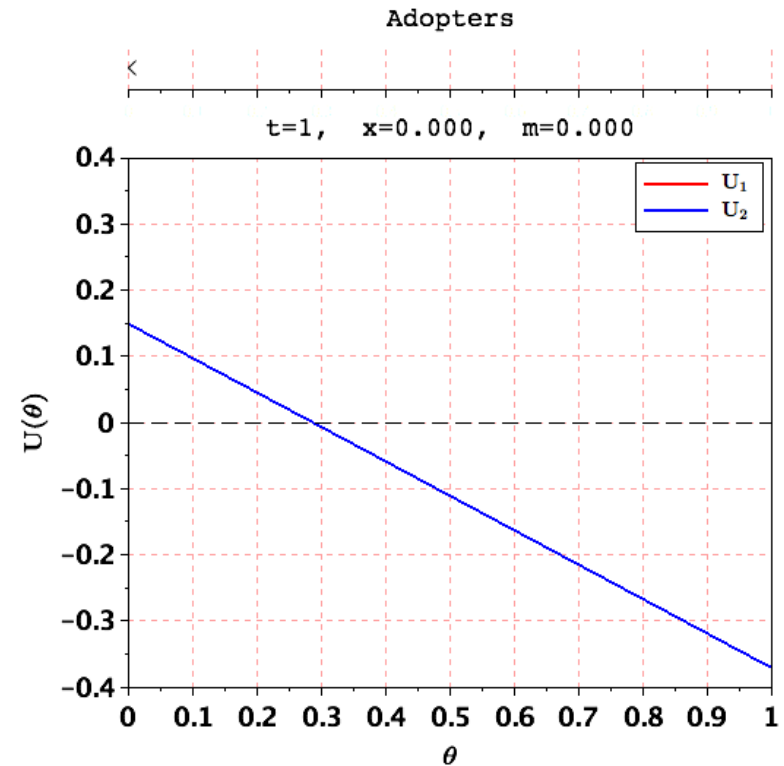
Giving Users Pricing Options

- 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 freeSeeks 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

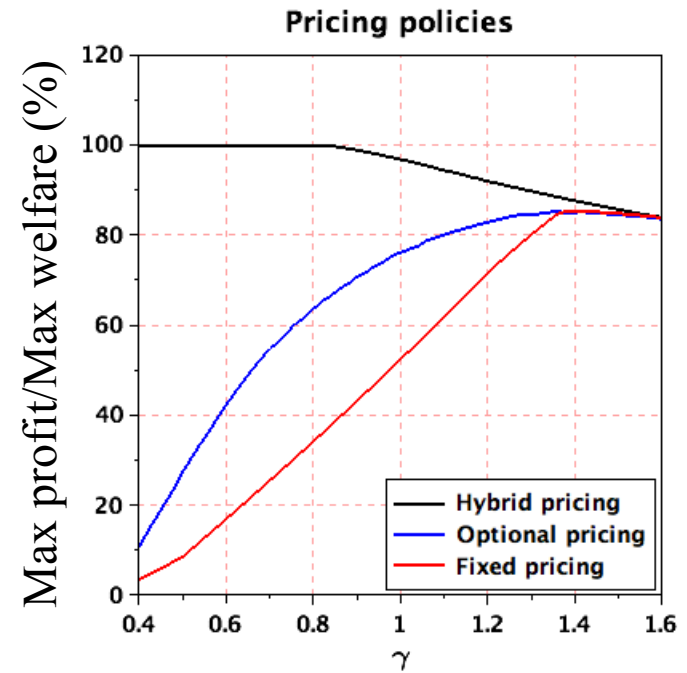
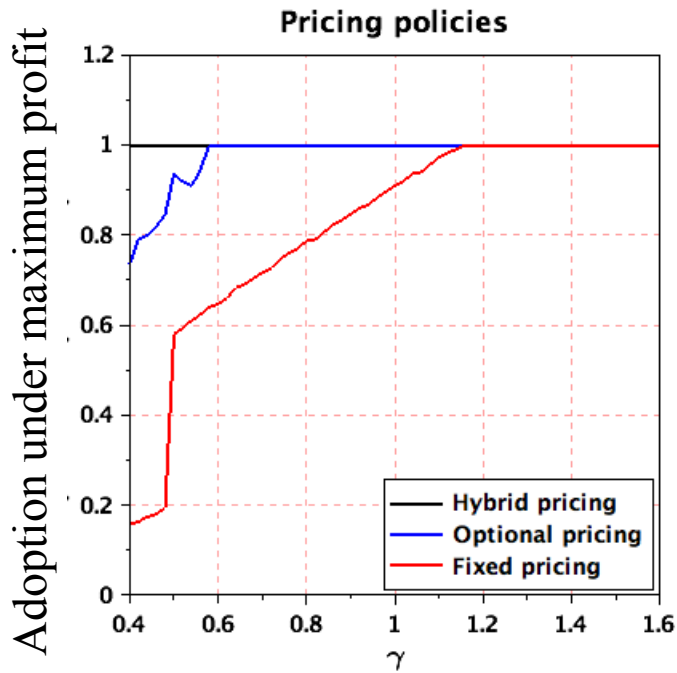
Adoption Progression Under a Two-Price Policy

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

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



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 an intermediate solution between hybrid and fixed-price policies
 - It achieves maximum adoption in most scenarios,
 - It improves profit over the fixed-price 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