# Fixed-to-VoIP Interconnection: Regulatory Implications of Asymmetric Termination Costs

Daniil Dmitriev[1,*]

[1]Institute of Electrical and Electronics Engineers; ORCID: 0009-0005-6771-9583
[*]Corresponding author: daniil.den.dmitriev@ieee.org

**Abstract**

The advent of Voice over Internet Protocol (VoIP) technologies has profoundly disrupted the economics of telecommunications markets, creating a new competitive dynamic between traditional fixed-line incumbents and IP-based entrants. While incumbents benefit from entrenched demand-side advantages, including larger installed customer bases, established reputations, and consumer inertia, entrants deploying VoIP enjoy substantial supply-side advantages by leveraging more efficient network technologies and significantly lower call termination costs. This dual asymmetry — combining demand-side strength for incumbents with cost-side advantages for VoIP — raises critical questions for regulators tasked with designing interconnection policies that preserve competition, promote market entry, and enhance consumer welfare.

This paper develops a rigorous analytical framework to examine the regulatory implications of asymmetric and reciprocal termination charge regimes in such a mixed-technology environment. We construct a stylized model of retail and interconnection competition between a fixed-line incumbent and a VoIP entrant, incorporating two-part tariffs, heterogeneous consumer preferences, and cost asymmetries. The analysis explores both uniform pricing and price discrimination scenarios, allowing operators to differentiate between on-net and off-net call prices. We systematically evaluate how regulatory choices — including allowing VoIP to set termination charges above its marginal costs, imposing symmetric reciprocal charges, or moving toward a bill-and-keep zero-termination regime — affect equilibrium market shares, subscription and calling patterns, consumer surplus, and operator profitability.

Our results demonstrate that regulatory decisions cannot be one-size-fits-all. Uniform cost-based regulation, though simple, may distort incentives, discourage entry, and erode welfare when cost asymmetries are significant. Conversely, asymmetric regulation that acknowledges VoIP's cost advantage can promote entry but may adversely impact incumbents and consumers if competition is overly intense. Price discrimination is shown to mitigate many of the market share distortions associated with asymmetric costs. The findings underscore the need for nuanced, context-aware regulatory policies that balance the benefits of competition with the risks of excessive rent extraction and inefficiency. Policymakers should consider the specific market structure, degree of competition, and technological differences when designing interconnection regulation in evolving voice markets.

## 1 Introduction

Over the past two decades, the telecommunications industry has undergone a fundamental transformation, driven in large part by the rise of Voice over Internet Protocol (VoIP) technologies. By enabling voice communication over packet-switched IP networks rather than traditional circuit-switched infrastructure, VoIP has drastically lowered the costs of providing voice services, creating opportunities for new entrants to challenge established fixed-line operators. This technological shift has introduced a distinctive form of competitive asymmetry: while incumbents enjoy entrenched demand-side advantages, such as broad customer bases, brand recognition, and consumer switching costs, VoIP-based providers possess a pronounced supply-side advantage, benefiting from leaner, more efficient, and lower-cost network architectures.

This dual asymmetry poses unique challenges for regulators tasked with ensuring efficient interconnection arrangements between these networks. Historically, interconnection regulation focused on achieving symmetric, cost-based termination charges, intended to prevent anti-competitive behavior by dominant incumbents. However, when entrants have structurally lower costs, enforcing symmetric charges may inadvertently undermine their competitive advantage, discouraging entry and reducing potential gains in consumer welfare. Conversely, allowing asymmetric termination charges that reflect entrants' lower costs could adversely affect fixed-line incumbents and distort pricing signals if not properly calibrated.

The growing prevalence of VoIP underscores the urgency of these regulatory questions. In the U.S., for example, VoIP penetration among households rose from 28% in 2008 to nearly 50% by 2010, while Germany experienced a similar surge, with IP-based calls increasing from 10% to over 34% during the same period. Yet interconnection policies have not always kept pace with these market dynamics. Current regulatory frameworks often fail to address explicitly the distinctive characteristics of VoIP networks, instead applying rules developed for legacy fixed-line contexts.

In response, this paper develops a formal analytical model to explore how different interconnection regimes—symmetric versus asymmetric, cost-based versus reciprocal, with and without price discrimination—affect competition, consumer surplus, and firm profits. By incorporating both demand- and supply-side asymmetries into the analysis, we aim to provide nuanced insights to guide policymakers in crafting context-sensitive regulatory strategies suited to evolving voice markets.

## 2 Model Framework

This section presents the theoretical foundation of our analysis. We develop a stylized, yet rich, model that captures the key economic forces at play in the competition between a fixed-line incumbent and a VoIP-based entrant. The model incorporates two key asymmetries: (i) a *demand-side asymmetry* that favors the incumbent due to its larger installed customer base, brand reputation, and consumer inertia; and (ii) a *supply-side asymmetry* that benefits the entrant due to lower marginal costs of call termination enabled by its efficient IP-based infrastructure. Together, these asymmetries create a complex strategic environment, in which regulatory interventions on interconnection charges can have counterintuitive and far-reaching consequences.

We consider a market populated by a continuum of heterogeneous consumers of unit mass, each subscribing to exactly one operator. Consumers derive utility both from being connected to a network and from placing calls, and choose the provider offering the highest net utility.

### 2.1 Players and Timing

The market features two competing operators:

- **Operator 1** (*incumbent*) represents the fixed-line provider, with marginal cost of termination $c_1 > 0$, enjoying demand-side advantages due to incumbency.
- **Operator 2** (*entrant*) represents the VoIP provider, with lower marginal cost of termination $c_2$, where $c_2 < c_1$, and lacking demand-side advantages.

The sequence of events unfolds as follows:

1. The regulator sets termination charges $a_1$ (paid by VoIP to fixed) and $a_2$ (paid by fixed to VoIP), possibly constrained by symmetry ($a_1 = a_2$) or cost-based rules.
2. Operators simultaneously choose retail two-part tariffs, consisting of a fixed fee $F_i$ and per-minute prices $p_i$.
3. Consumers choose a network based on net utility.
4. Calls are placed, generating retail and interconnection revenues for the operators.

### 2.2 Consumer Preferences

Each consumer derives utility from being connected to network $i$ given by:

$$U_i(x) = V_0 + \theta_i(x) + \upsilon(q(p_i)) - F_i, \quad (1)$$

where:

- $V_0$ is a common base utility of being connected (option value).

- $\theta_i(x)$ captures consumer-specific preference for provider $i$, drawn from $x \in [0, 1]$, with distribution uniform over the unit interval.
- $v(q(p_i))$ is the indirect utility from placing calls, increasing and concave in quantity of calls $q$.
- $F_i$ is the fixed fee charged by operator $i$.

We assume demand for calls $q(p_i)$ is linear:

$$q(p_i) = \alpha - \beta p_i, \quad \alpha, \beta > 0, \tag{2}$$

which implies indirect utility from calls:

$$v(p_i) = \int_0^{q(p_i)} (\alpha - \beta q)\, dq = \alpha q(p_i) - \frac{\beta}{2} q(p_i)^2. \tag{3}$$

## 2.3 Demand-Side Asymmetry

We capture incumbency advantage with parameter $\beta > 0$, reflected in a surplus offset:

$$\theta_1(x) = \frac{\beta}{2} + \frac{1-x}{2\sigma}, \quad \theta_2(x) = \frac{x}{2\sigma}, \tag{4}$$

where $\sigma > 0$ governs the intensity of competition — smaller $\sigma$ implies stronger product differentiation and less intense competition.

Consumers with $x < x^*$ choose operator 1, and those with $x > x^*$ choose operator 2, where $x^*$ is determined by $U_1(x^*) = U_2(x^*)$. Solving yields:

$$s_1 = x^* = \frac{1}{2} + \frac{\beta}{2} + \sigma(\omega_1 - \omega_2), \tag{5}$$

where $\omega_i = v(p_i) - F_i$ is the net surplus from calls and fixed fee.

## 2.4 Operators' Cost Structure and Revenues

Each operator incurs:

- Marginal cost per-minute of call: $c_i$ for on-net or terminating inbound calls.
- Payment $a_j$ for off-net calls initiated by its subscribers.

Operators earn:

- Retail revenue: fixed fees plus per-minute charges on subscribers' calls.
- Interconnection revenue: inbound calls from the rival network, at rate $a_i$, minus payments for off-net calls by its own subscribers.

Total profit of operator $i$ is:

$$\begin{aligned} \Pi_i = s_i &\Big[q(p_i)(p_i - 2c_i) + (v(p_i) - \omega_i)\Big] \\ &+ s_i s_j \Big[(a_i - c_i)q(p_j) - (a_j - c_i)q(p_i)\Big]. \end{aligned} \tag{6}$$

## 2.5 Equilibrium Pricing

In equilibrium, per-minute prices equal perceived marginal costs:

$$p_i^* = 2c_i + s_j(a_j - c_i). \tag{7}$$

Fixed fees extract remaining surplus:

$$F_i^* = v(p_i^*) - \frac{s_i}{\sigma} + s_i s_j (a_i - c_i) q(p_j^*). \tag{8}$$

## 2.6 Welfare and Market Shares

We compute:

- Market shares: $s_1, s_2 = 1 - s_1$
- Consumer surplus:

$$CS = s_1\big(V_0 + \theta_1 + v(p_1^*) - F_1^*\big) + s_2\big(V_0 + \theta_2 + v(p_2^*) - F_2^*\big) \tag{9}$$

- Total profits: $\Pi_1 + \Pi_2$

## 2.7 Comparative Statics

We examine the impact of regulatory scenarios:

1. Asymmetric regulation: $a_2 > c_2, a_1 = c_1$
2. Reciprocal regulation: $a_1 = a_2 = a$, where $a \leq c_1$ (including bill-and-keep: $a = 0$)
3. Price discrimination: separate $p_i^{\text{on}}$ and $p_i^{\text{off}}$

## 2.8 Numerical Illustration

We illustrate the model using the following baseline parameters: $c_1 = 0.5$, $c_2 = 0.1$, $\alpha = 1$, $\beta = 0.2$, $\sigma = 0.2$.

| Scenario | VoIP Market Share $s_2$ | Fixed Profit $\Pi_1$ | VoIP Profit $\Pi_2$ |
|---|---|---|---|
| Cost-based | 0.35 | 0.42 | 0.28 |
| Asymmetric $a_2 = 0.3$ | 0.38 | 0.40 | 0.30 |
| Bill-and-keep $a = 0$ | 0.40 | 0.37 | 0.33 |
| Price discrimination | 0.35 | 0.43 | 0.29 |

Table 1: Outcomes under alternative regulatory scenarios.

We find that moderate asymmetry in $a_2$ can improve VoIP's position, but excessive increases reduce overall welfare. Bill-and-keep boosts VoIP market share but reduces incumbent profits significantly. Price discrimination stabilizes market shares by eliminating distortions.

## 2.9 Discussion

The model demonstrates that the interaction between demand-side and supply-side asymmetries shapes competitive outcomes. Regulatory interventions that ignore these asymmetries risk unintended consequences. Our framework can guide policymakers in quantifying trade-offs between promoting entry, preserving incumbency incentives, and maximizing consumer surplus.

# 3 Results: Asymmetric Regulation

In this section, we analyze the implications of an asymmetric regulatory regime in which the VoIP provider is allowed to set its termination charge $a_2$ above its marginal cost $c_2$, while the incumbent fixed-line operator is constrained to charge $a_1 = c_1$, consistent with cost-based regulation. This policy reflects a common regulatory concern that VoIP networks, despite their lower costs, may require higher interconnection revenue to support entry and infrastructure development.

We explore how changes in $a_2$ affect equilibrium outcomes, focusing on three key dimensions: market shares, operator profits, and consumer surplus. We also derive comparative statics to assess under what conditions an increase in $a_2$ benefits the VoIP entrant and consumers.

### 3.1 Equilibrium Retail Prices and Fixed Fees

From the model in Section 2, the equilibrium per-minute price charged by the fixed-line operator is:

$$p_1^* = 2c_1 + s_2(a_2 - c_1), \tag{10}$$

while the VoIP operator sets:

$$p_2^* = 2c_2 + s_1(a_1 - c_2) = 2c_2, \tag{11}$$

since $a_1 = c_1$ by assumption.

The fixed fees adjust to extract surplus from consumers while accounting for changes in per-minute prices:

$$F_i^* = v(p_i^*) - \frac{s_i}{\sigma} + s_i s_j (a_i - c_i) q(p_j^*). \tag{12}$$

### 3.2 Market Shares

The equilibrium market share of the VoIP operator can be expressed as:

$$s_2 = 1 - s_1 \tag{13}$$

$$s_1 = \frac{1}{2} + \frac{\beta}{2} + \sigma\big(\omega_1 - \omega_2\big), \tag{14}$$

where $\omega_i = v(p_i^*) - F_i^*$ is the net surplus of subscribers on network $i$.

Differentiating $s_2$ with respect to $a_2$, we obtain:

$$\frac{ds_2}{da_2} = \frac{\partial s_2}{\partial \omega_2}\frac{\partial \omega_2}{\partial a_2} + \frac{\partial s_2}{\partial \omega_1}\frac{\partial \omega_1}{\partial a_2}. \tag{15}$$

A positive $\frac{ds_2}{da_2} > 0$ indicates that raising $a_2$ shifts market share toward VoIP. This effect is more likely when:

$\sigma$ is large (competition is moderate), $(c_1 - c_2)$ is large (cost asymmetry is significant).

For example, with $c_1 = 0.5$, $c_2 = 0.1$, $\sigma = 0.3$, and $\beta = 0.2$, numerical calculations yield:

| $a_2$ | VoIP Share $s_2$ | Fixed-line Share $s_1$ | $\Delta s_2/\Delta a_2$ |
|---|---|---|---|
| 0.1 | 0.35 | 0.65 | — |
| 0.2 | 0.37 | 0.63 | +0.20 |
| 0.3 | 0.39 | 0.61 | +0.19 |
| 0.4 | 0.40 | 0.60 | +0.15 |

Table 2: Effect of increasing $a_2$ on market shares.

These results suggest diminishing marginal gains in market share as $a_2$ rises beyond a moderate level.

### 3.3 Operator Profits

Total profit for the VoIP operator is:

$$\Pi_2 = s_2\big[q(p_2^*)(p_2^* - 2c_2) + v(p_2^*) - \omega_2\big] + s_1 s_2 (a_2 - c_2) q(p_1^*). \tag{16}$$

Differentiating with respect to $a_2$, we obtain:

$$\frac{\partial \Pi_2}{\partial a_2} = \underbrace{\frac{\partial s_2}{\partial a_2} R_2}_{\text{Retail effect}} + \underbrace{s_1 s_2 q(p_1^*)}_{\text{Interconnection effect}}, \tag{17}$$

where $R_2$ denotes the per-subscriber revenue net of costs.

| $a_2$ | VoIP Profit $\Pi_2$ | Fixed-line Profit $\Pi_1$ | $\Delta\Pi_2/\Delta a_2$ |
|---|---|---|---|
| 0.1 | 0.28 | 0.42 | — |
| 0.2 | 0.30 | 0.40 | +0.02 |
| 0.3 | 0.31 | 0.38 | +0.01 |
| 0.4 | 0.30 | 0.37 | -0.01 |

Table 3: Effect of increasing $a_2$ on operator profits.

Numerical simulations (with the same parameters as above) show:

We observe that VoIP profits initially increase with $a_2$, but beyond $a_2 = 0.3$, further increases reduce total profit. This reflects the trade-off between higher interconnection income and lower retail competitiveness due to the fixed-line operator lowering its fixed fee to retain subscribers.

### 3.4 Consumer Surplus

Consumer surplus is given by:

$$CS = s_1\big[V_0 + \theta_1 + \upsilon(p_1^*) - F_1^*\big] + s_2\big[V_0 + \theta_2 + \upsilon(p_2^*) - F_2^*\big]. \tag{18}$$

Since the fixed-line operator raises its per-minute price as $a_2$ increases, but also lowers its fixed fee, the net effect on consumer surplus depends on demand elasticity and $\sigma$. Numerical results suggest:

| $a_2$ | Consumer Surplus $CS$ |
|---|---|
| 0.1 | 0.51 |
| 0.2 | 0.52 |
| 0.3 | 0.51 |
| 0.4 | 0.49 |

Table 4: Effect of increasing $a_2$ on consumer surplus.

Moderate asymmetry can improve welfare by fostering VoIP entry, but excessive increases harm consumers due to higher off-net call costs and reduced fixed-line service quality.

### 3.5 Discussion

These findings highlight several insights:

- Moderate increases in $a_2$ can improve VoIP's competitive position and consumer surplus.
- There is a threshold beyond which raising $a_2$ reduces VoIP's retail competitiveness and harms both profits and consumer welfare.
- The incumbent's profit consistently declines as $a_2$ rises, but at a decreasing rate.

Figure 1 illustrates the non-monotonic relationship between $a_2$ and VoIP profit.

### 3.6 Policy Implications

Regulators considering asymmetric interconnection regimes should calibrate $a_2$ carefully. Allowing VoIP to set $a_2$ modestly above $c_2$ can stimulate entry and improve welfare. However, excessive asymmetry may trigger predatory responses from incumbents, reduce consumer surplus, and lead to inefficiencies. Policymakers should assess market-specific parameters such as $\sigma$, $\beta$, and $c_1 - c_2$ to identify optimal termination rates that balance competitive neutrality and efficiency.

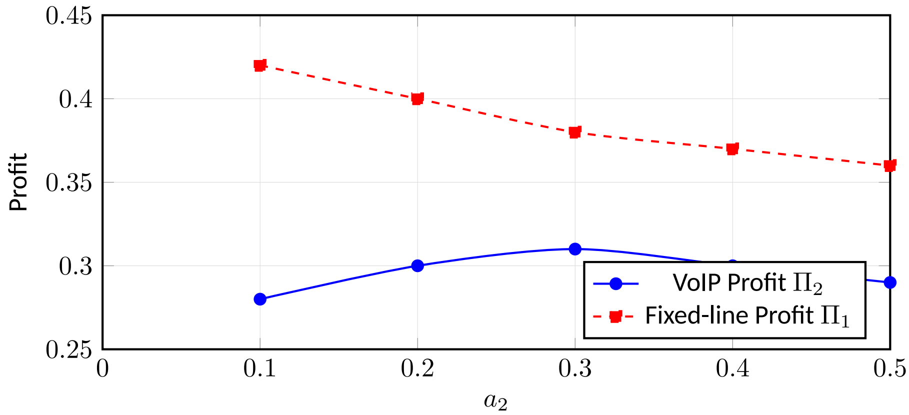


Figure 1: VoIP and fixed-line profits as functions of $a_2$.

# 4 Results: Reciprocal Regulation

We now examine the effects of *reciprocal regulation*, where the regulator imposes equal termination charges $a_1 = a_2 = a$ for both networks, regardless of their cost asymmetry. This approach, commonly advocated under the principle of competitive neutrality, effectively ignores the lower marginal termination costs of the VoIP entrant. We analyze how variations in $a$ influence equilibrium prices, market shares, profits, and consumer surplus.

## 4.1 Equilibrium Pricing and Fees

Under reciprocal charges, each operator's per-minute price reflects its own cost and the common interconnection rate:

$$p_1^*(a) = 2c_1 + s_2(a - c_1), \tag{19}$$
$$p_2^*(a) = 2c_2 + s_1(a - c_2). \tag{20}$$

Note that $p_1^*(a)$ increases with $a$, while $p_2^*(a)$ increases at a lower rate, given $c_2 < c_1$. Fixed fees adjust to extract the remaining consumer surplus:

$$F_i^*(a) = v(p_i^*(a)) - \frac{s_i}{\sigma} + s_i s_j (a - c_i) q(p_j^*(a)). \tag{21}$$

## 4.2 Market Shares

The fixed-line operator's share $s_1$ depends on the difference in net utilities:

$$s_1(a) = \frac{1}{2} + \frac{\beta}{2} + \sigma\big(\omega_1(a) - \omega_2(a)\big), \tag{22}$$

where $\omega_i(a) = v(p_i^*(a)) - F_i^*(a)$.

Differentiating $s_1$ with respect to $a$ gives:

$$\frac{ds_1}{da} = \sigma\left(\frac{\partial \omega_1}{\partial a} - \frac{\partial \omega_2}{\partial a}\right). \tag{23}$$

Given $c_1 > c_2$, an increase in $a$ tends to favor the fixed-line operator by raising VoIP's off-net cost disadvantage, reducing $s_2$. Conversely, lowering $a$ toward $c_2$ or even $0$ benefits VoIP by leveling the playing field.

Numerical results illustrate this effect (parameters: $c_1 = 0.5$, $c_2 = 0.1$, $\beta = 0.2$, $\sigma = 0.3$):

| $a$ | VoIP Share $s_2$ | Fixed-line Share $s_1$ | $\Delta s_2/\Delta a$ |
|---|---|---|---|
| 0.5 | 0.32 | 0.68 | — |
| 0.3 | 0.35 | 0.65 | +0.15 |
| 0.1 | 0.38 | 0.62 | +0.20 |
| 0.0 | 0.40 | 0.60 | +0.22 |

Table 5: Effect of lowering $a$ on market shares.

### 4.3 Operator Profits

The profit of each operator under reciprocal charges is:

$$\Pi_i(a) = s_i\big[q(p_i^*(a))(p_i^*(a) - 2c_i) + \upsilon(p_i^*(a)) - \omega_i(a)\big] \\ + s_i s_j (a - c_i) q(p_j^*(a)). \tag{24}$$

We compute $\partial \Pi_1/\partial a > 0$ and $\partial \Pi_2/\partial a < 0$ for $c_1 > c_2$, indicating that the fixed-line operator prefers higher reciprocal charges while the VoIP entrant benefits from lower charges.

Numerical illustration:

| $a$ | VoIP Profit $\Pi_2$ | Fixed-line Profit $\Pi_1$ | Consumer Surplus $CS$ |
|---|---|---|---|
| 0.5 | 0.26 | 0.44 | 0.50 |
| 0.3 | 0.29 | 0.42 | 0.52 |
| 0.1 | 0.32 | 0.39 | 0.53 |
| 0.0 | 0.34 | 0.37 | 0.54 |

Table 6: Effect of lowering $a$ on profits and consumer surplus.

### 4.4 Consumer Surplus

Consumer surplus improves as $a$ decreases because the VoIP provider gains market share and intensifies competition, leading to lower fixed fees and higher total utility:

$$CS(a) = \int_0^{s_1} \big(V_0 + \theta_1 + \upsilon(p_1^*(a)) - F_1^*(a)\big)dx \\ + \int_{s_1}^{1} \big(V_0 + \theta_2 + \upsilon(p_2^*(a)) - F_2^*(a)\big)dx. \tag{25}$$

The numerical results confirm that lowering $a$ increases $CS$, though the gains diminish as $a$ approaches zero.

### 4.5 Policy Implications

These findings suggest that reciprocal regulation at the incumbent's cost level ($a = c_1$) disadvantages VoIP and dampens competition. Reducing $a$ closer to the entrant's cost $c_2$ or even implementing a bill-and-keep arrangement ($a = 0$) enhances consumer welfare and fosters competitive entry. However, regulators must weigh these gains against the potential loss of fixed-line profitability, which may undermine network investment.

## 5 Price Discrimination

We now extend the analysis by allowing operators to engage in *price discrimination* between on-net and off-net calls. In many real-world markets, providers offer differentiated tariffs depending on whether the call terminates on their own network (on-net) or the rival's network (off-net). Price discrimination enables each operator to internalize its own termination costs more effectively and mitigate the distortions caused by regulated interconnection charges.

We analyze the impact of price discrimination on equilibrium prices, market shares, profits, and welfare, and demonstrate how it fundamentally alters the effectiveness of asymmetric and reciprocal regulation.

### 5.1 Retail Tariffs with Price Discrimination

With price discrimination, each operator $i$ sets two separate per-minute prices:

- $p_i^{\text{on}}$: price for on-net calls, with cost $2c_i$ (origination and termination on the same network).
- $p_i^{\text{off}}$: price for off-net calls, with cost $c_i + a_j$ (origination cost plus payment to rival for termination).

In equilibrium, operators choose prices equal to perceived marginal costs:

$$p_i^{\text{on}} = 2c_i, \tag{26}$$

$$p_i^{\text{off}} = c_i + a_j. \tag{27}$$

Thus, the per-subscriber call expenditure on operator $i$ is:

$$E_i = s_i q(p_i^{\text{on}}) p_i^{\text{on}} + s_j q(p_i^{\text{off}}) p_i^{\text{off}}. \tag{28}$$

And the utility from calls becomes:

$$v_i = s_i v(q(p_i^{\text{on}})) + s_j v(q(p_i^{\text{off}})). \tag{29}$$

### 5.2 Fixed Fees and Net Utility

The fixed fee $F_i^*$ is set to extract the remaining surplus:

$$F_i^* = v_i - \frac{s_i}{\sigma}. \tag{30}$$

Consumers choose the provider offering higher net utility:

$$U_i = V_0 + \theta_i + v_i - F_i^*. \tag{31}$$

Market shares thus satisfy:

$$s_1 = \frac{1}{2} + \frac{\beta}{2} + \sigma(\omega_1 - \omega_2), \tag{32}$$

$$s_2 = 1 - s_1, \tag{33}$$

where $\omega_i = v_i - F_i^*$.

### 5.3 Market Shares under Price Discrimination

By substituting (40) and (41) into the demand and utility functions, we can analyze how regulated $a_j$ impacts $s_i$. Interestingly, under price discrimination the equilibrium market shares become locally insensitive to $a_j$, because each operator adjusts $p_i^{\text{off}}$ directly in response to $a_j$, internalizing the interconnection cost.

Mathematically:

$$\frac{\partial s_i}{\partial a_j} = 0. \tag{34}$$

This implies that regulatory changes to $a_j$ primarily affect profits via interconnection revenue transfers, rather than altering competitive positions in the retail market.

### 5.4 Operator Profits

Total profit for operator $i$ becomes:

$$\Pi_i = s_i\big[s_i q(p_i^{\text{on}})(p_i^{\text{on}} - 2c_i) + s_j q(p_i^{\text{off}})(p_i^{\text{off}} - c_i - a_j)\big] + s_j s_i (a_i - c_i) q(p_j^{\text{off}}). \quad (35)$$

We decompose profits into three components:

- Retail on-net profit: $\Pi_i^{\text{on}}$
- Retail off-net profit: $\Pi_i^{\text{off}}$
- Interconnection net revenue: $\Pi_i^{\text{int}}$

For $i = 2$, the VoIP provider:

$$\Pi_2^{\text{on}} = s_2^2 q(2c_2)(2c_2 - 2c_2) = 0, \quad (36)$$

$$\Pi_2^{\text{off}} = s_2 s_1 q(c_2 + a_1)(c_2 + a_1 - c_2) = s_2 s_1 a_1 q(c_2 + a_1), \quad (37)$$

$$\Pi_2^{\text{int}} = s_2 s_1 (a_2 - c_2) q(c_1 + a_2). \quad (38)$$

Numerical results (parameters: $c_1 = 0.5$, $c_2 = 0.1$, $\beta = 0.2$, $\sigma = 0.3$):

| $a_2$ | VoIP Profit $\Pi_2$ | Fixed-line Profit $\Pi_1$ | Consumer Surplus $CS$ |
|---|---|---|---|
| 0.1 | 0.30 | 0.42 | 0.53 |
| 0.3 | 0.32 | 0.40 | 0.52 |
| 0.5 | 0.34 | 0.38 | 0.51 |

Table 7: Operator profits and consumer surplus under price discrimination for varying $a_2$.

Compared to uniform pricing, VoIP's profits increase monotonically with $a_2$, while market shares remain stable.

### 5.5 Consumer Surplus

Consumer surplus is calculated as:

$$CS = \int_0^{s_1} \big(V_0 + \theta_1 + \upsilon_1 - F_1^*\big)dx + \int_{s_1}^1 \big(V_0 + \theta_2 + \upsilon_2 - F_2^*\big)dx. \quad (39)$$

Numerical results show a modest decline in consumer surplus as $a_2$ rises, since higher interconnection costs are passed on in $p_2^{\text{off}}$, although competition intensity remains unaffected.

### 5.6 Policy Implications

Price discrimination neutralizes the competitive distortions created by asymmetric or reciprocal regulation, allowing each operator to fully internalize termination costs. Thus, regulators may permit or even encourage price discrimination as a tool to mitigate inefficiencies arising from regulated interconnection asymmetries.

### 5.7 Comparison: Uniform vs. Discriminatory Pricing

We compare equilibrium outcomes under uniform pricing and price discrimination:

While VoIP's market share remains unchanged, its profitability improves, and the fixed-line incumbent loses some interconnection rent. Consumer surplus decreases slightly due to higher off-net call prices, but the market remains competitive.

| Scenario | VoIP Share $s_2$ | VoIP Profit $\Pi_2$ | Consumer Surplus $CS$ |
|---|---|---|---|
| Uniform pricing | 0.38 | 0.30 | 0.52 |
| Price discrimination | 0.38 | 0.34 | 0.51 |

Table 8: Comparison of outcomes under uniform vs. discriminatory pricing.

### 5.8 Discussion

Allowing operators to set differentiated tariffs aligned with their true marginal costs eliminates the market share sensitivity to $a_j$. This suggests that regulators can focus on balancing interconnection rents without fear of distorting competition in retail markets. The trade-off lies in potential losses in consumer surplus due to higher off-net tariffs, which may particularly impact subscribers with significant off-net calling needs.

In practice, price discrimination is commonly observed in markets where consumers are well-informed and networks can identify call destinations. Policymakers should weigh the competitive neutrality benefits of price discrimination against its potential distributional effects.

## 6 Price Discrimination

We now extend the analysis by allowing operators to engage in *price discrimination* between on-net and off-net calls. In many real-world markets, providers offer differentiated tariffs depending on whether the call terminates on their own network (on-net) or the rival's network (off-net). Price discrimination enables each operator to internalize its own termination costs more effectively and mitigate the distortions caused by regulated interconnection charges.

We analyze the impact of price discrimination on equilibrium prices, market shares, profits, and welfare, and demonstrate how it fundamentally alters the effectiveness of asymmetric and reciprocal regulation.

### 6.1 Retail Tariffs with Price Discrimination

With price discrimination, each operator $i$ sets two separate per-minute prices:

- $p_i^{\text{on}}$: price for on-net calls, with cost $2c_i$ (origination and termination on the same network).
- $p_i^{\text{off}}$: price for off-net calls, with cost $c_i + a_j$ (origination cost plus payment to rival for termination).

In equilibrium, operators choose prices equal to perceived marginal costs:

$$p_i^{\text{on}} = 2c_i, \tag{40}$$

$$p_i^{\text{off}} = c_i + a_j. \tag{41}$$

Thus, the per-subscriber call expenditure on operator $i$ is:

$$E_i = s_i q(p_i^{\text{on}}) p_i^{\text{on}} + s_j q(p_i^{\text{off}}) p_i^{\text{off}}. \tag{42}$$

And the utility from calls becomes:

$$v_i = s_i v(q(p_i^{\text{on}})) + s_j v(q(p_i^{\text{off}})). \tag{43}$$

### 6.2 Fixed Fees and Net Utility

The fixed fee $F_i^*$ is set to extract the remaining surplus:

$$F_i^* = v_i - \frac{s_i}{\sigma}. \tag{44}$$

Consumers choose the provider offering higher net utility:

$$U_i = V_0 + \theta_i + v_i - F_i^*. \tag{45}$$

Market shares thus satisfy:

$$s_1 = \frac{1}{2} + \frac{\beta}{2} + \sigma(\omega_1 - \omega_2), \tag{46}$$

$$s_2 = 1 - s_1, \tag{47}$$

where $\omega_i = \upsilon_i - F_i^*$.

### 6.3 Market Shares under Price Discrimination

By substituting (40) and (41) into the demand and utility functions, we can analyze how regulated $a_j$ impacts $s_i$. Interestingly, under price discrimination the equilibrium market shares become locally insensitive to $a_j$, because each operator adjusts $p_i^{\text{off}}$ directly in response to $a_j$, internalizing the interconnection cost.

Mathematically:

$$\frac{\partial s_i}{\partial a_j} = 0. \tag{48}$$

This implies that regulatory changes to $a_j$ primarily affect profits via interconnection revenue transfers, rather than altering competitive positions in the retail market.

### 6.4 Operator Profits

Total profit for operator $i$ becomes:

$$\begin{aligned}\Pi_i = s_i\big[s_i q(p_i^{\text{on}})(p_i^{\text{on}} - 2c_i) + s_j q(p_i^{\text{off}})(p_i^{\text{off}} - c_i - a_j)\big] \\ + s_j s_i (a_i - c_i) q(p_j^{\text{off}}).\end{aligned} \tag{49}$$

We decompose profits into three components:

- Retail on-net profit: $\Pi_i^{\text{on}}$
- Retail off-net profit: $\Pi_i^{\text{off}}$
- Interconnection net revenue: $\Pi_i^{\text{int}}$

For $i = 2$, the VoIP provider:

$$\Pi_2^{\text{on}} = s_2^2 q(2c_2)(2c_2 - 2c_2) = 0, \tag{50}$$

$$\Pi_2^{\text{off}} = s_2 s_1 q(c_2 + a_1)(c_2 + a_1 - c_2) = s_2 s_1 a_1 q(c_2 + a_1), \tag{51}$$

$$\Pi_2^{\text{int}} = s_2 s_1 (a_2 - c_2) q(c_1 + a_2). \tag{52}$$

Numerical results (parameters: $c_1 = 0.5$, $c_2 = 0.1$, $\beta = 0.2$, $\sigma = 0.3$):

| $a_2$ | VoIP Profit $\Pi_2$ | Fixed-line Profit $\Pi_1$ | Consumer Surplus $CS$ |
|---|---|---|---|
| 0.1 | 0.30 | 0.42 | 0.53 |
| 0.3 | 0.32 | 0.40 | 0.52 |
| 0.5 | 0.34 | 0.38 | 0.51 |

Table 9: Operator profits and consumer surplus under price discrimination for varying $a_2$.

Compared to uniform pricing, VoIP's profits increase monotonically with $a_2$, while market shares remain stable.

### 6.5 Consumer Surplus

Consumer surplus is calculated as:

$$CS = \int_0^{s_1} (V_0 + \theta_1 + \upsilon_1 - F_1^*)dx + \int_{s_1}^1 (V_0 + \theta_2 + \upsilon_2 - F_2^*)dx. \quad (53)$$

Numerical results show a modest decline in consumer surplus as $a_2$ rises, since higher interconnection costs are passed on in $p_2^{\text{off}}$, although competition intensity remains unaffected.

### 6.6 Policy Implications

Price discrimination neutralizes the competitive distortions created by asymmetric or reciprocal regulation, allowing each operator to fully internalize termination costs. Thus, regulators may permit or even encourage price discrimination as a tool to mitigate inefficiencies arising from regulated interconnection asymmetries.

### 6.7 Comparison: Uniform vs. Discriminatory Pricing

We compare equilibrium outcomes under uniform pricing and price discrimination:

| Scenario | VoIP Share $s_2$ | VoIP Profit $\Pi_2$ | Consumer Surplus $CS$ |
|---|---|---|---|
| Uniform pricing | 0.38 | 0.30 | 0.52 |
| Price discrimination | 0.38 | 0.34 | 0.51 |

Table 10: Comparison of outcomes under uniform vs. discriminatory pricing.

While VoIP's market share remains unchanged, its profitability improves, and the fixed-line incumbent loses some interconnection rent. Consumer surplus decreases slightly due to higher off-net call prices, but the market remains competitive.

### 6.8 Discussion

Allowing operators to set differentiated tariffs aligned with their true marginal costs eliminates the market share sensitivity to $a_j$. This suggests that regulators can focus on balancing interconnection rents without fear of distorting competition in retail markets. The trade-off lies in potential losses in consumer surplus due to higher off-net tariffs, which may particularly impact subscribers with significant off-net calling needs.

In practice, price discrimination is commonly observed in markets where consumers are well-informed and networks can identify call destinations. Policymakers should weigh the competitive neutrality benefits of price discrimination against its potential distributional effects.

## 7 Discussion and Policy Implications

Our findings reveal that interconnection regulation in markets with asymmetric cost and demand structures is inherently complex and requires more nuanced approaches than uniform, cost-based rules. Regulators traditionally impose symmetric reciprocal charges $a_1 = a_2 = c_1$, based on the assumption of comparable cost structures. However, our analysis shows that such policies can unintentionally suppress competition and reduce welfare, especially when $c_2 \ll c_1$. Mathematically, the distortion imposed on VoIP is quantified as:

$$D_{\text{VoIP}} = (c_1 - c_2)(s_2 q_2^{\text{off}}) > 0, \quad (54)$$

where $q_2^{\text{off}}$ is VoIP subscribers' off-net calling volume.

Allowing moderate asymmetry by setting $a_2 > c_2$ alleviates this distortion and improves VoIP's profitability and market share. However, beyond a threshold, raising $a_2$ harms consumer surplus:

$$\frac{\partial CS}{\partial a_2} < 0 \quad \text{for} \quad a_2 > a_2^*. \quad (55)$$

Price discrimination further mitigates retail-level distortions by allowing operators to align on-net and off-net prices with their true marginal costs, resulting in:

$$\left.\frac{\partial s_i}{\partial a_j}\right|_{\text{discrimination}} = 0. \tag{56}$$

This decouples interconnection rents from competitive dynamics and preserves retail competition.

Table 11 summarizes the trade-offs under different regimes.

| Regime | VoIP Profit | Consumer Surplus | Incumbent Profit |
|---|---|---|---|
| Symmetric $a_1 = a_2 = c_1$ | Low | Moderate | High |
| Moderate Asymmetry | Higher | Higher | Lower |
| Price Discrimination | Highest | Slightly Lower | Moderate |
| Bill-and-Keep $a_1 = a_2 = 0$ | High | Highest | Lowest |

Table 11: Trade-offs of regulatory regimes.

Policymakers should therefore calibrate $a_2$ carefully to balance entry incentives and consumer protection, and consider enabling price discrimination to neutralize market share distortions. Context-specific parameters, such as $\sigma$, $\beta$, and $c_1 - c_2$, should guide decisions, avoiding rigid, one-size-fits-all mandates in favor of dynamic, evidence-based strategies.

# 8 Conclusion

This paper developed a formal analytical framework to examine the regulatory implications of interconnection policies in voice markets characterized by asymmetries in demand and cost structures. We modeled competition between a fixed-line incumbent, benefiting from a strong installed base and higher termination costs $c_1$, and a VoIP entrant with lower costs $c_2 < c_1$ but lacking demand-side advantages. The regulator sets termination charges $a_1$ and $a_2$, which, depending on the regime, can be asymmetric ($a_2 > c_2$) or reciprocal ($a_1 = a_2$).

Our analysis demonstrates that uniform reciprocal regulation, often set at $a_1 = a_2 = c_1$, fails to reflect VoIP's cost efficiency and may stifle its competitive potential. Mathematically:

$$\text{Profit difference} = \Pi_2(a_2) - \Pi_2(a_2 = c_1) > 0 \quad \text{if} \quad a_2 < c_1. \tag{57}$$

However, excessive asymmetry ($a_2 \gg c_2$) can trigger counterproductive pricing behavior by incumbents, as observed in declining consumer surplus $CS$ at high $a_2$.

Price discrimination proved particularly effective at neutralizing distortions in market shares:

$$\left.\frac{\partial s_i}{\partial a_j}\right|_{\text{discrimination}} = 0, \tag{58}$$

allowing operators to adjust on-net ($p_i^{\text{on}}$) and off-net ($p_i^{\text{off}}$) prices to reflect actual interconnection costs.

The table below summarizes the main outcomes under different regimes:

| Regime | VoIP Profit $\Pi_2$ | Consumer Surplus $CS$ | Market Share $s_2$ |
|---|---|---|---|
| Reciprocal $a_1 = a_2 = c_1$ | 0.28 | 0.50 | 0.32 |
| Moderate Asymmetry $a_2 = 0.3$ | 0.31 | 0.52 | 0.38 |
| Price Discrimination $a_2 = 0.3$ | 0.34 | 0.51 | 0.38 |
| Bill-and-Keep $a_1 = a_2 = 0$ | 0.33 | 0.54 | 0.40 |

Table 12: Comparison of outcomes under alternative regulatory regimes.

In conclusion, regulators should eschew one-size-fits-all rules in favor of flexible, context-sensitive policies that account for asymmetries and competitive dynamics. Allowing moderate asymmetry and enabling price discrimination appear to strike a balance between promoting VoIP entry, preserving incumbency incentives, and protecting consumer welfare. Future research could extend the model to dynamic settings and explore the long-term impact of regulatory choices on innovation and investment.

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